Natural Environment Research Council

Institute of Terrestrial Ecology

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COVER PHOTOGRAPHS

The cover shows clockwise from the top:
a recently fledged kestrel, photograph G Riddle; male spider, *Eresus niger,* photograph P Merrett; Japanese knotweed (*Reynoutria sachalinensis*), one season's growth, photograph T V Callaghan; snout of a normal tadpole showing mouth and nostrils, photograph ITE Collection; aerial view of the scrub rotational management scheme at Castor Hanglands National Nature Reserve in 1978, when six plots had been cut. Plot 1 is smaller because of the difficulties in scrub clearance, photograph by kind permission of Dr J Mason, Nature Conservancy Council; stems of *Furnaria hygrometrica* Hedw. growing on agar on a petri dish, photograph T D Murray; sheathing mycorrhiza of *Hebeloma sacchariolens* Quélet, photograph P Mason; adult female *Scolytus intricatus,* photograph M G Yates; collection of silt for use in experimental work on radionuclides, photograph A D Horrill; otter (*Lutra lutra*), heads of male and female, photograph Beverley Trowbridge.

ACKNOWLEDGEMENT

The Institute wishes to thank Miss Sue Nicholson for drawing the figures in this report. The work was carried out a part of her year's sandwich course at our Monks Wood Experimental Station, Huntingdon. Sue is a cartography student at the Luton College of Higher Education, Bedfordshire.

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.

One quarter of ITE's work is research commissioned by customers, such as the Nature Conservancy Council, who require information for wildlife conservation, the Department of Energy and the Department of the Environment, and the EEC. 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

Ecology in the 1980s

1. *Introduction*

As we enter the 1980s, there are at least 4 questions that ecologists need to ask about their role in this decade:

i. What are likely to be the important environmental problems of the 1980s?

ii. What research needs are these problems likely to generate, if ecologists are to make a worthwhile contribution to planning and policy-making?

iii. What particular role should ITE play in meeting these research needs?

iv. How can ITE best collaborate with other research institutes, and with universities, in seeking solutions for the environmental problems of the 1980s.

These questions have been a particular focus for discussion within ITE during the year reviewed in this Annual Report. An attempt has been made to develop a consensus and, in reaching this consensus, it has been necessary to identify the priorities for new research, a task which has itself involved the review of the relevance of ITE's present research programme. In short, we are concerned to increase the relevance of ITE's research to the problems in the 1980s.

In making this review, it has been important to recognise that ITE, as a component institute of NERC, is an integral part of the world-wide scientific profession. It is therefore necessary to ensure that we collaborate with colleagues elsewhere so as to make the best use of our strengths, and to complement the work that others are doing both nationally and internationally.

2. *Environmental problems of the 1980s*

Perhaps the major environmental problem of the 1980s will be the need to ensure that the limited resources of the world are used to the best advantage, leading to an understanding that our use of these resources will place an even greater pressure on the environment in the future. Much of the concern is likely to be focused on the development of energy resources, including oil, coal, and nuclear power, for which exploration and exploitation are likely to have major effects. Coupled with this search for and development of new sources of energy, pollution from new and existing industrial processes will continue to attract attention and will require critical research, especially in the fields of air and water pollution, the use of pesticides and herbicides, identification of pathways of radionuclides, and determination of effects of heavy metals. It seems likely that this focus on industrial development and the exploitation of mineral resources will stimulate and enhance demand for effective and predictive environmental impact analysis by world populations, and that this analysis will be extended from the developed world to the nations of the developing world, as these processes begin to be applied increasingly in nations seeking the advantages of industrial development, without, hopefully, suffering the disadvantages which have been experienced by the nations which have already seen the consequences of that development. It seems likely, also, that there will be an increased emphasis on the reduction of waste in industrial and commercial practices, including the management of forest, agricultural, and horticultural crops.

In the rural environment, the increased attention to resource utilization is likely to place a major emphasis on land use, including the re-evaluation of policies for agriculture and forestry, and nowhere is this emphasis more likely to be felt than in Britain, where we have a high population and a relatively small land area with many competing users. Table 1 shows the present estimates for land use in the United Kingdom.

Table 1. Total area in hectares × 10^6 and percentages of United Kingdom by land use.

Total UK 24·4 (100%)	Rural 22.6 (92·4%)	Cultivated 13·4 (55·0%)	Grassland 7·21 (29·6%)
			Arable 4·74 (19·4%)
			Forest 1·42 (5·8%)
			Orchards ·053 (0·2%)
		Natural and semi-natural 9·14 (37·4%)	Rough grazing 6·56 (26.9%)
			Woodland ·64 (2.6%)
			Inland water ·31 (1·3%)
			Other semi-natural 1·62 (6·6%)
	Urban 1.8% (7.6%)	Amenity 0·52 (2·2%)	
		Other 1·32 (5.4%)	

The greatest technological development seems likely to take place in lowland Britain, as the demand for cheap food leads to greater intensification of agriculture on the better soils, by increased use of single cropping over large areas, new and greater use of pesticides, and the removal of marginal land (including hedges, ditches, etc). The effects on wildlife are likely to be considerable as there are increased attempts to improve marginal grassland by drainage, by the use of fertilisers, or by reseeding, with a consequent threat to herb-rich grasslands. With this increasing intensification of agriculture and horticulture on the better soils, unimproved grassland is likely to be even less actively managed than at present, and so to become scrub and woodland which will be mainly used for recreation, forestry, or energy production. In all of these changes, however, the importance of external influences cannot be over-emphasised, including such factors as the cost of energy, climatic change, political decisions about pricing policies in the EEC, etc. The present trend towards increased production of grass, together with reliance on imported concentrates, also seems to indicate the need for more information about the effects of nitrogen on the growth of grass and on the growth of crops which might provide an alternative to imported concentrates.

Just as agriculture and horticulture will continue to be the most important land uses in the lowlands of Britain, forestry is almost certain to be the major issue in the uplands. In addition to the existing area of forest in Britain (Table 2), an increase in the total forest area is likely as a response to world shortages of timber and wood pulp, and the increased reluctance of exporting nations to sell us the 92% of our annual requirements that we have become accustomed to import. Recent reports by the Forestry Commission and by the Centre for Agricultural Strategy have both recommended modest increases from 8% to 10%, or 12%, of the total land area. It may be necessary to consider even greater increases, say to 16% of the total land area in Britain.

Table 2. Area of forest in the United Kingdom (1977)

Forest type	Areas ha × 10^6	Percentage of total forest area
Conifers	1.36	63
Broadleaved	.40	19
Unproductive	·30	14
Unplanted	·09	4
Total	2.15	100

Studies will therefore be required of the effects that this increased area of forest might have on the environment, and particularly on the integration of forestry with other land uses such as agriculture, water resources, recreation and visual amenity, and wildlife conservation. Most of these effects are assumed to take place in the uplands, as the most likely place for expansion of forestry, but the relative demand for wood and food may lead to agricultural land also being used for growth of high quality and fast growing timber. A particular problem will be the effects of forests on hydrology and water resources, especially where forests are planted in areas which traditionally supply water for major urban centres.

Even for the present relatively low proportion of land devoted to forestry, dependence on a limited range of provenances of one or 2 species by foresters during the last 30 years gives cause for concern because of the vulnerability of British forests to attack by pests and pathogens. A more effective long-term strategy for the choice of species and for methods of forest management is almost certainly necessary, especially if the area of forest is to be increased substantially. The present outbreaks of the infestations of pine beauty moth in Scotland on lodgepole pine provide an example of the dangers which have been run by an over-dependence upon a limited range of genetic material. If a similar outbreak were to occur on Sitka spruce, dependence on widespread use of pesticides, currently regarded as the solution to the pine beauty moth infestation, might provide an unacceptable hazard to the environment.

There also exists a considerable area of broadleaved woodland which is regarded as unproductive, or even derelict, under existing forms of commercial management. Such areas will almost certainly be scheduled for rehabilitation during the decade, but care will be needed to see that minimum damage occurs to wildlife conservation, for which these woodlands provide an important resource. Indeed, in many cases, the woodlands themselves, as "primary" woodland, are of conservation value.

During the last 2 or 3 years, land use has already emerged as a major issue, with renewed demand by conservation and other bodies for a national land use policy. Such a demand assumes that an agreed policy could be negotiated, and also assumes that any negotiated policy would be more favourable to conservation than the interaction of the separate policies of land-using agencies, buffered by the general conservatism of land owners and tenants. It seems more likely that, as in the past, land use policy in Britain will continue to be the result of several interacting and conflicting policies, derived from the major land-using agencies. Nevertheless, there will be a need to monitor the effects of the past, present and future policies for land use by some independent body like NERC. Ideally, NERC should be in a position to predict the effects of existing and proposed policies before it is too late to make the changes necessary to prevent positive damage to the environment. Furthermore, an independent Research Council like NERC could extend the range of feasible options which are discussed by the policy-making organisations. Frequently, the range of options discussed is severely limited at the time at which policy is formulated.

Although resource conservation is likely to become the primary concern for the 1980s, there will also be continuing interest and support for wildlife conservation —wildlife, quite properly, being regarded as an important national and international resource. For many wildlife species, destruction of habitat is probably the most important influence, and we will need to find ways of ensuring the compatibility of emerging patterns of land management with the maintenance of adequate habitats for wildlife. Special emphasis will probably need to be placed on rare and disappearing species, which are affected by pollutants, by exploitation for collectors, etc, and by the disturbance of habitats or life processes, especially in the regeneration of the species. Studies of the population dynamics of both plants and animals may also be necessary to determine the effect of wildlife epidemics, particularly where these affect rare or disappearing species.

Closely associated with the protection of rare or disappearing species is the problem of the management of nature reserves and protected areas, because it cannot be assumed that merely declaring areas as reserves or protected areas will necessarily ensure the survival of the species to be protected. Appropriate forms of management are required, and how to arrange for such forms of management, or even to describe them, is largely unknown at present. In some instances, it may be necessary to recreate habitats which have been lost, either from existing sources of seed and genetic material, or through systems of management which lead to appropriate successions. The monitoring of change in habitats designed to protect and increase levels of wildlife may best be done through studies of population dynamics of relatively short-lived organisms, like moths and butterflies.

The trends so far identified have mainly been concerned with rural land use, and with land as a source of food, fuel, wood fibre, etc, but we have to recognise that Britain is essentially an urban society. There are frequently problems of derelict land in and around urban areas, and it seems likely that the rehabilitation and management of these areas will assume increased importance, as part of the concern for our natural resources. In particular, the rehabilitation and management of mineral workings, waste tips, disused railways and canals within, and on the fringes of, urban and industrial areas form an environmental problem easily recognised by a large proportion of the urban population.

Urban populations will also require areas for amenity and recreation, and the development and management of such recreation and amenity areas are likely to assume increased importance. The cost of travel may increase pressure on areas close to urban settlements, as existing patterns of weekend and holiday recreation are adapted to meet the changed economic conditions. The selection of organisms and forms of management which reduce the cost of maintaining recreation areas, and which can survive under urban conditions, may then become more critical than at present, for example in the selection of amenity trees, and in the management of amenity grass. There is also likely to be a considerable interest in the landscaping and development of new centres within urban areas.

Closely related to urban problems are the role of wildlife as reservoirs of pests and pathogens, and the epidemiology of wildlife diseases which are capable of infecting man. Examples of these kinds of problems are already attracting particular interest, as in the interaction between rabies and the urban fox, and between bovine TB and badgers. Both of these existing areas of interest are centres of controversy, and the arguments will only be resolved by a clearer knowledge of the basic ecology of the organisms concerned.

3. *Research needs*

What research needs to be done to meet these problems of the 1980s? It is important to stress that, despite much progress in the study of ecology, particularly since the end of the Second World War, there are still many major areas of virtual ignorance. We cannot, therefore, assume that we have the knowledge that we need to manage our environment sensibly, although, regrettably, many politicians and industrialists seem to think that this is the case. There is, therefore, a major research need across the whole field of ecology. This introduction to ITE's first Annual Report of the 1980s can only touch briefly upon some of the more important areas for the development of ITE's research in particular.

3.1 Monitoring

Development of effective methods of monitoring short-term and long-term change in natural and man-made systems in the environment requires the understanding of basic and fundamental ecological processes. Past experience with the monitoring of the environment has already shown that it is not sufficient to count numbers of organisms, or to measure the quantities of pollutants in organisms, or parts of organisms. Without a firm and clear understanding of the basic processes, we simply do not have enough information to either design or interpret effective schemes for monitoring change. In contrast, any study of processes in ecology must be backed up by well planned and well documented schemes for the monitoring of defined forms of change. We already know from past experience that it is not possible to monitor in the abstract, and that biological health must be defined in terms of the effect of changes of populations of plants and animals. However, given a clearly defined objective for monitoring, the identification and testing of relationships between observed changes and measures of policy and forms of management may help to provide us with an efficient and early warning scheme for unexpected impacts on the environment.

3.2 Study of fundamental processes

The study of fundamental processes is also needed for a clearer understanding of the complex relationships between ecosystem components, and as the basis for more applied research. This more fundamental aspect of environmental research is likely to come under increasing pressure as research becomes more expensive, and as the demand for the results of applied research escalates with the gravity of the problems that are likely to face us. Nevertheless, it is essential to maintain, and, if possible, to extend, the work which is being done on fundamental processes in ecology. The following 5 examples will have to serve as representative samples of the areas for which increased fundamental knowledge is essential.

3.2.1 Nutrient cycles

Although most biological textbooks contain neat diagrams showing the cycles of nitrogen, phosphorus, potassium and calcium in the environment, relatively little knowledge still exists of such cycles. In particular, almost nothing is known about the actual quantities of these various elements flowing through different parts of the ecosystem at different stages of the development of the system, or at different times of the year. Knowledge of nutrient and decomposer cycles is essential for the wise management of agricultural, horticultural, pastoral, and forest systems. Intensification of management of such systems assumes that the nutrients cycle sufficiently quickly, or can be replaced artificially, to maintain the essential life processes, but we have already experienced many situations where such systems are being forced to run faster than essential nutrients can be transferred from compartment to compartment. The incorporation of pollutants into natural and man-made cycles represents one of the forms of change, which, increasingly, we will need to predict. The study of pathways or pollutants and the storage of pollutants within organisms is therefore likely to assume increased importance. In particular, it is only by the tracing of these pathways that the effects of pollutants will be determined, and the importance of seasonal and breeding mechanisms in specific organisms understood.

3.2.2 Genetic and physiological mechanisms

Many of these mechanisms are important for breeding and selection where man is deliberately exploiting plant or animal organisms. However, the importance of genetic ecology and the study of variation extends into the natural and semi-natural environment, and includes serious gaps in our knowledge of flowering and seed dispersal in trees and other vascular plants. Similarly, such basic mechanisms have a profound effect on growth forms and production, and interact with the effects of climate and environment in ways which we cannot at present predict.

3.2.3 Succession and vegetational change

Because, in general, change in ecological systems is relatively slow, our understanding of the mechanism and the processes of succession in vegetation remains extremely limited. Only recently have we recognised the importance of propagules and seed banks in succession, and further studies are necessary to enable us to predict the effects of disturbance. Again, better understanding of the processes involved in colonisation by plants may enable us to manipulate processes of succession which are frequently extremely slow, and therefore speed up the processes towards the establishment of relatively stable vegetation populations.

3.2.4 Population dynamics

Even for quite common plants and animals, there is still inadequate understanding of the basic population dynamics and life cycles of the organisms. In particular, we still do not have sufficient information on the importance and influence of external factors (eg climate) on the survival and growth of many organisms. Studies of population dynamics become even more difficult when there are complex density-dependent relationships between a particular organism and environmental factors, and when there are predator-prey relationships between several organisms. In particular, further research is almost certainly necessary on even such well known pest species as the rabbit and the grey squirrel. Past work on such species has not concentrated sufficiently on the understanding of basic physiology and population dynamics.

4. *Commissioned research*

Under the Rothschild principle, much of the applied research required by Government departments and other agencies will be expected to be commissioned by these agencies, so that the objectives of applied research will continue to be defined by the agencies themselves. Nevertheless, even at the beginning of a new decade, it is possible to detect some clear trends in the kinds of applied research which are being required by the customer departments and agencies.

4.1 Environmental impact

Public concern and pressure has stimulated increased interest amongst Government departments and industrial companies on the environmental impact of developments and of policies, although such concern is often shown after the impact has taken place, as in SO_2 pollution and acid rainfall, fluorine, and the fragmentation of southern heathlands. Nevertheless, we may confidently expect that there will be a substantial increase in commissioned research to determine environmental impact, and we may hope that, in future, such studies will be commissioned before, rather than after, the development has taken place.

4.2 Ecosystem management

The management of semi-natural systems for specific purposes, as in country parks, nature reserves and amenity grasslands, necessarily draws upon understanding of the dynamics of such systems. Increasingly, therefore, we may expect the agencies concerned with their management to require applied research to ensure that management is done as economically as possible and that the forms of management adopted achieve the desired aims.

4.3 Control of pests and pathogens

The resilience of biological organisms ensures that relatively unexpected outbreaks of pests and pathogens will occur in the future, so that applied research on the monitoring and the control of epidemics and outbreaks of specific pests will almost certainly be necessary. In the past, there has been undue reliance upon the use of pesticides as the only form of treatment for such outbreaks. Better understanding of the population dynamics of the organisms, and of their hosts, may well lead to potentially less harmful solutions to the problems of such outbreaks.

4.4 Desk studies

If the experience of the last half of the decade of the 70s is any fair indication, much of the applied research for the 1980s will take the form of desk studies of existing knowledge on specific applications of ecology. Such studies as pathways of radionuclides, biological health monitoring, genetic resources, etc, have drawn upon the accumulated experience of the ITE staff, and the main task has been to present scientific information in a form in which it can be used readily by decision-makers, and by those who wish to advocate particular policies. While applied research of this kind is not popular among scientists, there is no doubt that the translation and interpretation of the results of scientific research to this usable form is an essential and important task which can only be done adequately by the scientists themselves.

4.5 Design and analysis of experiments and surveys

The efficient design of experiments and surveys in the environmental sciences remains a relatively rare phenomenon. Such design, and the subsequent analysis of the data derived from experiments and surveys, is complicated by the heterogeneity of ecosystems and organisms, and requires special expertise, but the fact remains that a large part of what passes for research in the environment is wasteful and inefficient. An important form of applied research in the future, therefore, will be to provide advice on the efficient and effective design and analysis of experiments and surveys in the environmental sciences.

4.6 Systems analysis and modelling

Perhaps the biggest change in research needs in the 1980s will be in the demand for the modelling and prediction of ecological change by the use of systems analysis and mathematical modelling. The techniques for work of this kind have been developed over the past 20 years, but have not so far been used to any great extent in the solution of practical problems. However, the rapid development of mathematics and of the associated computers has brought within practical possibilities the use of systems analysis and mathematical modelling for the solution of major environmental problems, and we may expect to see increased research in this field during the 1980s.

5. *Role of ITE*

ITE as a component Institute of NERC has a special role in the ecology of the 1980s. This role is dependent upon 4 major factors. First, NERC is independent of any of the policy-advocating agencies, so that its research is capable of being completely unbiased by the need to conform to proposals for future policies. Indeed, the primary task of NERC is to create knowledge about the natural environment as a basis for the formulation of future policies and as a way of evaluating the effects of past and present policies. ITE's own objectives were defined in the first ITE Annual Report as: "To improve understanding of the factors determining the structure, composition and processes of terrestrial ecological systems and the abundance and performance of individual species and organisms. 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". These objectives are likely to remain valid for the coming decade.

Second, ITE's contribution will mainly be in terms of long-term research and monitoring. As a Research Council Institute, ITE does not have the constraints which are imposed by having to design research programmes around the need to train post-graduate research workers. It is possible therefore to maintain research programmes over a number of years, and to make the necessary capital investment in expensive equipment and facilities. Having obtained the equipment and the facilities, it is possible to ensure that they are used to the fullest possible extent for the whole of their working life. In this way, ITE can provide "value for money" in the difficult and expensive field of environmental research.

Third, because it possesses a wide range of different disciplines within its own organisation, this expertise can be drawn together for appropriate periods of time, and highly specialised individuals can be involved in research projects, even if they are only required for a relatively short time. As world problems become increasingly more complex, the need for this multidisciplinarity and interdisciplinarity increases rather than decreases, and only the relatively large institutes are therefore capable of mounting a programme of sufficient extent to cover the many important ramifications of the management of ecological systems.

Fourth, because of ITE's wide geographic distribution, with 10 research stations at 8 separate locations (see Figure 1), it is possible for its scientists to work at a range of sites over Britain as a whole. Indeed, considerable effort has been devoted to retaining this geographic spread of ITE's research staff and stations, so as to ensure that, if particular problems break out in any part of the country, there are terrestrial ecologists

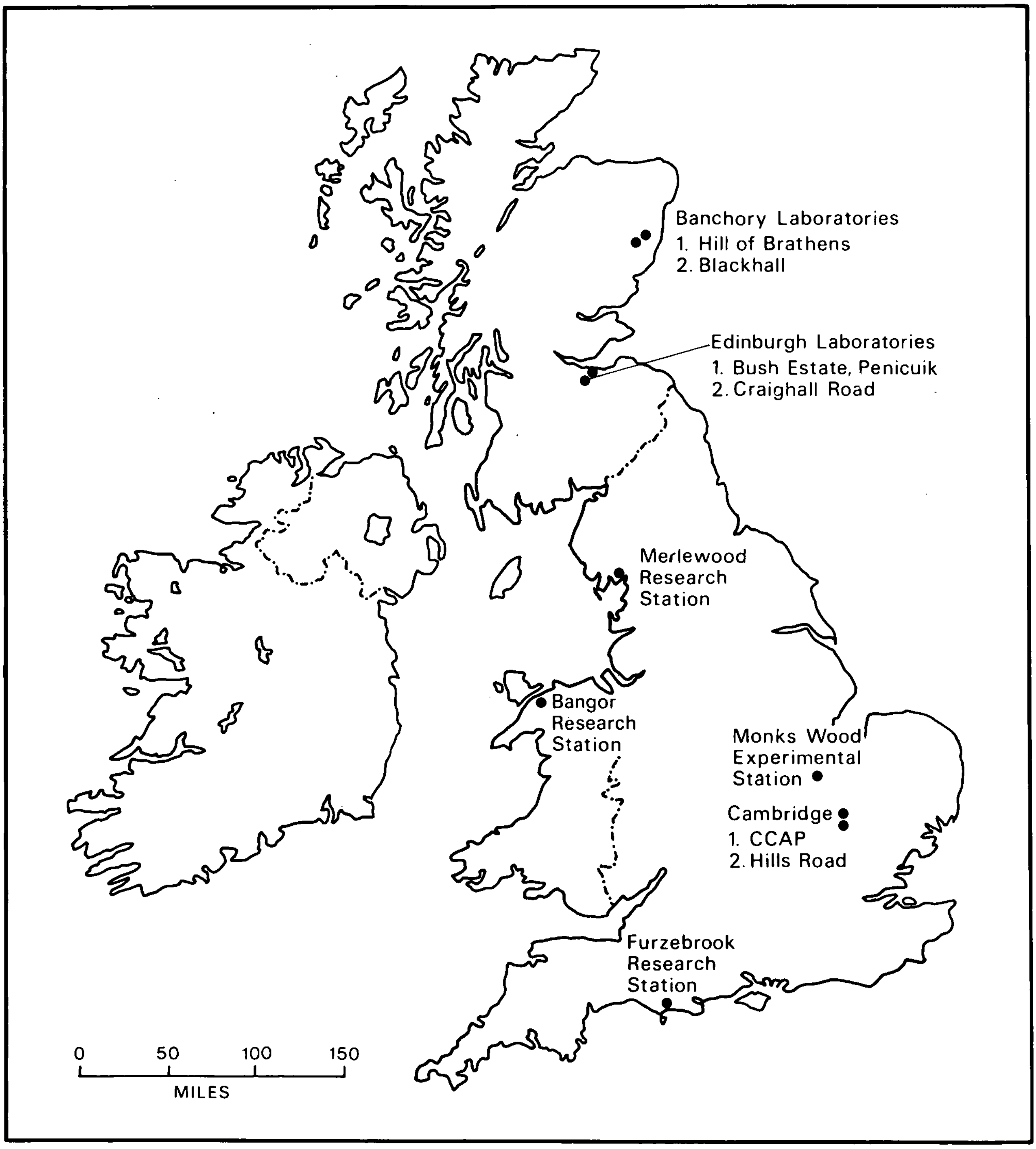

Figure 1 Map showing location of ITE Stations.

within reasonable reach of the problem and of the research sites. Although travel in Britain cannot be regarded as being wildly expensive or difficult by comparison with many other parts of the world, there are still considerable economies to be gained from having research facilities close to most of the major areas in which problems are likely to arise.

6. *Collaboration with others*

Clearly, ITE will not be attempting to tackle the ecological problems of the 1980s on its own. For one thing, NERC has a number of component institutes and grant-aided bodies, spanning between them the whole range of the natural environment. As relatively few environmental problems stop tidily at the boundaries of terrestrial, marine, or freshwater ecosystems, it will be necessary for ITE to collaborate closely with its sister institutes at the interface of the different problems. The distinctive skills and philosophies of these institutes can only help in tackling the kinds of complex problems which are envisaged as arising in the 1980s. Collaboration will not, however, be limited to the other NERC institutes. ITE scientists are part of the scientific profession in Britain, and will therefore play an active part in the work of scientific societies and in collaboration with their colleagues in universities, polytechnics, and colleges of advanced education. We have already shown that it is possible to devise joint projects between ITE staff and research workers in universities, and to sub-contract some of the commissioned research which is done by ITE to colleagues in universities and elsewhere. These positive and active moves towards increased collaboration will be strengthened.

Internationally, and in addition to collaboration with colleagues in research institutes and in universities overseas, ITE will collaborate closely with the Governmental and non-Governmental agencies, including FAO, UNESCO, IUCN, etc. There are many problems, both in the developed west and in the developing countries of the world, for which ITE's expertise can be used, and from which ITE staff can learn more about a wider range of ecosystems and environmental problems. As in the past, therefore, ITE will continue to take every opportunity to be involved in international work in the broad field of terrestrial ecology.

7. *Conclusions*

In the joint IUCN/UNEP/WWF Strategy for World Conservation entitled 'How to save the world', 3 main aims of resource conservation were defined, namely:

i. to maintain essential ecological processes and life support systems;
ii. to preserve genetic diversity;
iii. to utilise species and ecosystems sustainably.

These 3 aims summarise succinctly the principal problems for ecology in the 1980s. Britain has a responsibility to provide a lead in fulfilling these aims, and ITE (within NERC) has a major role to play in fulfilling that responsibility. It should perhaps also be stressed that the responsibility extends outside of the boundaries of Britain itself. Only in the political world do the national boundaries provide a legitimate limit to the concern which can be expressed through research for the conservation and wise use of the limited resources of the world.

J. N. R. JEFFERS
Director, ITE

Longer research reports

Introduction
This section contains 7 descriptions of research which has either been completed or has reached a stage where it warrants a fuller account than the reports in section III.

The first 2 reports describe research on 2 species of bird, the starling and the puffin. In the first of these projects, experiments have been conducted to study the effect of environmental variables on the onset of breeding. Light has been shown to be an important factor, but it has long been recognised that other environmental variables must be involved in modifying the timing of breeding, and observations have been made on the relationship between food eaten and natural daily fluctuations in temperature, and also on weather conditions related to feeding activity. The report describes experimental investigations of nutritional factors and gonad growth in caged male starlings.

The second report describes an attempt to show the sublethal effects of environmental pollutants on seabirds. The puffin was chosen for the field trials as it had already been shown in a previous programme of research to have low concentrations of toxic chemicals compared to many other seabirds. A polychlorinated biphenyl (PCB) was the pollutant chosen because it had been implicated several times as at least a partial cause of seabird mortality. The field trials involved the contamination of some individuals in a primarily clean population and evaluated their performance in comparison with adequate controls. This work was commissioned by the Nature Conservancy Council as part of its programme of research on wildlife conservation.

The third report describes 2 projects undertaken with funds from the UK Overseas Development Administration. The first of these projects was established in 1971 at the Forestry Research Institute of Nigeria and studied the practical aspects of developing techniques for conserving and 'improving' West African hardwoods, and particularly *Triplochiton scleroxylon*; this project was supported by a second study based in Edinburgh, Scotland, which was designed to provide a basic understanding of physiological mechanisms. The subsequent development of techniques for rooting leafy cuttings from young trees has enabled gene banks and clonal trials to be established at 8 sites in Nigeria. The results of these 2 projects illustrate how some of the biological constraints limiting the wider use of *T. scleroxylon* can be overcome, enabling it to be considered for planned programmes of reafforestation.

The fourth report describes a system of land classification based on the multivariate analysis of 282 environmental attributes concerned with climate, physiography, geology and human artefacts. In a survey of Cumbria, data were recorded for every 1 km square of the National Grid, while for Britain as a whole the survey focused on a 1 km^2 at each 15 km × 15 km intersection. The analysis classified the squares into 32 land classes, which had well-defined patterns of distribution, indicating the existence of continuous environmental gradients. The natural vegetation has been classified into 75 types, which provide a supporting system for land use and land type classifications. By associating actual land uses with the different land classes, it has been possible to predict land uses in unsurveyed areas of Britain, but many other aspects of importance to physical planning remain to be investigated. The project is still in its early stages of development, but the land classification described is being used in a number of ITE projects, and possible future applications are suggested.

A previous contract study of the general features of upland land use and character and their influence on vegetation encouraged the Department of Environment to seek a more detailed analysis of the nature of gradual vegetation change in 12 areas in the uplands of England and Wales. The fifth report describes how attempts have been made, from the analysis, to predict the vegetation patterns which could result from gradual changes attributed to modified management practices, and indicates how the scale of change would vary considerably between study areas. The predictions are speculative, but the study has provided a base line against which future changes could be monitored.

Plant growth experiments have shown that soils of deciduous and mixed deciduous woodlands of the Lake District are phosphorus deficient, and that the availability of this element limits, sometimes markedly, the growth of trees. The next report describes analyses which have been made of the amounts of phosphorus in Lake District woodland soils, their physico-chemical state, availability to plants, and rates of turnover, in an attempt to assess the demand for, and uptake of, phosphorus by trees and woodland vegetation. Results suggest that soil pH and calcium status are key factors.

The final report is an account of a 3-month tour of south-east Europe under a Churchill Fellowship awarded to compare the organisation of nature conservation in different countries. The tour included visits to Yugoslavia, Greece, Italy, Sicily, Sardinia and Corsica, and the account describes how attitudes to nature conservation are determined by factors such as standards of living, cultural values, traditional attitudes to wildlife, education, legislation for nature protection and its enforcement, etc.

ENVIRONMENTAL VARIABLES AND ONSET OF BREEDING IN THE STARLING

Seasonally breeding birds have evolved mechanisms for timing the onset of reproduction, so as to maximise the survival of the offspring. For the young to be produced at the optimal time for parental support and fledgling survival, the physiological changes preceding egg laying must be initiated some time before. Thus, the environmental factors ("ultimate factors", Baker 1938) which influence reproductive success have little predictive value in most cases. In order to time its breeding most efficiently, a bird must therefore respond directly to those "proximate factors" which adequately predict the ultimate factors and thus bring it into breeding at the appropriate time. The most widely investigated proximate factor is light, since daylength has good predictive value. A body of experimental work exists to show the importance of light, and to outline the physiological mechanisms involved in measurement of photoperiod. Few predictions of this kind are perfect and modifications of response to suit unseasonal conditions are likely. The onset of egg-laying does not occur at exactly the same time each year, despite a reasonably constant photoperiodic stimulus. It has long been recognised, therefore, that other environmental variables must be involved in timing breeding, but little experimental work has been done on factors other than light.

We have begun to investigate some of the variables which might be involved in modifying the time of breeding in the starling (*Sturnus vulgaris*). Obvious candidates include weather (temperature; rain; snow cover; wind) and nutritional factors (food availability; the achievement of food targets; or adequate body reserves). Some of these variables will clearly be interdependent with others.

Observations have been made on the relationship between food eaten and natural daily fluctuations in temperature, and also on other weather conditions related to feeding activity. Some preliminary results are available on these aspects. Experimental investigation of nutritional factors and gonad growth in the male will here be reported more fully.

Caged male starlings kept at constant temperature were maintained on short (8 hours) or long (14 hours) daylengths, with short or long feeding days (8 hours and *ad lib*; the latter is equivalent to a 14 hour feeding day since, in these circumstances, the birds do not eat in the dark). The long days of light were either a continuous light period of 14 hours or a split (skeleton) photoperiod consisting of 2 light periods, with 14 hours between the beginning of the first and end of the second. The treatments are illustrated in Figure 2. It is important to realise that a shortened feeding day does not simply cut off the birds feeding prematurely. The starlings can

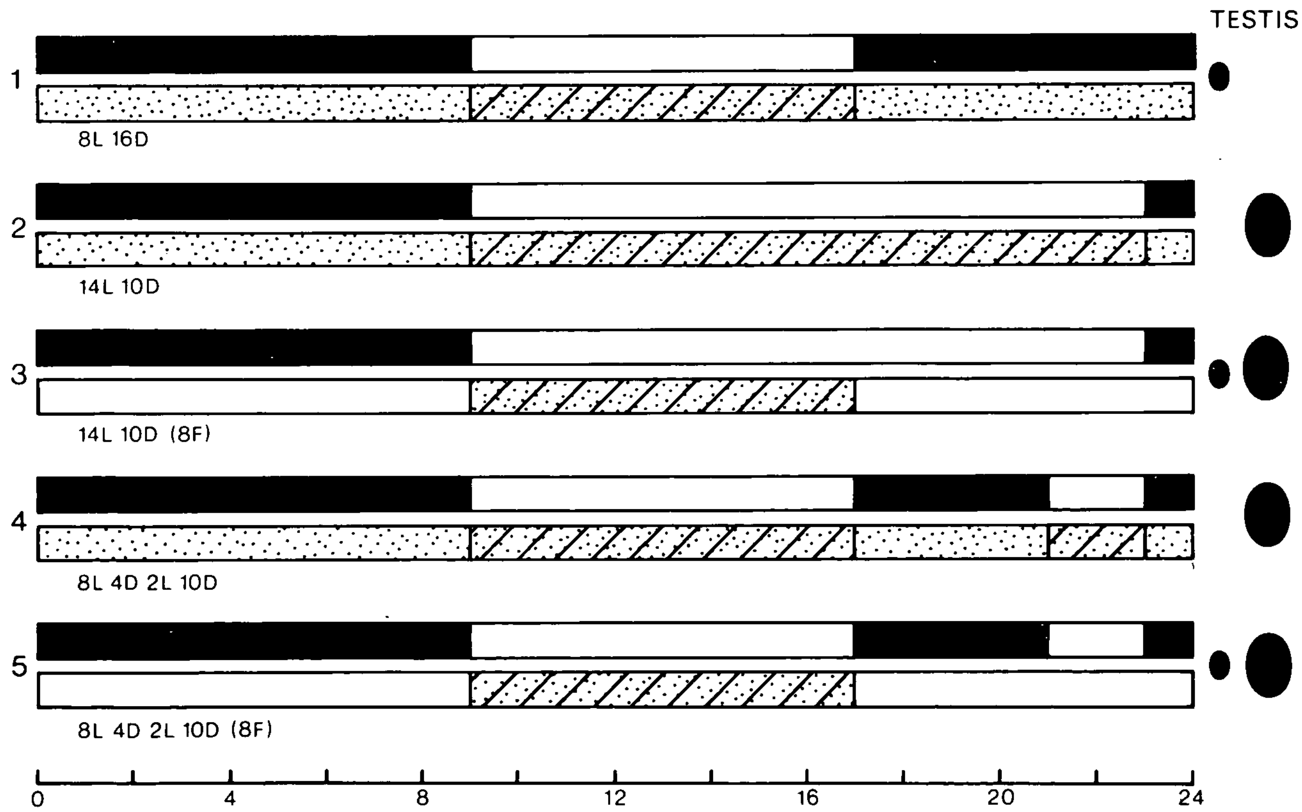

Figure 2 The 5 experimental treatments. The upper bar in each case shows the light treatment during 24 h. The lower bars show when food is available to the birds, and deeper hatching the probable or actual feeding period. Testicular response to 48 days of each treatment is given on the right (to scale).

adapt completely separately to food and light periods (Gill & Dobson 1980), even when these are more widely separated than in the present case. Thus, attempts to feed will be confined to the 8 h food period on a 14L (8F) treatment. Several birds killed at the beginning of the experiment were analysed for body condition (stored fat; and lean, dry flight muscle weight as an indicator of stored protein) and gonad development (Jones & Ward 1976). Experimental birds were given a weighed amount of balanced diet (chick crumbs), well in excess of their daily requirements (100 g), in an arrangement to catch any spillage and minimise fouling. The amount eaten was measured at the end of each short feeding day and at dawn on the *ad lib* treatments before the day's feeding began. After 48 days, the birds were killed, gonads weighed and body condition assessed in the same way as in the pre-experiment controls. At this time of year (January/February), a slow rate of gonad growth occurs in starlings irrespective of treatment. Treatment 1, on short days, showed this minimum growth rate and after 48 days the paired testes weight was 69·9 mg, significantly greater than the starting weight of 12·8 mg ($P<0{\cdot}01$). Treatments 2 and 4, long days with unrestricted food, induced maximum testis growth in all birds, with a mean paired testes weight of 1313·5 mg (significance of difference from starting weight $P<0{\cdot}001$). The birds on the skeleton photoperiod showed greater variation in testis weight (range 666 to 2008 mg) than the complete photoperiod (range 1138 to 1634 mg), a typical response of "simulated" long days. In treatments 3 and 5, half the birds showed maximal testis growth (1450·50 mg) not significantly different from birds on treatments 2 and 4, and the other half showed minimal growth (112·87 mg) not significantly different from short day birds.

There was no difference in body condition (fat and protein) between birds on any of the treatments, nor between birds after treatment and birds examined at the start. Long day birds which showed gonadal growth had 11·5 ± 1·7 (SE) g of fat and 3·9 ± 0·1 g of protein, while those not showing gonad growth had 11·4 ± 1·9 g of fat and 3·8 ± 0·05 g of protein, compared to starting values of 12·8 ± 1·4 g of fat and 4·0 ± 0·1 g of protein. These various values for fat and protein respectively are not significantly different from one another ($P>0{\cdot}3$). Whilst we cannot say whether these stores changed during the course of the experiment, it seems that adequate stored reserves will not in themselves cause gonadal development (as suggested by Jones & Ward 1976 for a tropical species), because they were as high at the beginning as at the end of treatment, and some birds showed testicular growth, whilst others did not. This result does not, of course, imply that body reserves might not be limiting in the wild.

On all long day treatments, irrespective of the length of the feeding day, the total amount eaten by each bird per day was greater (24·8 g) than on the short day treatment (22·8 g). Those long day birds which showed maximum testis growth at the end of the experiment ate an average of 24·7 g/day and those showing minimum growth ate 24·8 g/day. Birds on all treatments spent about a week at the beginning of the experiment when they ate less, gradually building up to a stable intake, presumably as the birds became acclimatised to the experimental cages (Figure 3). Once stabilised, all long day treated birds consistently ate more than short day birds. All treatments showed some variation between individuals, but, in treatments which produced a split response, those individuals whose testes grew ate no more than those whose testes did not grow.

The results suggest that a food target is indeed set each day, as has been suggested by several authors, and that this target can be achieved on a short feeding day when the food supply is not limiting. The target set appears to relate to daylength and to be independent of gonadal growth. Conversely, gonadal growth seems to be independent of the achievement of a food target, as those birds showing minimal testis growth ate the same amount as those birds whose testes grew maximally. We have no information yet on females. They might be expected to require more food resources than males at a late stage of ovarian development involving yolk deposition, and these extra needs might influence feeding targets. However, initial ovarian development is unlikely to require more material than testis growth.

There was a clear indication of the operation of a switch in treatments 3 and 5, which appeared to operate as either fully on or fully off, as there was no graded response. This switch was presumably related to food treatment, because this was the only difference between these 2 groups and treatments 2 and 4. Such a switch did not, however, relate to the attainment of a food target, as all birds ate the same amount. The decision on which this switch operated appeared to relate to the length of the feeding day (or the food 'night'), which was the only variable here. How this decision might operate physiologically is unknown.

The achievement of food targets implies some monitoring of food reserves. Observation of overnight fat stores in several bird species (Newton 1969 and references) also implies close monitoring of such reserves. Our preliminary observations of temperature effects on feeding show a positive correlation between food eaten on a particular day and temperature during the previous day and night. This correlation might imply a capability of monitoring stored reserves before the beginning of a feeding day. Such information would be of obvious advantage in setting requirements for the following night, and also as a criterion for a decision on the adequacy of food supply for breeding. Field observations on rural populations of wood pigeons (Murton 1975), where gonad growth occurs well before the decision to pair, nest-build and lay eggs is made, strongly suggest that the birds monitor the length of feeding day as an indicator of likely breeding success. Although there is good circumstantial evidence that many animals can monitor their food resources in this

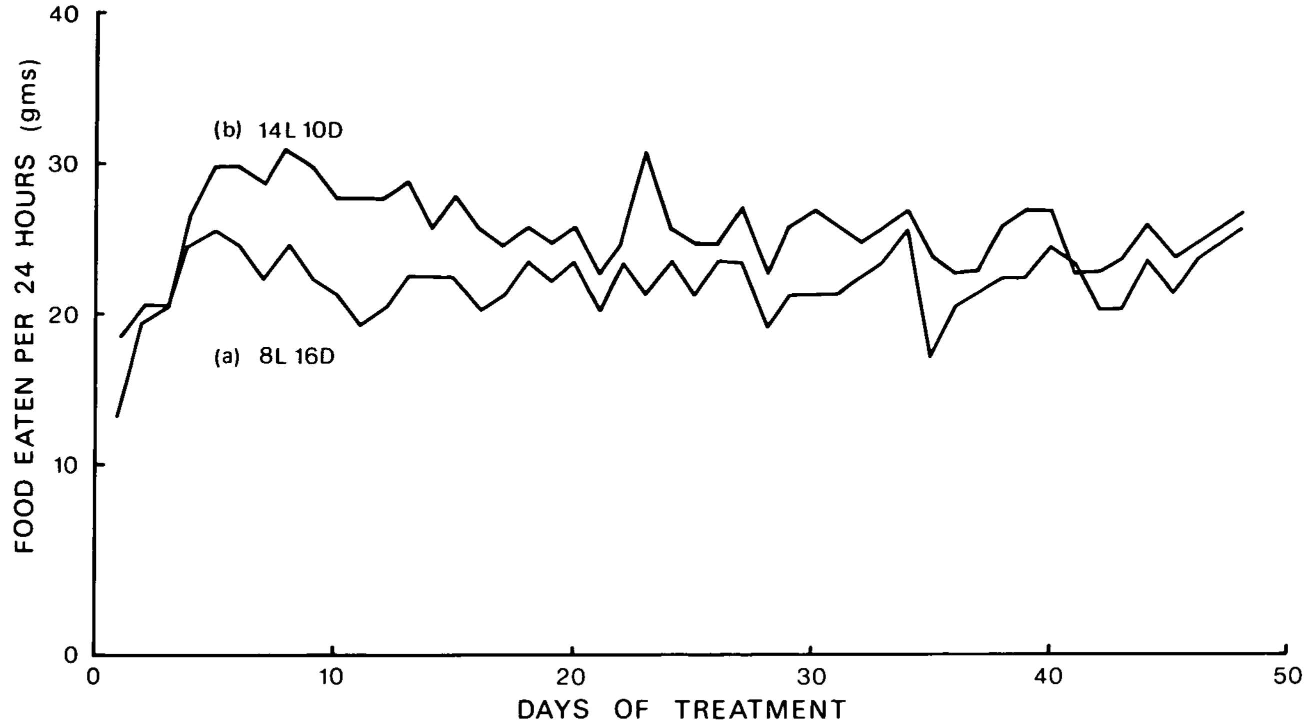

Figure 3 Means for food eaten per day over the 48 day period of the experiment. Two treatments are graphed: (a) 8L:16D (treatment 1) and (b) 14L:10D (treatment 2), n = 6 in all cases.

way (papers and discussion groups, Silverstone 1976), the mechanism by which this monitoring operates is unknown. These observations imply that a timing mechanism is important to nutritional response in birds, as for the response to light.

Many factors in addition to those considered here might influence birds breeding in the field. Feeding seems to be inhibited by rain, even when the bird is sheltered from direct effects, and, if food targets are not met, breeding would probably be inhibited. Interestingly, captive starlings in a sheltered aviary with a more than adequate food supply delayed the onset of breeding in a poor spring to exactly the same extent as did free-living birds. The mechanisms are likely to be complex, and considerably more experimental work is required to determine the responses to individual environmental variables. There are also likely to be considerable differences between species.

N. J. Westwood and S. Dobson

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RESEARCH ON PUFFINS AND PCBs

(This work was largely supported by Nature Conservancy Council funds)

Introduction

A great quantity of data has been amassed by many research laboratories, including ITE's Monks Wood Experimental Station, on the incidence of various environmental pollutants in seabirds (eg Bourne 1976). However, there is no direct experimental evidence to show that any of these chemicals has an adverse effect on seabirds. The few previous attempts to show the sublethal effects of chemicals have involved comparing the biology of contaminated and clean populations of birds. The interpretation of such results is extremely difficult because the populations occur in widely separated areas, often with different migration habits, food preferences, breeding times, and so on. This report presents information from a study based on a different experimental approach, involving the contamination of some individuals in a primarily clean population and evaluating their performance in comparison with adequate controls. A field trial was chosen in preference to laboratory studies because it is extremely difficult to keep seabirds in captivity without causing severe, often fatal, stress, and any subtle differences noted between groups of birds might have had no consequence in the wild.

Between 1972 and 1977, ITE carried out a programme of research on the biology of the puffin (*Fratercula arctica*) at the Isle of May NNR, Fife. We found that the puffins there had low concentrations of toxic chemicals relative to many other seabirds. As a result, we decided to use the puffin for field trials.

A polychlorinated biphenyl (PCB) was the pollutant chosen because it has been implicated several times as at least a partial cause of seabird mortality (eg Parslow & Jefferies 1973). The compound used, Aroclor 1252, was most like the PCB found in the tissue of guillemots (*Uria aalge*), a member of the same family as the puffin, killed in the 1969 seabird wreck in the Irish Sea (Holdgate 1971).

Breeding of puffins

Puffins return to the Isle of May in March (Plates 1 & 2), fight for nest burrows (as there are many more sexually mature birds than burrows), and lay a single egg in late April. This egg is incubated by each adult in turn for about 40 days. If an egg is lost early in the incubation period, it is replaced; otherwise, it is not. After hatching, the chick is brooded for a few days and then left while both adults are away foraging. It is fed 4–6 times per day with fish carried back in the adult's bill, so that feeding frequency can be monitored by direct observation (Plate 3). The chick reaches a peak weight of about 80% of that of the adult when aged 4–5 weeks, and then loses some 20% of this weight, as a result of receiving fewer feeds, before fleding when aged 38–42 days.

The provision of artificial lids on the nest burrows enables the majority of eggs and young to be removed when required, and some adults can be caught on the nest. However, adults handled during incubation often desert. Adults are caught more successfully in flight nets set across the colony. In order to reduce the risk of desertions during the experiments, only one bird of any pair was dosed. If there is a change in behaviour of one parent, it should affect breeding success, as one adult alone cannot successfully rear a young.

Adults leave the nesting island during August and spend the winter in the North Sea. The main moult of the year occurs in late winter and the puffin is then flightless. Analysis of ringing recoveries, collected by the British Trust for Ornithology, shows a peak of mortality at that time. About 95% of adults survive from one year to the next, among the highest survival rates recorded for any bird.

Implantation

Three possible ways of administering the PCB were considered—oral dosing, injection and implantation. Repeated oral dosing, even if the bird could be caught when required, would almost certainly have resulted in the bird deserting its burrow, and injection of PCB would probably have caused inflammation of the skin. Consequently, implantation was preferred. Laboratory trials were done first using pigeons and open-ended implants containing 35 ± 2 mg of viscous PCB. These trials showed that the PCB was taken up by the birds. After one month, the levels in the livers (10–19 mg kg^{-1} wet weight) were in the upper range found in samples of 'killed' rather than 'found dead' wildlife, ie the dose was unlikely to prove lethal in the wild.

Puffins were caught in the late afternoon (Plate 4). Each bird was measured, sexed by bill measurement, and uniquely colour-ringed (Plate 5). A small implant, containing either Aroclor 1254 PCB (dosed birds) or sucrose (control birds), was inserted under the skin to lie alongside the ribs (Osborn & Harris 1979). It was hoped to remove samples of fat for biopsy, but this removal proved impossible. The birds were kept overnight and released away from the breeding areas (Plate 6). In 1977–79, 108 puffins were implanted with PCB and 42 with sucrose. The sample sizes were restricted under the various licences needed for the work.

The subsequent survivals of these and normal (ie individually identifiable but not operated on) birds were monitored up to August 1980 and their breeding performance was followed from 1977–79. Some of the puffins were later killed, and samples of mesenteric fat, pectoral muscle, kidney, liver and brain were taken and analysed by gas chromatography. Eggs laid by dosed and normal females were collected and analysed in the same way. All concentrations are expressed as mg kg^{-1} wet weight.

Results

Most birds returned to the colonies within a few days after the implant, and all 150 were found eventually and appeared healthy. Obviously, the operation caused little, if any, distress.

Tissue levels

The levels of PCBs in the tissues of 10 controls (ie normal birds implanted with sucrose) killed at various times were similar to those in 19 normal birds killed in the same period. All these birds had PCB in the fat (mean of normal birds = 31·0 mg kg^{-1} ± SE 2·7; the mean of the controls = 40·5 ± 7·1); 4 normal and one control had PCB in the liver (5·9 mg kg^{-1} ± 2·4; 1·3); one control had <2·0 mg kg^{-1} in the kidney, muscle and brain; and one normal puffin had a trace in the kidney. The concentrations of PCB in the dosed birds varied with time after dosing, but were always much higher than the amounts in controls or normal birds. The mean body load of 7 adults killed within 3·5 months of dosing was 5·99 mg ± 0·93 PCB. This compared to 0·58 ± 0·08 for 11 normal puffins and was higher than the body loads of guillemots found dead in the 1969 seabird wreck in the Irish Sea (Parslow & Jefferies 1973).

The PCB was taken up by the body and the amount remaining in the implanted tube was always less than 10 µg after 12 months. PCBs are fat-soluble and levels in the mesenteric fat quickly reached 10–14 times that of normal birds (Figure 4). Levels remained high for several months before gradually declining. Even after 34 months, the concentrations were still double the normal. Within 3·5 months, the PCB had found its way into the liver and muscle of most dosed birds (Figures 5 and 6), but the concentrations there declined subsequently. Concentrations in the kidney (Figure 7)

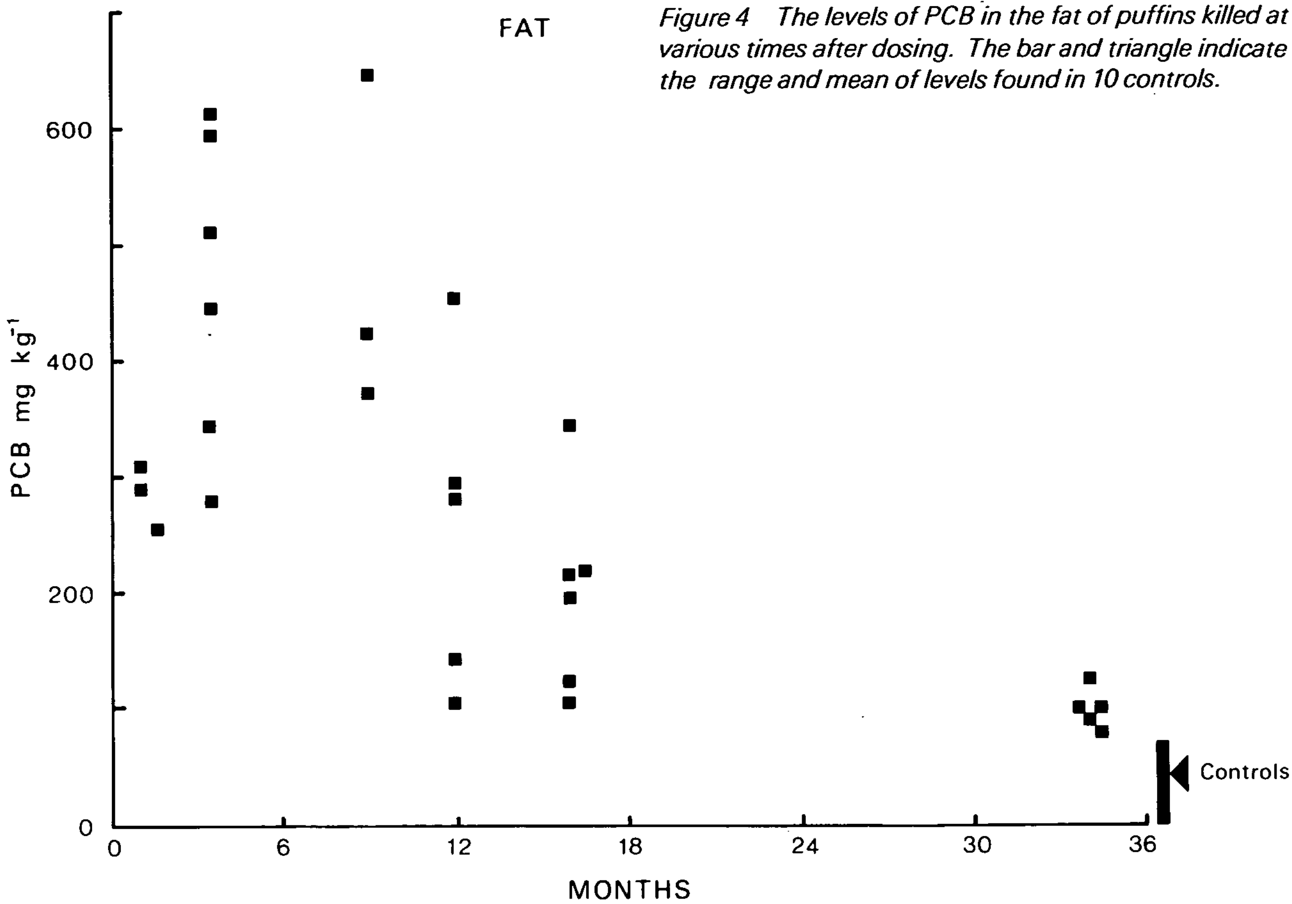

Figure 4 The levels of PCB in the fat of puffins killed at various times after dosing. The bar and triangle indicate the range and mean of levels found in 10 controls.

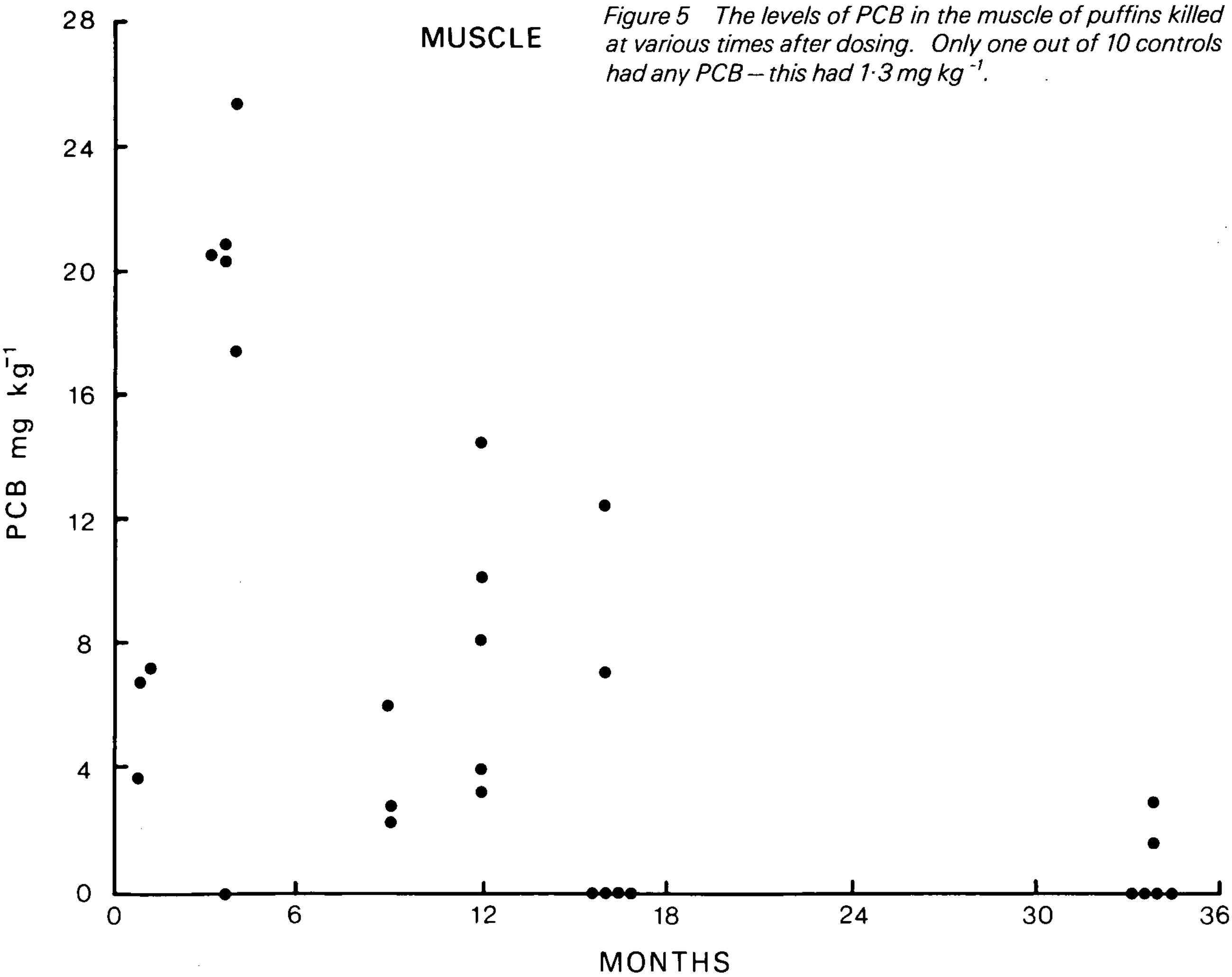

Figure 5 The levels of PCB in the muscle of puffins killed at various times after dosing. Only one out of 10 controls had any PCB – this had 1·3 mg kg $^{-1}$.

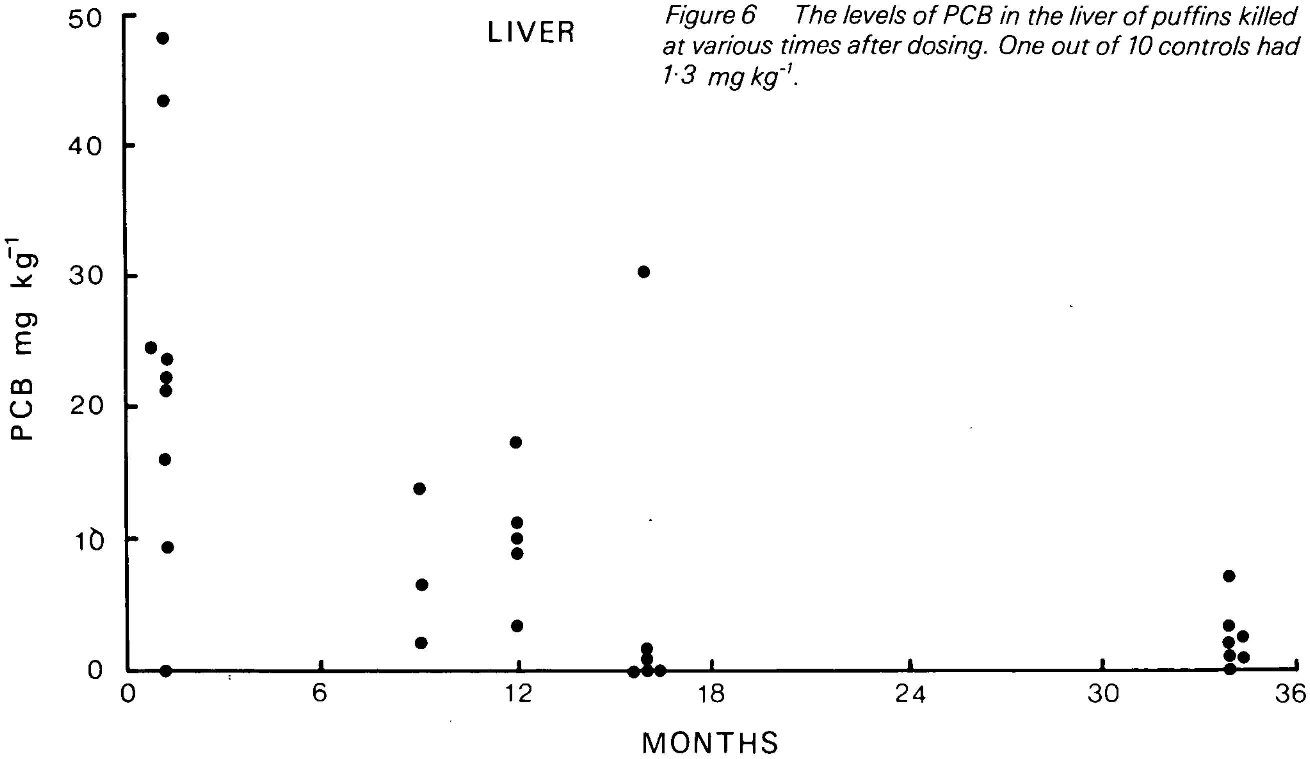

Figure 6 *The levels of PCB in the liver of puffins killed at various times after dosing. One out of 10 controls had 1·3 mg kg^{-1}.*

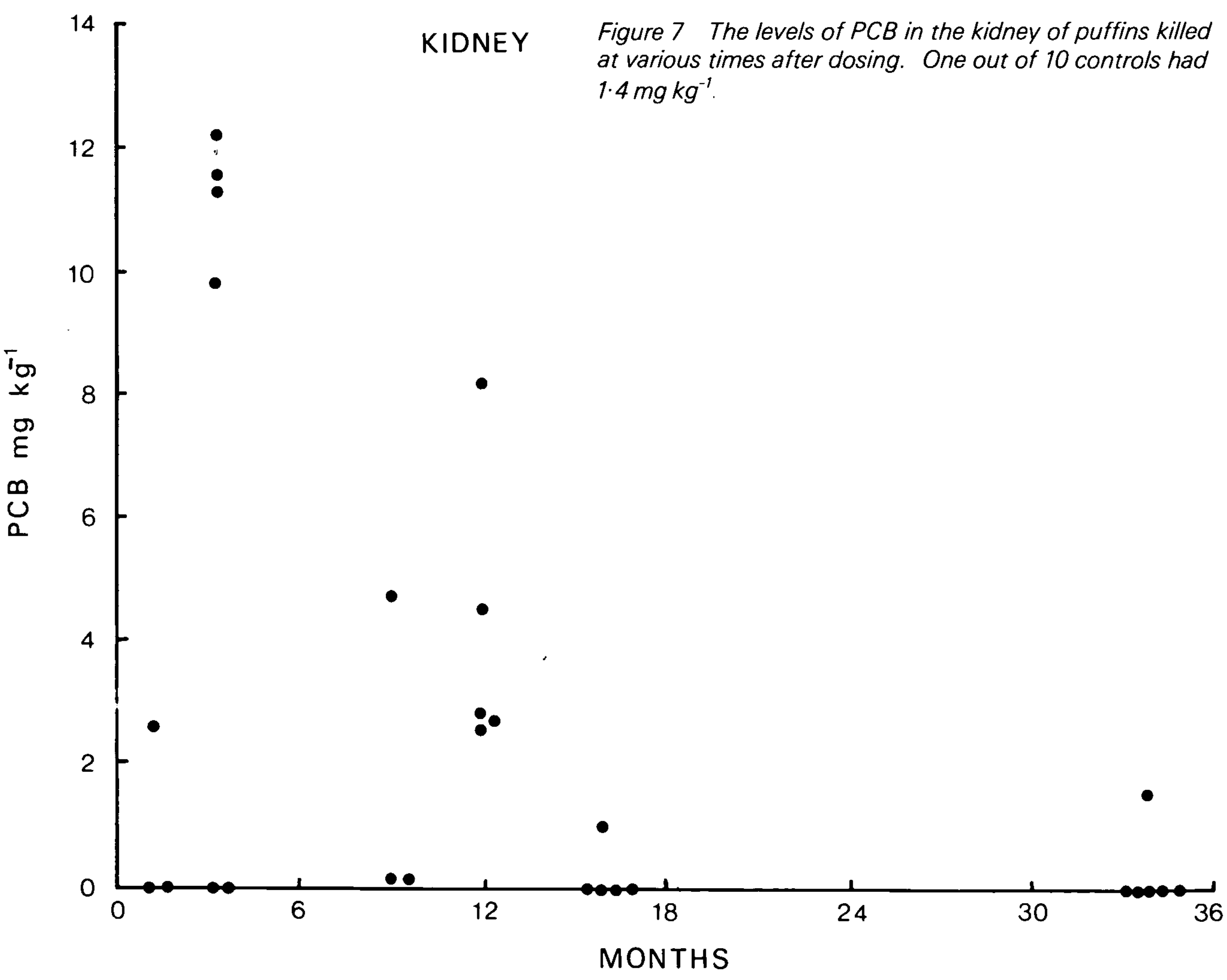

Figure 7 *The levels of PCB in the kidney of puffins killed at various times after dosing. One out of 10 controls had 1·4 mg kg^{-1}.*

and brain were variable. One exceptional bird had very high levels in all tissues 16 months after dosing. The reasons for these high levels were unknown, unless the bird had recently mobilized much of its fat. It was killed just after rearing a chick, when body weight is minimal.

PCB was found in 5 eggs laid by dosed females, the mean level being 43·4 mg kg^{-1} ± 12·7 compared to a mean of 8·4 ± 2·6 for 18 normal eggs. Two few dosed breeding females were available to investigate the levels in their bodies and their eggs, but there was no significant correlation (r = 0·30) between the levels of PCB in 10 normal and one dosed female birds (Table 3).

Table 3. Relationship between PCBs in female puffins and their eggs

PCB in puffin fat		PCB in puffin egg	
normal female	dosed female	normal female	dosed female
25		9	
16		6	
46		4	
17		4	
28		5	
33		5	
33		3	
37		10	
23		4	
44		7	
	299		10

Residues are expressed as mg kg^{-1} wet weight

Biological results

The survival of all classes of adults was extremely high during the winters of 1977–78, 1978–79 and 1979–80. The annual survivals of dosed birds were 94·5, 96·6 and 90·0% respectively, of control adults 100, 100 and 97·2%, and normal adults 96·4, 95·8 and 90·8%. There were no significant differences between the groups.

There were no detectable differences between the breeding of the groups (Harris & Osborn in press). In 1978–79, 39% of the dosed birds were proved to be breeding, and the breeding output was 0·58 young fledged per occupied burrow. This compared with 38 and 28% of control and normal birds found breeding, and outputs of 0·55 and 0·61 young fledged per burrow. Parents in all groups fed their chicks at the same rate (mean daily rates of 4·6, 5·1 and 5·0 feeds for young fed by a dosed, a control or 2 normal adults), and the chicks grew at the same rates (Table 4).

Table 4. Weights (g) and fledging ages (days) of young puffins where one parent had been implanted with PCB (dosed) or sucrose (control), or where both adults were untreated (normal). Means are given ± SE (From Harris & Osborn in press)

	Dosed			Control			Normal		
	No.	Mean	SE	No.	Mean	SE	No.	Mean	SE
1977									
Peak weight	10	321	3·2	3	311	5·3	27	326	4·6
Fledging weight	10	286	5·0	3	274	7·5	23	281	5·6
Age at fledging	10	43	0·9	3	41	1·5	22	43	0·7
1978									
Peak weight	20	329	5·9	11	334	6·4	56	329	4·1
Fledging weight	15	287	8·5	10	290	8·8	38	290	5·1
Age at fledging	14	40	0·8	9	41	1·0	40	41	0·6
1979									
Peak weight	13	318	5·2	12	322	6·6	71	325	2·8
Fledging weight	12	268	5·5	10	270	9·5	60	278	2·6
Age at fledging	11	40	0·7	10	40	1·0	62	40	0·4

Discussion

Despite the marked increase of concentrations in the tissues of the puffin and the persistence of elevated concentrations in the fat 3 years after dosing, the PCB appeared to cause no ill effects to the birds. Recently, Custer and Heinz (1980) failed to detect deleterious effects of PCB on the breeding of the mallard (*Anas platyrhynchos*). If anything, the performance of dosed ducks was slightly better than that of their controls.

These results run contrary to much circumstantial and a little experimental evidence (eg Peakall & Peakall 1973) that PCB has a deleterious impact on the breeding and survival of birds. There were at least 4 possible explanations for these apparent anomalies.

1. The doses were not high enough, although the levels attained were in excess of those claimed to cause disturbance of neurotransmitter levels (Heinz *et al.* 1980).
2. This particular isomer mixture had no effect on puffins, which seems unlikely as this, or a very similar compound, was involved in another auk in the seabird wreck in the Irish Sea.
3. Conditions may have been exceptionally favourable for puffins during these years, and the birds did not need to deplete their fat reserves and so liberate the fat-soluble chemical into the blood streams. Monitoring the survival of the remaining birds is continuing to check this hypothesis. However, the survival of these puffins was similar to results obtained elsewhere (Ashcroft 1979).
4. Puffins may be better able than some other birds to excrete compounds such as these. Other studies on Isle of May puffins (Knight *et al.* in press) have shown that puffins have an exceptionally high activity of an enzyme microsomal mono-oxygenase which converts foreign compounds, including PCBs, into more easily excreted water-soluble compounds. This ability could limit the concentrations of PCB in the tissues and reduce the toxicity of any dose. This possibility underlines how much we must know about any animal before we can predict how it is likely to be able to cope with increasing contamination of the environment. Even if puffins can cope with high levels of contaminants, no assumptions can be made about closely related species.

The future

Two aspects of this work are continuing. First, annual samples of dosed and control birds are being analysed to determine how long it takes them to remove the chemical from their bodies. There is no information on the excretion rates of toxic chemicals by birds. Second, the survival rates of these birds are being monitored in case the years of the study were atypical.

This study has shown that it is possible to conduct field trials on the effects of pollutants without causing cruelty to the animal. Our techniques might well be extended to other suspect chemicals and animals, assuming that the animals' biology is well understood.

M. P. Harris and D. Osborn

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CONSERVATION AND IMPROVEMENT OF TROPICAL TREES

(This work was largely supported by UK Overseas Development Administration funds)

There are currently about 900 million ha of tropical moist forest in the world, but this area is decreasing by about 50 ha per minute (Myers 1980). However, although the situation is serious and will become increasingly so, it is unlikely that the entire area will be lost, because attitudes are changing. Although 1·5% of the area has been nominally set aside for conservation, the protected areas should be increased to 10% or more to include a greater diversity of habitats and both within and between species variation. *In situ* conservation is preferable, providing the strict reserves are of sufficient size (10000–100000 ha) to sustain diverse breeding populations of plants, animals and microbes on different soil types. Additionally, the perpetuation of individual species can often be achieved by *ex situ* conservation, which should be practised especially for species which are threatened or whose importance to mankind warrants domestication (FAO 1975). In this process, plant genetic resources should be conserved as a whole, with collections being made from the *entire* natural range.

In the tropics, many trees which are candidates for domestication produce seed erratically, and poor quality is common because of inherently low viability and the damage done by pests and pathogens. As a result, reafforestation and *ex situ* conservation with these species are impracticable. However, these problems of seed supply can sometimes be overcome by vegetative propagation (Longman 1976), a technique frequently used to domesticate horticultural and agricultural crops but rarely applied to forest trees, with the notable exception of species of *Populus, Salix*, and *Cryptomeria japonica*.

Utilisation of natural forests

Tropical forests have generally been utilised very selectively and wastefully, with perhaps only 20 out of 400 trees per hectare harvested (Myers 1980). The remainder have often been considered to be of no economic value, and in West Africa and South America only 2–10% of the standing volume has been utilised (10 species accounting for 70% of exports). In South-East Asia, where species currently in demand form a larger proportion of the total growing stock, less than 25% of standing volume is harvested (Spears 1980). Unutilised trees are often damaged or felled, and burnt or allowed to rot, at least partially replenishing mineral nutrient reserves.

Although there are large areas of natural forest remaining in Zaire, the Central African Republic, People's Republic of Congo, Gabon and Brazil, the domestic demand for timber has generally outstripped the productive capacity of natural forest in about a third of the countries containing significant areas of moist forest. In West Africa, Central America and parts of South-East Asia, for example, the demand for wood products has stimulated interest in (i) the establishment of plantations of faster growing introduced trees, and (ii) the utilisation of indigenous species previously regarded as worthless or of only secondary importance. Thus, in Nigeria, where only 10 species were exploited in the 1950s, more than 40 are being used today (Spears 1980). In Amazonia, only 50 of about 2500 species are utilised at present, although 400 have some commercial value (Myers 1980). In many instances, appropriate selections of the lesser known species could usefully supplement, both within and outside their natural ranges, the exotic plantations of *Pinus, Eucalyptus, Tectona, Gmelina*, etc, established over the last 30 years. They could provide the greater species diversity which is increasingly being recognised as commercially and ecologically desirable.

Plate 2 — Hide, study colony on Isle of May.
Photograph M. P. Harris.

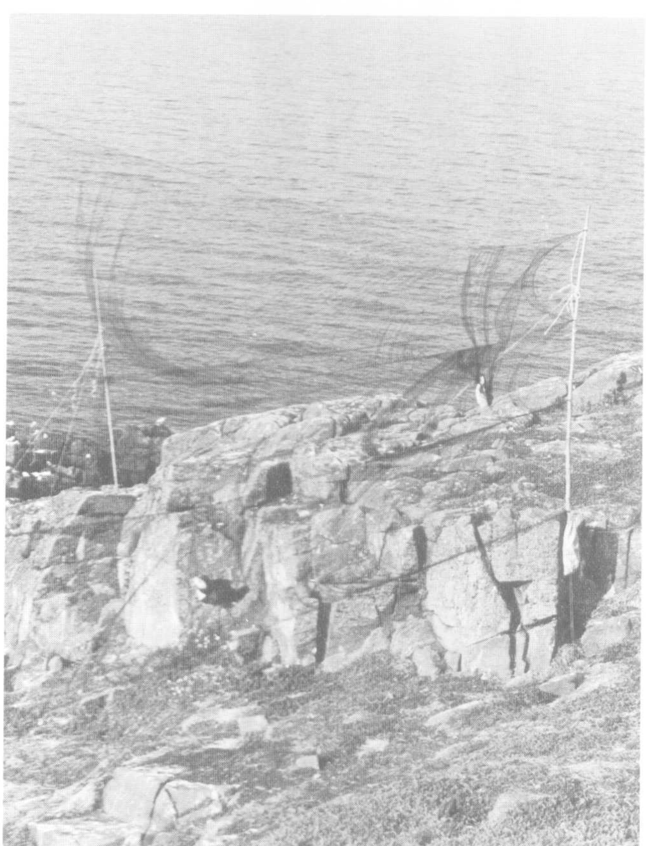

Plate 4 — Puffins caught in mist-nets.
Photograph M. P. Harris.

Plate 7—Plantation of T. scleroxylon *14 years after planting at Onigambari Forest Reserve, Nigeria. Photograph R. R. B. Leakey.*

Plate 8—Winged fruits of T. scleroxylon *formed by cross-pollinating flowers formed on a plant 79 months old using deep-frozen pollen in tropical glasshouses at ITE Bush, near Edinburgh. Photograph R. R. B. Leakey.*

Natural tropical forests yield a wide variety of products such as fruits, nuts, gums, resins, oils, tannins, fibres, latex, dyes and medicinal products on a sustainable, non-destructive basis. Quantities are difficult to estimate, but are clearly less than those which could be sustained (Robbins & Matthews 1974). With an adequate trading infrastructure, increased local demand, as well as export potential, could be satisfied without further threat to the ecosystem, and might also sustain species diversity.

Experience with Triplochiton scleroxylon
Before the high forest was exploited *T. scleroxylon* was one of the commonest species in the moist lowland forests of West Africa, accounting for up to 13% of trees (Hall & Bada 1979). Although a pioneer, it was able to sustain itself in forests on ferruginous soils, derived from the Basement Complex, in areas with rainfall in excess of 1 800 mm per annum (Leakey *et al.* in press b). During the 1950s and 1960s, *T. scleroxylon* provided 60% of Nigeria's roundwood exports, the good peeling properties of its timber 'Obeche' favouring its use in plywood manufacture. In spite of its importance, few plantations were established before 1975, because of the scarcity of viable seeds. *T. scleroxylon* flowers erratically and sets few fruits, many of which are attacked by the weevil *Apion ghanaense* and the smut fungus *Mycosyrinx* spp.

The first of 2 projects, sponsored by the UK Overseas Development Administration, was established in 1971 at the Forestry Research Institute of Nigeria (FRIN). It was to be concerned with practical aspects of the development of techniques for conserving and 'improving' West African hardwoods, in particular *T. scleroxylon.* In 1974, it was supported by a second project, based in Edinburgh, designed to provide a basic understanding of physiological mechanisms. The subsequent development of techniques for rooting leafy cuttings from young trees has enabled gene banks and clonal trials to be established at 8 sites in Nigeria (Plate 7), with a concentration at Onigambari Forest Reserve (Longman *et al.* 1978). Material from the entire natural range of *T. scleroxylon*, namely Sierra Leone in the west to Cameroon in the east (Figure 8), is being sustained at 3 of the sites – Ore, Nimbia and Afaka.

Initially, stem cuttings of *T. scleroxylon* were rooted at FRIN in mist propagators, but success was then achieved with simple, shaded polythene frames (Howland & Bowen 1977). Cuttings, provided they were taken from juvenile shoots, were successfully rooted without applying auxins, but nonetheless rates of rooting were usually accelerated and numbers of roots per cutting increased by applying IBA (indole-3-butyric acid). More recently, it has been found that the optimal auxin requirements of different clones may vary considerably (Figure 9). However, 40 μg per cutting of a 50:50 mixture of IBA and NAA (α – napththalene acetic acid), applied in alcohol (or a quick dip in 0·4% solution), seems to ensure that at least 60% of cuttings root in 6–8 weeks (Leakey *et al.* in press a). Rooting was maximal when cuttings, retaining one leaf, were set in coarse sand at 30°C. Undamaged leaves are relatively large and therefore restrict numbers of cuttings that can be propagated per unit area of propagating bed. Tests showed that the optimum leaf area for root production was 50 cm^2, and trimming to this size is now routine.

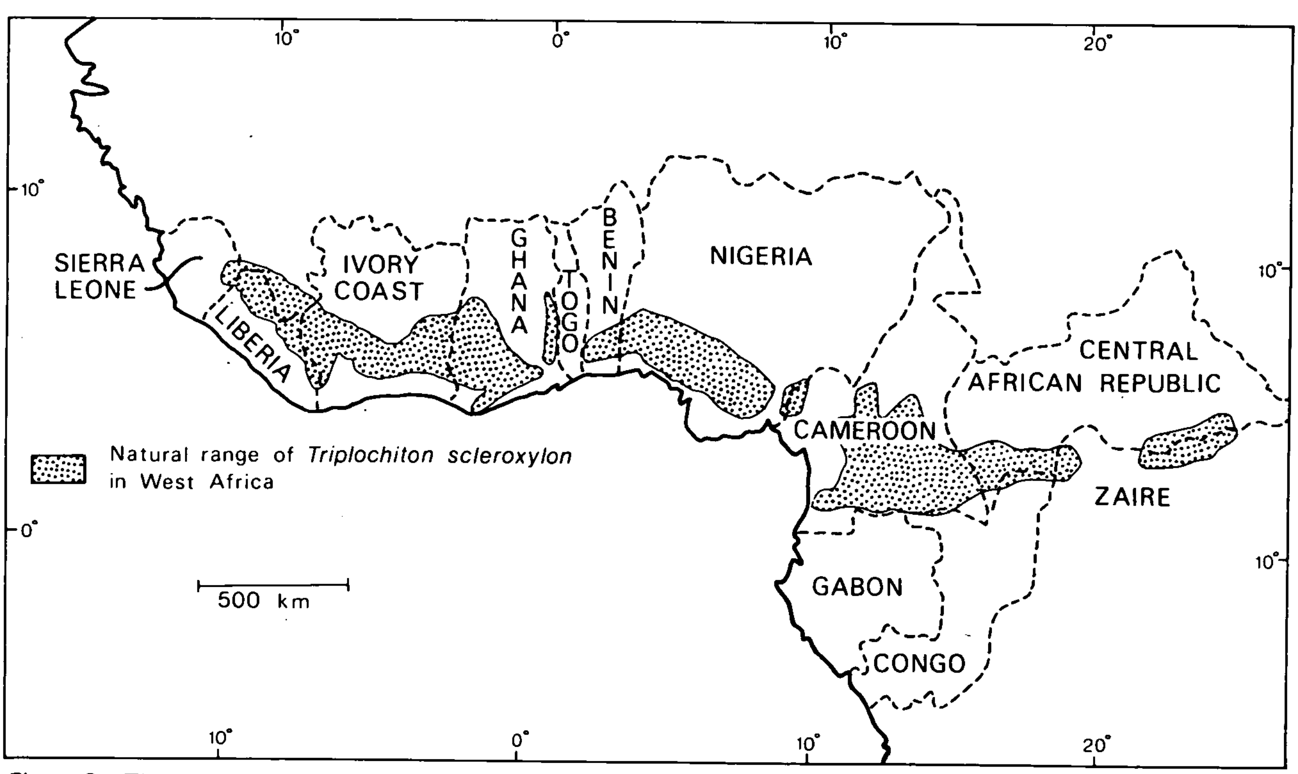

Figure 8 The natural range of T. scleroxylon *in West Africa.*

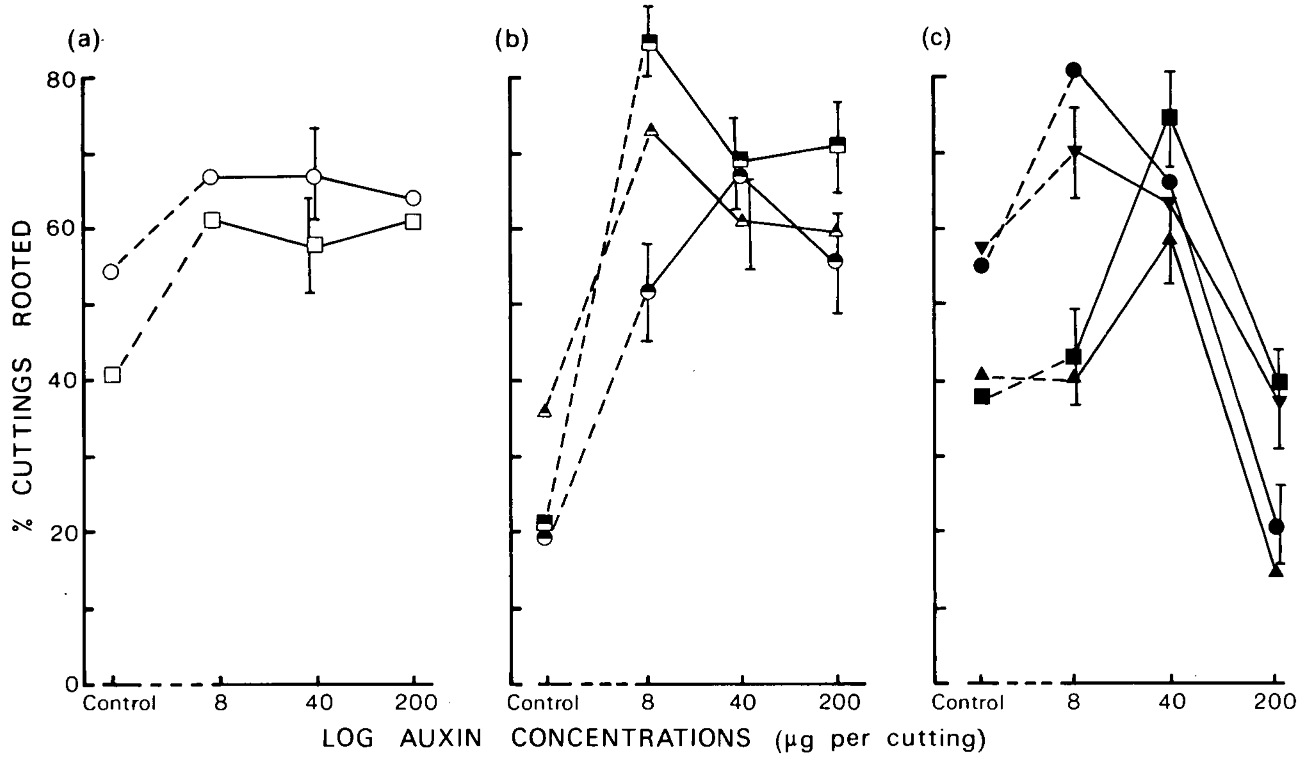

Figure 9 Effects on rooting, after 12 weeks, of applying different amounts of 50:50: :IBA:NAA mixtures to leafy single-node cuttings from a range of T. scleroxylon *clones (○ = 8038, □ = 8021, ◓ = 8035, △ = 8028, ⬓ = 8019, ● = 8036, ▲ = 8032, ▼ = 8020, ■ = 8034).*

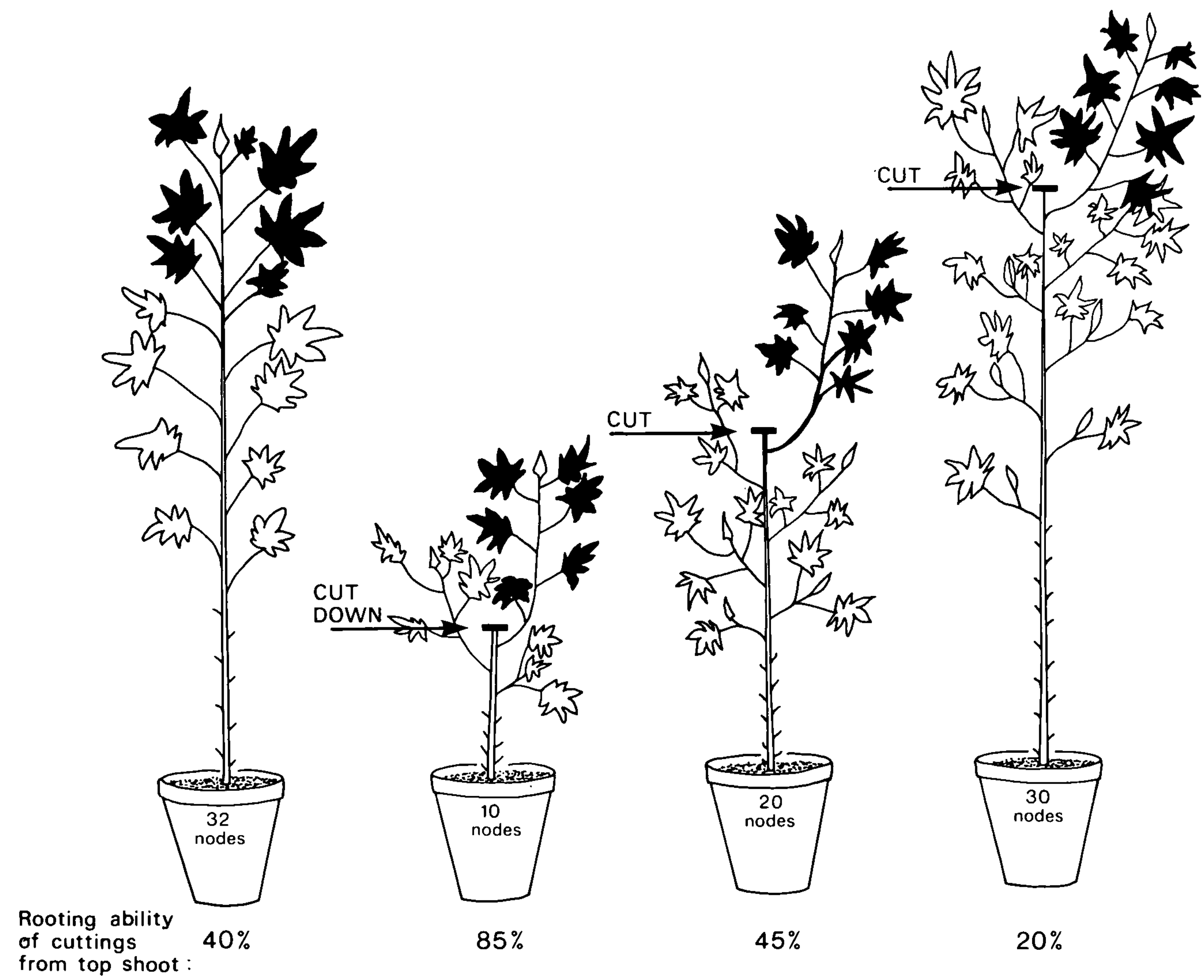

Figure 10 Effects on the rooting ability of T. scleroxylon *cuttings of decapitating stockplants to different heights.*

The rooting ability of cuttings is also greatly affected by the ways in which stockplants are maintained (Figure 10). It was maximised when plants were cut close to the ground, with the subsequent production of only one or 2 shoots, each allowed to grow to provide 5–6 single node cuttings. If a greater number of shoots developed, rooting ability progressively decreased, possibly because nutrients and other root factors became limiting. Cuttings from shaded stockplants tend to root more readily than those from exposed plants.

With the development of these horticulturally based methods, forest geneticists can readily examine the extent of intra-specific variation, and test and multiply genetically superior *T. scleroxylon* individuals. Preliminary results from trials already planted suggest that branching habit may strongly influence height growth, presumably through the partitioning of dry matter to mainstem and branches (Ladipo *et al.* in press). The tallest clones have fewest primary branches per metre of mainstem (Figure 11). Assessments made on one trial, 4 years after planting, indicate that there might be a height gain of 16·5% if the 10 tallest of 100 clones were selected (Figure 12), a hopeful sign for the future, bearing in mind that the gain might be considerably greater when larger numbers of clones have been screened.

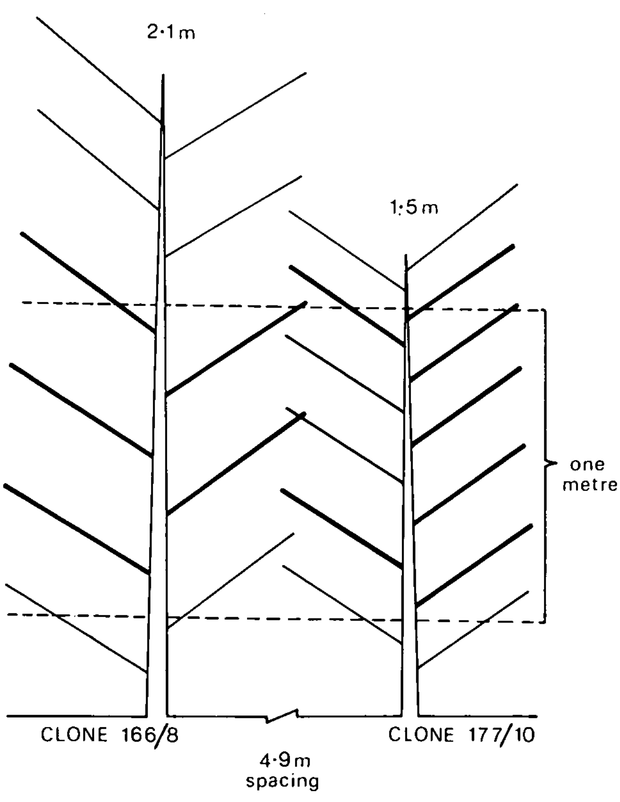

Figure 11 Contrast between growth strategies of 2 clones of T. scleroxylon *having similar total lengths of primary branches when 18 months old.*

At least 2 physiological processes control branching in trees: (i) apical dominance, that is the ability of terminal buds to inhibit the growth of axillary buds on the current year's growth, and (ii) apical control, the influence of one or more shoots on the extension growth of other, usually more proximal, shoots. These studies with *T. scleroxylon* indicate that the control exerted by these processes differs in different clones. Further, there is a suggestion that the branching habit of mature trees might be predictable from the responses of small plants to the removal of apical buds. With this in mind, the effects of changed environmental and physiological conditions on the outgrowth and extension of lateral buds after mainstem decapitation are being studied, as is the subsequent re-assertion of dominance by one of the lateral shoots. The evidence so far suggests that the sprouting of small plants following decapitation is related to the branching patterns of the same clones in field experiments. If this correlation is confirmed, a basis will have been provided for a rapid, simple and inexpensive test predicting the branching habit, and possibly mature form and height, of *T. scleroxylon* selections; the implications of this result for commercial forestry hardly need stressing. Experience with another West African hardwood, *Terminalia superba*, suggests that it may also be important to screen separately for wood quality, which is not necessarily linked to rates of growth and patterns of branching (Longman *et al.* 1979).

Having facilitated the conservation of *Triplochiton scleroxylon*, by means of vegetation propagation, it would then be appropriate to further its domestication by the production of vigorous progenies with improved form using controlled crosses between selected parents. In phenological studies, Howland and Bowen (1977) found that prolific flowering and seed production in December–April seemed to be associated with severe dry periods in the previous July and August. Using scions from 'mature' trees grafted on to seedling rootstocks in Nigeria, controlled pollinations by Howland and Bowen (1977) indicated that *T. scleroxylon* is self-sterile. Other experiments done in tropical glasshouses in Scotland confirmed this fact, and also showed that the time to first flowering could be considerably shortened, with viable seeds, yielding normal seedlings, being formed on trees 2–5 years old (Table 5, Plate 8). This result was achieved with pollen which was dried before being stored at -25°C, when it remained viable for at least 21 weeks. Similarly, prior drying at appropriate rates prolonged the storage life of seeds at -15°C by 18 months or more (Bowen *et al.* 1977). Flowering normally does not commence for 15–20 years, and it will certainly be a useful development if fruiting and seed production can be triggered on small trees, which can easily be interbred and protected from pests and pathogens.

Together, the results of the 2 collaborative projects illustrate how some of the biological constraints limiting the wider use of *T. scleroxylon* can be overcome, enabling it to be considered for planned programmes of reafforestation—an event which was unthinkable 10

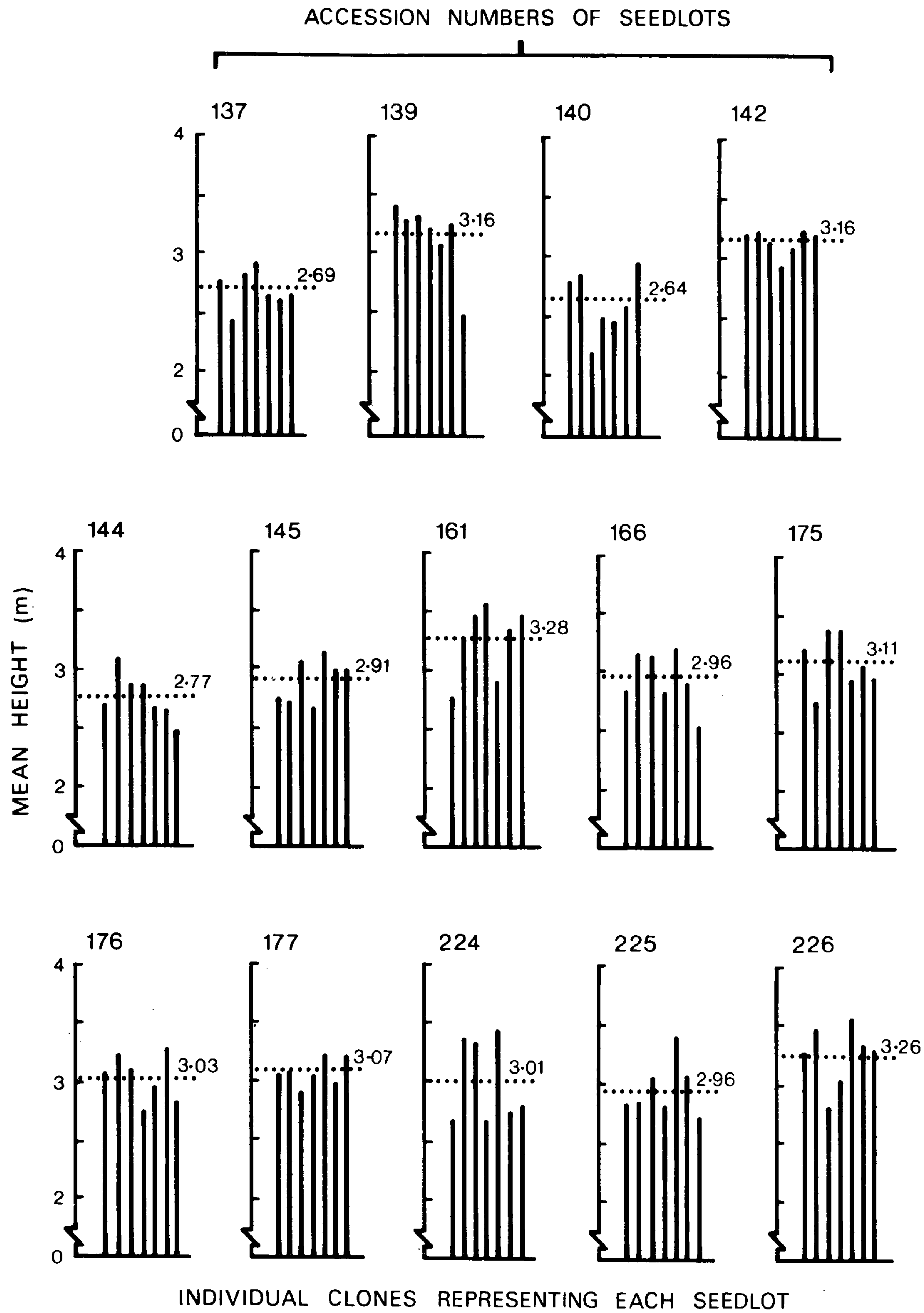

Figure 12 Variation in height after 18 months of 7 clones of each of 14 seedlots (half-sib) of T. scleroxylon *collected from different locations when planted at 2·4 m within and between rows, at Onigambari Forest Reserve, Nigeria (dotted line indicates mean height of seedlot: L. s. d. (P = 0·05) for individual clones and seedlot means are 0·54 and 0·18 m respectively).*

Table 5. Numbers of flowers produced, opened and successfully pollinated on 'juvenile' and 'mature' cuttings of *T. scleroxylon* grown in tropical glasshouses at the Bush Estate, near Edinburgh.

Clone no. (cutting no.)	Age; months from germinating parent seed	Temperature regime in tropicalised glasshouse Day °C	Night °C	No. of flower buds formed	No. of flowers opened	Self (S) or cross (C) pollinated	No. of fruits harvested (potentially 5 per flower bud)	No. of seeds germinated
I. *Juvenile*								
8051 (2998)	26	20°	20°	7	5	S†	0	0
" (2998)	33	20°	20°	22	20	C†	56	1
8045 (2880)	27	20°	20°	160	108	S†	4	0
" (2880)	33	20°	20°	4	1	C	0	0
" (2880)	60	30°	20°	53	38	C	0	0
8001 (seedling)	33	20°	20°	33	1	S†	0	0
" (763)	72	20°	20°	12	10	C†	5	0
" (2350)	76	20°	20°	14	5	C	0	0
" (775)	78	30°	20°	20	9	C*	5	0
" (1169)	79	30°	20°	84	34	C*	18	3
" (786)	79	30°	20°	18	10	C*	9	1
" (778)	81	30°	20°	24	20	C*	8	0
8037 (29)	36	20°	20°	11	0	–	0	0
8053 (2923)	37	20°	20°	4	0	–	0	0
8019 (169)	38	30°	30°	3	0	–	0	0
8020 (2116)	64	20°	20°	4 reproductive spurs found after flowers opened		–	0	0
" (2712)	70	20°	20°	15	11	C	0	0
8002 (seedling)	72	20°	20°	13	11	C†	2	2
" (seedling)	75	30°	20°	6	5	S†	0	0
" (seedling)	82	30°	20°	305	284	C*	117	22
				572	808		224	32
II. *Mature*								
8057 (171)	Cuttings	30°	30°	23	0	–	0	0
" (172)	taken from	30°	30°	6	5	C†	8	0
" (178)	mature	30°	30°	24	10	C†	35	0
" (5065)	grafted	20°	20°	160	122	C†	62	19
	scion of unknown age			213	137		105	19

*, deep-frozen pollen; †, fresh pollen; unmarked, pollen stored in dessicator at room temperature.

Table 6. Tropical trees with timber potential vegetatively propagated in tropical glasshouses at the Bush Estate, near Edinburgh.

1. Moist forest		
	West Africa	*Ceiba pentandra* *Chlorophora excelsa* *Nauclea diderichii* *Terminalia ivorensis* *Terminalia superba* *Triplochiton scleroxylon*
	East and Central Africa	*Dalbergia melanoxylon* *Vateria seychellarum*
	Central and South America	*Albizzia carabeae* *Cedrela odorata* *Cordia alliodora* *Swietenia mahogani* *Tipuana tipu* *Toona ciliata*
	S. E. Asia and Australasia	*Agathis australis* *Agathis damara* *Agathis macrophylla* *Agathis obtusa* *Agathis robusta* *Agathis vitiensis* *Araucaria hunsteinii* *Gmelina arborea* *Shorea albida* *Shorea almon* *Shorea contorta* *Shorea macrophylla*
2. Savannah and dry forest		*Acacia senegal* *Afzelia africana* *Azadiracta indica* *Khaya senegalensis* *Prosopis juliflora*

years ago. *T. scleroxylon* is only one of a wide variety of tropical trees from moist forests to semi-deserts (Leakey & Last 1980) that can be propagated vegetatively (Tables 6 and 7). The possibilities of similarly domesticating other trees for the production of timber, fuel and a whole range of valuable minor products seem virtually limitless.

R. R. B. Leakey, K. A. Longman and F. T. Last

Table 7. Tropical trees capable of providing 'amenity' or minor forest products vegetatively propagated in tropicalised glasshouses at the Bush Estate, near Edinburgh.

Fruit	*Casimiroa edulis* *Chrysophyllum cainito* *Citrus halimi* *Shorea macrophylla* *Tamarindus indica*
Pharmaceutical	*Teclea verdoorniana* *Oricia suaveolens*
Kapok	*Ceiba pentandra*
Multi-purpose (gum/fodder/tannins etc.)	*Acacia senegal* *Prosopis juliflora*
Amenity	*Delonix regia* *Caesalpina spinosa*

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AN INTEGRATED SYSTEM OF LAND CLASSIFICATION

Introduction and objectives

A system of land classification should provide a framework within which to identify all land uses, both actual and potential. However, most methods adopted by agencies such as the Ministry of Agriculture, Fisheries and Food (MAFF), the Department of Agriculture and Fisheries, Scotland (DAFS), and the Forestry Commission (FC) have usually had restricted objectives, in keeping with their statutory obligations. As a result, sets of independent and non-interactive descriptions, often based on a variety of irreconcilable subjective judgements, have been produced at one of 2 levels, either (i) broadsweep generalised assessments rarely supported by detailed ground surveys, or (ii) complete censuses which are time-consuming and expensive to make. However, it is possible to visualize a unified system of classification, with subjective judgements restricted to a minimum, which could provide a common framework for many users at one and the same time, not only for agriculture and forestry, but also for such purposes as the conservation of wildlife and water resources, and the provision of recreation.

Recent surveys, starting with a part of Cumbria (Bunce *et al.* 1975) and expanded to include the entire region (Bunce & Smith 1978), have encouraged the evolution of a classification based on the multivariate analysis (Hill *et al.* 1975) of 282 environmental attributes concerned with:

i. Climate—eg temperature taken from 1:1 000 000 climate maps.
ii. Physiography—eg altitude taken from 1:50 000 Ordnance Survey maps.
iii. Geology—eg bedrock taken from geological maps, and
iv. Human artefacts—eg road lengths taken from 1:50 000 Ordnance Survey maps.

In surveys of Cumbria, data were recorded for every 1 km square of the National Grid, which provides a useful, and readily available, reference system. The square usually, and desirably, contained a fairly restricted range of environments and was of a size that could be readily encompassed if, and when, field surveys were required. Because it would be impossible to survey every one of the 230 000 squares, measuring 1 km^2, into which Britain can be divided, it was decided to focus on a 1 km square at each 15 × 15 km intersection, giving a total sample of 1 228 squares; a further 4 826 squares have been abstracted more recently. Multivariate analysis of the 282 attributes classified the squares into 32 land classes (Figure 13) which were produced as a result of a series of successive dichotomous divisions for which key indicator attributes were identified. Knowledge of these key attributes enables 'unknown' 1 km squares to be assigned rapidly to their appropriate land classes.

How can these land classes, based on physical attributes alone, be interpreted? Can they be associated with areas with different assemblages of natural or semi-natural plants, with different soils or combinations of soil types, with different mosaics of agricultural crops, forests and woodlands? In order to verify the ecological worth of the land classes, surveys were made of 8 replicate, randomly-chosen squares of each of the 32 land classes. Records were made of:

i. the occurrence of species of higher plants and a restricted list of bryophytes in (a) each of 5 random quadrats, each 200 m^2 and (b) linear 'quadrats' 10 m × 1 m alongside streams, roads and hedges;
ii. soil profiles exposed after digging a pit, up to 75 cm deep, in the centre of each of the quadrats used for listing plants; and
iii. land uses (using 65 categories), the composition of forests and woodlands, and the occurrence of different breeds of farm animals.

By associating actual land uses with the different land classes, it has been possible to predict, with high degrees of accuracy, land uses in unsurveyed areas of Britain. The same has been done for soil types, but many other aspects of importance to physical planning, eg landscape types and possible forestry impacts, remain to be investigated.

RESULTS

Land class descriptions

Although there are frequent outliers, most of the 32 land classes have well-defined patterns of distribution within Britain indicating the existence of continuous environmental gradients (Figure 13). For example, the distribution of land class 4, fenland, is much as expected, virtually confined to East Anglia, but that of some of the others was not foreseen, eg land class 7, which extends from the coastal regions of west England into west Wales and south-west Scotland. Two examples of land classes may be shown with reference to Scotland, where land classes 24 and 25 have contrasting distributions. Land class 24, typical of north and western Scotland (Plates 9 & 10), includes high altitude sites with comparatively heavy rainfall (Figure 14, and contrasts with land class 25, tending to be distributed in the Scottish borders and near the east coast of Scotland and northern England (Plates 11 & 12), which is located at lower altitudes with much less rain (Figure 15), both classes having similar light regimes. From assessments of the soil pits in replicate quadrats and of the surveys made of land use and vegetation, land class 24 is dominated by rankers and peats; its predominant land uses are hill grazings and grouse moors, with its natural vegetation having appreciable amounts of purple moor-grass and heather. In contrast, the soils in land class 25 include a range of brown earths, with barley and leys being the major land uses, and perennial rye-grass being the dominant plant species in natural assemblages.

These thumb-nail sketches show that the land classes, which can be made from existing maps, provide arrays of habitats which are ecologically meaningful, and bring together locations with similar types of soil and land use. For the future, it is intended to explore the relationships of land classes with visual features of the landscape, and with aspects of recreation, amenity and conservation. As these series of linkages are extended, the inter-relations between different land uses should be clarified, a task that has proved virtually impossible until now, in the absence of a framework upon which all land uses can be inserted with equal facility. For the present, natural vegetation in Britain has been classified into 75 types (a key will shortly be published) which provide a supporting system for land use and land type classifications.

LAND CLASS 24

High altitude rugged mountains of north and western Scotland with moorland vegetation

Topography

Mean max altitude (m)		611
Mean min altitude (m)		267
Altitude class	0-76 m	1
(mean % area)	77-198 m	12
	199-488 m	56
	489-1189 m	31
Slope (°C)		18

Climate

Mean min temp January (°C)	0·1
Mean max temp July (°C)	18·0
Mean soil deficit (mm)	2·5
Mean annual rainfall (mm)	2290
Mean snowfall days	51·4
Duration bright sunshine (hrs)	4·1

Soils

Mean pH	4·5
Mean loss on ignition (%)	59·3
Percentage of total area	
Brown earths	5·0
Gleys	7·5
Gleyed brown earths	–
Brown podsolic soils	2·5
Rankers	37·5
Peaty podsols	17·5
Podsols	7·5
Peaty gleys	12·5
Peats	30·0

Land use

Percentage of total area	
Wheat	–
Barley	–
Other crops	–
Horticulture	–
Leys	–
Permanent grass	–
Rough pasture	2·9
Bracken	3·7
Rushes	1·6
Moorland	10·5
Peatland	45·5
Mountain grass	15·7
Woodland	8·6
Cliffs/sand/mud	9·9
Built-up	0·6

Native species

Percentage cover of major species	
Perennial rye-grass	–
Ling heather	12·5
Common bent	1·0
Purple moor-grass	38·8
Yorkshire fog	0·1
White clover	0·8
Cock's-foot	–
Mat-grass	6·9
Bracken	4·1
Crested dog's-tail	–
Italian rye-grass	–
Timothy	–
Deergrass	8·3
Sheep's fescue	1·9
Creeping bent	–

Figure 14 Description and occurrence of land class 24, high, steep-sided rugged mountains.

*Plate 9 — Glen Cannich, Highland Region.
Photograph R. G. H. Bunce.*

*Plate 10 — The top of Glencoe, Highland Region.
Photograph R. G. H. Bunce.*

Common caption: Land Class 24 — High altitude rugged mountains of north and western Scotland, with moorland vegetation.

Plate 11 — The Black Isle, Highland Region.
Photograph R. G. H. Bunce.

Plate 12 — Annan valley, Dumfries and Galloway Region.
Photograph R. G. H. Bunce.

Common caption: Land Class 25 — Low altitude land in eastern Scotland and northern England mainly under intensive cultivation.

LAND CLASS 25

Low altitude land in eastern Scotland and northern England, mainly under intensive cultivation

Topography

Mean max altitude (m)		144
Mean min altitude (m)		88
Altitude class	0-76 m	42
(mean % area)	77-198 m	30
	199-488 m	28
	489-1189 m	–
Slope (°)		3

Climate

Mean min temp January (°C)	0·3
Mean max temp July (°C)	18·3
Mean soil deficit (mm)	8·0
Mean annual rainfall (mm)	880
Mean snowfall days	40·4
Duration bright sunshine (hrs)	4·8

Soils

Mean pH	6·1
Mean loss on ignition (%)	6·5
Percentage of total area	
Brown earths	38·5
Gleys	33·3
Gleyed brown earths	20·5
Brown podsolic soils	2·6
Rankers	5·1
Peaty podsols	–
Podsols	–
Peaty gleys	–
Peats	–

Land use

Percentage of total area	
Wheat	0·3
Barley	31·3
Other crops	10·5
Horticulture	2·5
Leys	32·4
Permanent grass	5·5
Rough pasture	5·1
Bracken	–
Rushes	1·3
Moorland	–
Peatland	–
Mountain grass	–
Woodland	2·3
Cliffs/sand/mud	1·8
Built-up	6·4

Native species

Percentage cover of major species	
Perennial rye-grass	20·3
Ling heather	–
Common bent	6·0
Purple moor-grass	–
Yorkshire fog	3·1
White clover	4·6
Cock's-foot	1·0
Mat-grass	–
Bracken	–
Crested dog's tail	1·0
Italian rye-grass	2·0
Timothy	2·4
Deergrass	–
Sheep's fescue	–
Creeping bent	2·3

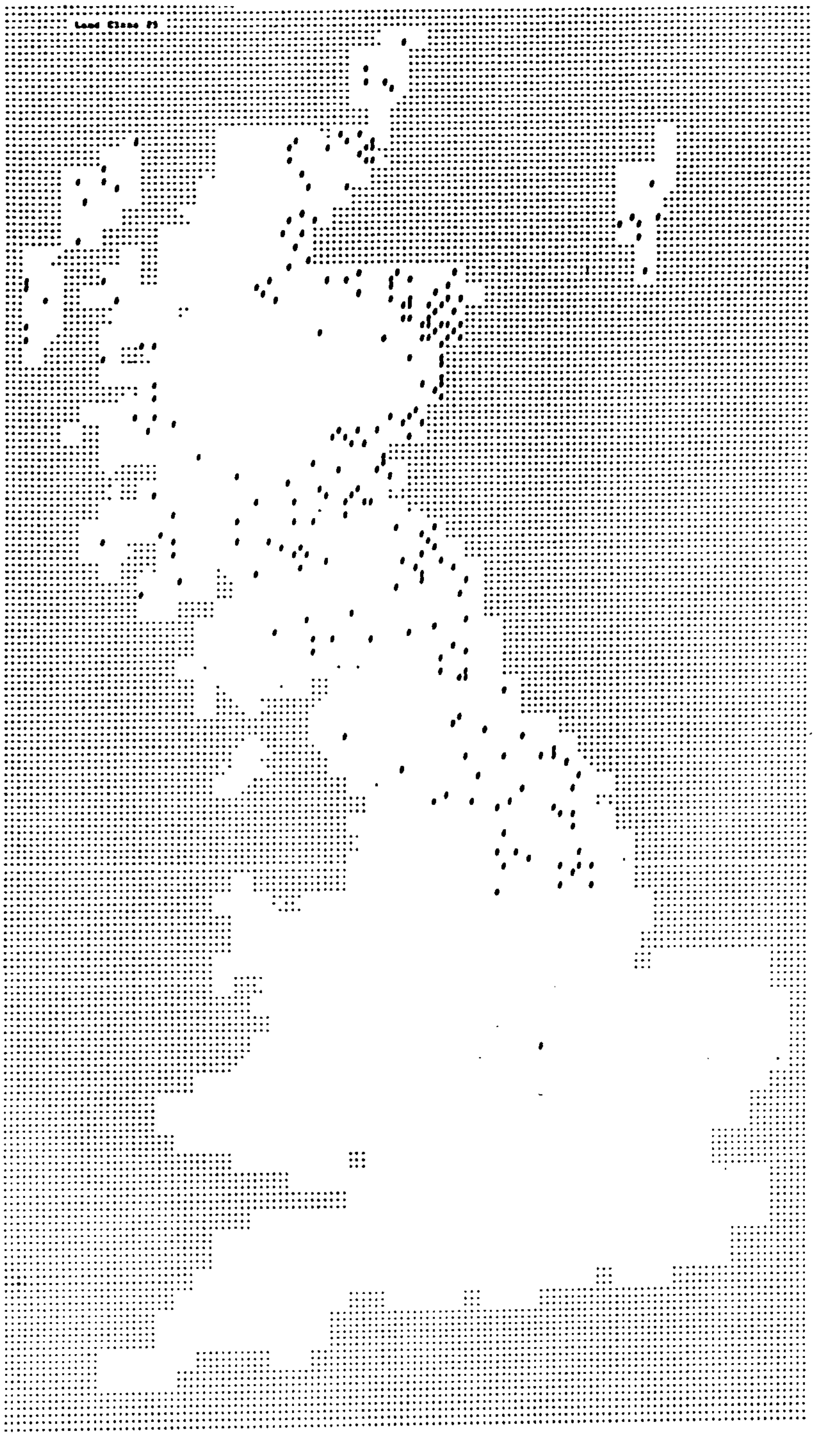

Figure 15 Description and occurrence of land class 25, northern lowlands with much less rain than land class 24 (see Figure 14).

Land classes and land use

The proportions of Britain assigned to different land classes can be calculated readily by relating numbers of squares in each land class to the total number of squares in the grids covering Britain. When assessments are made of areas devoted to different land uses, various errors are incurred. First, the proportions of each land class devoted to different land uses are calculated from samples and not from total enumerations. The mean values should, therefore, be qualified by their confidence limits. Second, the land use categories used by ITE and the differing agencies are not completely coincident. For example, the MAFF distinction between temporary and permanent grass differs from that adopted by ITE. Despite these reservations, which need further examination, estimates of areas devoted to different land uses agree reasonably with independent assessments. Unpublished sources apportion 90·6% of Britain to rural and 9·4% to urban land uses: estimates derived from the present method of land classification are 92·4:7·6. Estimates of afforested areas and those devoted to grassland and arable crops are virtually coincident. In comparisons with crop data from the Annual Reviews of Agriculture 1977 and 1978—the years in which the field surveys were made—there was again a high degree of agreement (Table 8). Broadly, the degree of agreement was maximal for crops occupying large areas, eg wheat, barley, oats and potatoes.

Table 8. Comparison of estimates of areas of different crops (km^2) in GB derived from (i) MAFF/DAFS statistics for the years 1978 and 1979 (the years of the field survey) and (ii) a survey of cropping in replicate areas of the different ITE land classes.

	Annual Review of Agriculture km^2	Estimates based on ITE land classes km^2
Wheat	11700	10600
Barley	23100	21200
Oats	1820	1830
Mixed grain	189	328
Rye	100	51
Potatoes	2100	2010
Sugar beet	2050	1470
Oil seed	600	445
Vegetables	2160	2340
Orchards	530	597
Maize	170	269
Lucerne	170	196
Fodder crops	2080	1900

Correlation between the 2 sets of data is $r = 0{\cdot}999^{***}$ $P = <0{\cdot}001$

Having reconciled land use estimates based on the land classification described in this article with those published elsewhere, a comparable examination has been made by Drs D. F. Ball and M. Hornung of the occurrence of different soil types. They made comparisons with soil maps of Britain and, with the exception of peaty podsols which are difficult to define, agreement was excellent, eg brown earths 30·6% to 33·5%, gleys 26·3% to 27·8%, and peats 11·6% as opposed to 10·8%.

The land classification project was initiated to meet problems posed locally in Cumbria. Now, having developed a national base, further regional interest can be investigated. For example, to aid the strategic consideration of land use in the region of Fife, a knowledge of land classes (derived from maps) and their associated (i) land uses and (ii) assemblages of plants enabled the estimates in Tables 9 and 10 to be prepared in a few days/weeks without field work. The tables show that:

a) Arable crops and leys are nearly equally common.
b) The proportion of Fife devoted to urban uses is twice as great as in Scotland generally (a figure in keeping with population distributions).
c) Pastures (leys and permanent) constitute 37·5% of the region (Scottish national average is 18·9%).
d) A quarter of the short-term leys in Scotland are found in Fife.
e) There is comparatively little woodland in the region, although it covers 100 km^2.
f) The region is primarily cultivated; it is also very uniform compared with other Scottish regions.

Excepting the urban areas and those devoted to arable crops, most of Fife is covered by vegetation which is grazed (22·7% ley; 14·8% permanent pasture; 6·8% rough pasture; and 7·9% moorland). Within the 'grazings', perennial rye-grass is the commonest species, followed by common bent and white clover, a distribution closer to the British average (perennial rye-grass, heather and common bent) than that of Scotland (heather, perennial rye-grass and purple moor-grass).

Comparisons such as these enable the resources at a regional level to be put readily into a national context. The system can be used in a similar way to examine potential impacts at a regional level—for example, a preliminary study in Fife suggested that only 14% of the land is likely to be planted with trees, whereas the figure is 32% for Scotland as a whole.

The evidence, so far, suggests that the array of objectively defined land classes provides a satisfactory series of strata upon which to structure surveys. Where it has been possible to compare the results of statistically designed partial surveys, based on land classes, with total enumerations, the degree of agreement has usually been highly satisfactory.

Further developments

Reference has been made to soil types and the growth of plants, but the variety of associated interests would seem to be extremely wide. So far, the exploitation of the land classification described in this report is in its early stages of development. It has been used to help the objective enumeration of vegetation on land adjacent to railways, and to arrange collections of seed from naturally regenerated birches subject to different selection pressures, in this instance equated with land classes. Perhaps more excitingly, it is being used in an assessment of the potential production of biomass as a

Table 9. Areas devoted to different land uses in the region of Fife compared with those in Scotland and GB

	Total GB		Total Scotland		Area in Scotland as % of GB	Fife		Area in Fife as % of	
	km²	%	km²	%		km²	%	Scotland	GB
Ley	34800	15	7300	9	21	300	23	4·3	0·9
Permanent pasture	29000	13	7300	9	25	200	15	2·8	0·7
Rough pasture	22300	10	10000	13	45	100	7	0·9	0·4
Moorland	35100	15	26100	34	75	100	8	0·4	0·3
Arable	43200	19	7600	10	18	300	24	4·3	0·8
Urban	30000	13	5100	7	17	200	13	3·6	0·6
Water and rock	12900	6	5400	7	42	50	3	0·9	0·4
Woodland	22100	10	8400	11	38	100	7	1·2	0·4

Table 10. Areas of different native species occurring in the combined ley, permanent pasture, rough pasture and moorland categories of Fife, Scotland, and Great Britain (list restricted to the 20 commonest species in GB)

	% of total GB area	Total predicted km²	% of total Scotland area	Total predicted km²	% of total Fife area
Perennial rye-grass	9·8	22500	8·9	5330	21·5
Heather	6·1	13900	16·8	10100	2·3
Common bent	3·3	7600	3·5	2110	6·7
Purple moor-grass	2·4	5400	6·8	4090	1·5
Yorkshire fog	2·0	4650	1·3	1020	2·4
White clover	1·8	4170	2·2	1340	5·5
Cock's-foot	1·3	3070	0·7	582	1·1
Mat-grass	1·3	2900	3·1	1870	0·4
Bracken	1·3	2880	1·2	981	0·3
Crested dog's-tail	1·2	2780	0·8	664	1·6
Italian rye-grass	1·2	2700	0·7	563	1·4
Timothy	1·1	2480	0·8	653	1·5
Deergrass	1·0	2390	3·3	1960	0·3
Sheep's fescue	1·0	2380	1·2	960	0·4
Creeping bent	1·0	2360	0·4	355	1·3
Wavy hair-grass	0·9	2060	2·1	1270	0·8
Sweet vernal-grass	0·7	1600	0·8	658	0·6
Meadow-grass	0·7	1500	0·5	382	0·4
Red fescue	0·6	1440	0·6	463	0·8
Bilberry	0·6	1330	1·1	912	0

renewable source of energy. In this project, agriculturists, foresters and ecologists, acquainted with the production of natural vegetation, were asked to assign production estimates for their differing 'crops' to the different land classes. From these estimates, it was a single step to calculate a figure for biomass potential which, in the instance, suggests that natural vegetation might be locally important as a renewable source of energy. This calculation included the concept of 'optimisation', the area in which land classification has its greatest potential. In Cumbria, attempts are being made to devise optimal patterns of land use for that region, in response to a series of politically decided objectives.

If it were decided to increase the area afforested, what would be the implications of this decision on other land uses and on the landscape? The use of linear programming and other mathematical models will facilitate investigations into these impacts, and is an area of research for future study. At present, in Britain as elsewhere, most discussion is concentrated on the implementation of regional changes without adequate monitoring of the effects of these changes. The present land classification enables changes to be monitored speedily, cheaply and effectively: there is thus no reason why direct and indirect effects should not be monitored at regular intervals in order to identify impacts that were not expected.

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VEGETATION CHANGE IN UPLAND LANDSCAPES

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In the uplands of England and Wales, recent abrupt land use changes such as afforestation and the agricultural reclamation of moorland have had conspicuous effects on the landscape. As well as these *direct* changes, the vegetation of upland landscapes can be affected more *gradually*, but significantly, by changes in the balance of plant species in less radically modified moorland and rough grazing. Rates and directions of these gradual vegetation changes are determined by alterations in animal stocking, species and numbers, surface drainage and fertiliser applications. Vegetation changes, both direct and gradual, are of importance to those concerned with the character of upland landscapes, as well as to ecologists.

There is little known on the nature, extent and possible future course of such changes. A previous contract study, concerned with the general features of upland land use and character, and their influence on vegetation, encouraged the Department of the Environment to seek a more detailed analysis of the nature of gradual vegetation change in 12 areas in the uplands of England and Wales. These areas had been selected for a parallel investigation by a team of consultants, working on behalf of the Countryside Commission (CC). Their 'Upland Landscapes Study' (ULS) aimed to examine the influence of land use on upland landscape character, and the way in which the present activities and future expressed intentions of hill farmers and other users were likely to modify the landscape. ITE was commissioned by DOE to make an ecological analysis of the present vegetation in the moorland-pasture sequence in the study areas, and of the influences of land character and management on vegetation. From the analysis, attempts have been made to predict the vegetation patterns which could result from gradual changes attributed to modified management.

The 12 areas, chosen to give a geographic cover of England and Wales, were single or paired parishes conforming with the EEC definition of 'Less-favoured areas': Alwinton, Northumberland; Lunedale, Durham; Shap Rural and Shap, Cumbria; Bransdale, North Yorkshire; Heptonstall, West Yorkshire; Monyash and Hartington Middle Quarter, Derbyshire; Llanfachreth, Gwynedd; Ysbyty Ystwyth, Dyfed; Glascwm, Powys; Ystradgynlais Higher and Glyntawe, Powys; Lynton, Devon; and Widecombe in the Moor and Buckland in the Moor, Devon. Their total area of 746 km^2 amounts to about 4% of the uplands of England and Wales. They include most of the national upland land classes (ITE 1978) but with a relatively small proportion of the most montane and marginal land classes, and greater representation of those classes in which land use change is most probable.

The main elements of the approach adopted by ITE were (i) to classify vegetation covering the range from improved grassland to moorland, so that subsequent sites of similar character could be characterised; (ii) to determine environmental variation in the study areas in terms of a land classification based on physiographic and topographic characteristics; (iii) to identify the historical land use of the study areas in categories of farmland, moorland, and moorland fringe from maps and air photograph sources; (iv) to define the association of vegetation classes with land types and land use history; and (v) to predict what gradual changes of vegetation could occur as a result of agricultural intensification or decline, by considering experimental evidence from outside the study areas, together with the associations found within the areas, and general knowledge of management effects on key plant species.

Vegetation

Although classifications for part of the range of upland vegetation have been developed (eg Evans *et al.* 1977), and will be extended by the National Vegetation Classification sponsored by the Nature Conservancy Council, nothing suitable for the present study, covering the range from agricultural grasslands to semi-natural moorlands, was immediately available. Therefore, a classification was developed based on species lists from between 70 and 115 sites in each study area. At these 'main sites', species presence and cover were recorded from quadrats up to 5000 m^2. Indicator Species Analysis (Hill *et al.* 1975) was used as a classification method. Sixteen vegetation classes from the analysis of species presence data fall into 4 groups: improved pastures, rough pastures, grassy heaths and shrubby heaths, occupying respectively 27%, 17%, 23% and 33% of the recorded sites, and broadly representing a sequence of decreasing intensity of agricultural management. The 'heath' groups represent the moorland element in the vegetation, and their frequency in the study areas ranks the 12 areas from most to least 'moorland' in the order: Lunedale-Ysbyty Ystwyth-Bransdale-Shap-Alwinton-Ystradgynlais and Heptonstall-Llanfachreth-Widecombe-Glascwm-Lynton-Monyash.

The cover of deciduous woodland in these areas has been determined by ULS to range from less than 1% in Alwinton, to nearly 7% in Lynton. Between 10 and 15 woodlands were examined by ITE in each study area. Based on the key to British woodland types developed by ITE, 3 categories were recognised: 'upland acid woodlands', 'lowland acid woodlands' and 'lowland basic woodlands', reflecting climatic and soil factors. In Alwinton, Lunedale, Shap, Bransdale and Llanfachreth, upland acid woodlands were most frequent, particularly 'western acid oak woodland' and 'upland birch/oak woodland'. Heptonstall woods were mainly lowland acid woodlands, especially 'dry acid oak woodland', while Monyash woods were of the lowland basic type, especially 'scrubby ash woodland'. Other areas show a more even mixture of 'lowland' and 'upland' woodland categories.

Land

In order to simplify description of the land character, and to compare the study areas, physiographic, topographic and climatic characteristics were analysed for 0·5 × 0·5 km grid squares. Seven land types were recognised from this analysis. Three, distinguished by combinations of slope and relief, fall in a relatively high altitude 'hill' land group; 3 others, also distinguished by slope and relief, occur at moderate altitude, representing an 'upland' land group; and one forms a lower altitude 'upland margin' land group. Hill, upland and upland margin occupy respectively 48%, 36% and 16% of the 12 areas combined. Alwinton, Lunedale, Shap, Ysbyty Ystwyth and Ystradgynlais contain more than 50% hill; Heptonstall, Monyash, Glascwm, Lynton and Widecombe include 50% or more upland; while Bransdale, Llanfachreth, Glascwm, Lynton and Widecombe have between 20% and 50% upland margin land.

The influence of the physical environment, and the limitation which the environment imposes on the intensity of management, is indicated by the frequency of vegetation samples in the land types. Thus, recorded sites in the hill land group were only 1% shrubby heaths. These vegetation groups respectively occurred at 36%, 20%, 23% and 21% of sites recorded in the upland land group and at 48%, 28%, 14% and 10% of all sites recorded in the lowest altitude, upland margin land. More speculatively, these frequencies suggest the vegetation potential of particular types of land, the probability of a vegetation type being developed, and, with the more detailed information on vegetation classes, the type of vegetation which is likely to develop given an increase or decrease in management intensity.

The recorded woodlands are largely restricted to 2 land types, steep upland and upland margin, which contain 30% and 41% respectively of the woodlands, although these land types each occupy only 16% of the 12 areas combined.

Land use history

The analysis of historical documents was designed to identify areas where the land management changed at particular periods in the past, and, from this identification, to determine the rate of vegetation change. From old maps and air photographs, it was possible to distinguish 3 sectors of land use: 'farmland' – sectors which have always been mapped as in intensive agricultural use; 'moorland' – which has never been in intensive agriculture; and 'moorland fringe' – which has, at different times, been farmland and moorland. It is moorland fringe where vegetation change has been concentrated in the past 150 years.

Moorland fringe occupies 11% of the 12 study areas as a whole. Of this 11%, about a third represents land reverted from former cultivation to moorland, while the remainder contains about one quarter reclaimed from moorland for agriculture and three-quarters converted to forestry. About one third of the reversion from farmland occurred before 1850, and rather more than a third since about 1940. Field survey of reverted sites showed that the succession from vegetation under intensive management to that of moorland is a very slow process. Assuming that the sites were initially improved pasture, 40% of them had developed rough pasture vegetation within about 40 years, 40% had reverted to grassy heath, while the remainder had reverted, either directly or through intermediate vegetation types, to shrubby heaths. Only after more than 130 years does the balance of vegetation in the reverted fringe (23% rough pasture, 42% grassy heaths, 35% shrubby heaths) come close to that of the adjacent moorland core (13%, 34%, 53%, respectively).

Future vegetation change

The implications of the historical analysis are that, given no major changes in upland land use, visually obvious alteration of the vegetation will be concentrated in a relatively small part of the uplands, ie the moorland fringe. Within this zone, the vegetation pattern will continue to fluctuate, with rapid change on improvement and a very slow succession following reversion. Some of the vegetation will still be responding to past events well into the 21st century.

General hypotheses of vegetation change in response to management were outlined in the earlier study on upland land use and have been developed in relation to the vegetation types identified in the 12 areas. Using these hypotheses, it has been possible to indicate the likely change in vegetation types which would result from a general intensification or decline in agricultural management. Based on the sample of sites, intensification could lead overall to a 60% increase in improved pastures; a 40% increase in rough pastures; an almost stable, though differently located, proportion of grassy heath sites; and a fall in shrubby heaths of 65%. Agricultural decline is predicted as capable of resulting in a reduction in improved pastures of 25%, in rough pastures of 40% and in grassy heaths of 45%, balanced by a 70% increase in shrubby heaths. The scale of change would vary considerably between study areas. For example, with intensification, only 4% of the sample sites in Monyash are expected to change, because management is already intensive. In contrast, more than 80% of the vegetation sample would probably change with intensification in Llanfachreth, and with decline in Bransdale.

Finally, an alternative prediction of the overall changes in vegetation in the study areas is based on the extent of land types in each area and on the vegetation potential of each land type. If agriculture is expanded to an assumed maximum in relation to the natural environment, the overall balance of vegetation groups in the study area has been calculated as 43% improved pastures, 18% rough pastures, 27% grassy heaths and 12% shrubby heaths. These estimates compare with the current proportions of 27%, 17%, 23% and 33%, respectively, and are similar to the projection based on the response of the specific sample sites. Given a major expansion of forestry, while still protecting the better agricultural land, the projected balance of farmland, forest and unplantable hill is calculated as 33%, 37% and 30%, of the 12 areas combined. These figures compare with the present 21% farmland and 10% woodland, including planted forests, recorded by the Upland Landscapes Study.

The results of the present study are being prepared in a report with 2 parts: Part I being a general synthesis, Part II considering each study area individually. The predictions must, by definition, be speculative. However, the study has provided a base line against which future changes could be monitored, thereby testing the predictions and allowing their refinement.

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PHOSPHORUS IN WOODLAND SOILS

Plant growth experiments, with and without fertilisers, have shown that soils of deciduous and mixed deciduous woodland of the Lake District are phosphorus deficient; the availability of this element limits, sometimes markedly, the growth of trees (Newnham & Carlisle 1969; Harrison & Helliwell 1979; Harrison & Helliwell in press). This is not an unusual occurrence, as phosphorus deficiences are widespread in afforested soils of the United Kingdom (UK) and, as a consequence, the application of phosphate fertilisers becomes routine (Binns 1975).

In considering the demand for, and uptake of, phosphorus by trees and woodland vegetation, analyses have been made of the amounts of phosphorus in Lake District woodland soils, their physico-chemical state, availability to plants and rates of turnover. The soils are mostly brown earths and brown podzols, usually considered to be among the more fertile soils available to forestry.

Phosphorus content of soils

In the surface layer of mineral soil profiles, where trees and ground vegetation root profusely, amounts of total phosphorus (as shown by nitric-perchloric-sulphuric acid digestion – Allen *et al.* 1974) range from 0·02 to 0·15% of the fine earth (<2 mm). Allowing for soil bulk-density differences, this estimate implies that there are about 70 to 780 mg P $litre^{-1}$ of soil or 1·5 to 15 g P m^{-2} 5 cm depth). Subsoils contain slightly lower concentrations of P in their fine earth fractions, but, because subsoils have higher bulk densities, they have larger overall concentrations of phosphorus (180 to 1 000 mg P $litre^{-1}$ soil) than surface soils.

Amounts of phosphorus in surface soils are related to site geology and soil bulk density. Soils on Borrowdale volcanic andesites and tuffs tend to have higher % P in their fine earths than those over slates and grits which, in turn, have greater concentrations than fine earths over limestone; however, when soil bulk density differences are taken into account, limestone soils generally have larger amounts of P per litre than those over slates and grits (Harrison 1979). Nevertheless, the amounts of P vary considerably within individual woodlands – coefficients of variation for individual woodlands range from 23% to 66% when expressed as content per unit volume (Harrison 1979) – and thus it is necessary to make many replicate analyses to detect small differences between woodlands. The amounts of phosphorus in unit volumes of the surface soils of Lake District woodlands – averaging 350 mg P $litre^{-1}$ – appear to be generally lower than elsewhere in the country (including agricultural and grassland areas), where they may be 1·5 to 3 times as great (Harrison 1979).

Conditions of phosphorus in soil

Phosphorus in soil is derived from parent materials by weathering processes and a minor input from dust and rain. The phosphorus in soil is involved in a biogeochemical cycle during which it changes its chemistry and physical state, through microbial activity and various physico-chemical processes, such as adsorption on to clays and combination with iron and aluminium. To understand the variation in the dynamics of phosphorus in soils and its availability to plants, it is necessary to identify various phosphorus fractions. The chemistry is complex (see Harrison 1970), but we have found it convenient to distinguish 4 fractions in our studies: 2 organic and 2 inorganic.

Organic –	phosphate esters in monomeric or polymeric form	labile fraction easily hydrolysed
		stable fraction in insoluble complexes
Inorganic –	mineral, crystalline or surface absorbed	labile fraction easily exchanged to soil solution
		fixed fraction absorbed on to clays or combined with iron and aluminium

Using the modified Anderson extraction technique (Allen *et al.* 1974), it has been found that 38 – 90% of surface soil phosphorus is organically bound (Harrison 1979). As a percentage of surface soil organic matter, amounts of organic phosphorus ranged from 0·4 to 0·74%, these percentages being positively related to soil bulk densities (Harrison 1979). With the buffered (pH 8·5) bicarbonate extraction procedure of Olsen (Allen *et al.* 1974), it is possible to quantify the most labile phosphorus fractions, the amounts of organic phosphorus being calculated by difference in (i) total phosphorus in the extract, after digesting an aliquot with nitric-perchloric-sulphuric acid, and (ii) the inorganic P component. On average, extractable inorganic and organic phosphorus accounted for 2·3 and 5·8% of total phosphorus content, respectively (Table 11).

Table 11. Inorganic (Pi) and organic (Po) forms of phosphorus as percentages (minimum, average and maximum) of the total phosphorus in 50 different surface soils

	Percentages		
	Min.	Mean	Max.
Extractable, inorganic (Pi)	0·79	2·27	6·44
Fixed, inorganic (Pi)*	1·8	26·4	45·0
Extractable, organic (Po)	0·11	5·82	13·8
Stable, organic (Po)*	39·6	65·5	93·3

*Total Pi and total Po minus their respective extractable fractions give fixed Pi and stable Po.

As with amounts of total phosphorus, the proportions of the different forms of phosphorus varied considerably, with extractable inorganic and organic phosphorus having ranges of 10 and more than 100 fold differences, respectively. These proportions were significantly correlated with soil pH, and amounts of organic matter, extractable iron and aluminium (3% oxalic acid—Allen *et al.* 1974), clay and silt (Table 12). Amounts of extractable inorganic phosphorus are strongly, but negatively, correlated with amounts of extractable iron and aluminium (iron and aluminium strongly fix inorganic P making it insoluble); they are less strongly correlated with soil pH and amounts of silt and clay. Amounts of extractable organic phosphorus, however, are strongly negatively related to soil pH and, to a lesser extent, to extractable iron, aluminium and silt contents and, in contrast, they are positively related to amounts of organic matter (Table 12). Most inorganic and organic phosphorus in surface soils occurs in fixed or stable forms (both, on average, 92% of their respective totals). These large amounts probably reflect the state of pedogenetic development reached by Lake District woodland soils (Floate 1971; Harrison 1978), the brown earths and brown podzolic soils, like those elsewhere (Harrison & Hornung, unpublished results), generally having large capacities to fix phosphorus, primarily a function of the amounts of their iron and aluminium contents. The capacities ranged from about 1 to 2·5 times the amounts of total phosphorus contents, using the method of Bache and Williams (1971). While more than 70% of the variation associated with extractable forms of phosphorus was attributable to a range of 6 soil properties (Table 12), less than 40% of that associated with fixed inorganic and stable organic forms (expressed as percentages of total phosphorus) was identified with the same properties (Table 12). Fixed inorganic phosphorus, as a proportion of total phosphorus, is positively related to organic matter and clay contents, whereas the stable organic phosphorus is positively related to pH and clay, but negatively to organic matter (Table 12).

Table 12. Relationships (R^2) between properties of a range of surface soils and the proportion (%) of total phosphorus in extractable and fixed (stable) inorganic and organic forms.

a. R^2 values

	Form of phosphorus			
	Inorganic		Organic	
Soil properties§	Extractable	Fixed	Extractable	Stable
1. pH	0·25**	0·08^{ns}	0·69**	0·17**
2. Organic matter	0·09^{ns}	0·16*	0·24**	0·24**
3. Extr. Al	0·65**	0·07^{ns}	0·33**	0·02^{ns}
4. Extr. Fe	0·67**	0·08^{ns}	0·12*	0·10^{ns}
5. Clay	0·14**	0·14**	−0·14*	0·12*
6. Silt	0·36**	0·04^{ns}	0·26**	0·02^{ns}
Proportion of variation attributable to properties (1)-(6)	0·71	0·25	0·88	0·40

§expressed as mg or g litre^{-1} fine earth
*, **; R^2 significant at probabilities of 0·05 and 0·01 respectively
ns = not significant at probability of 0·05

b. nature of relationships (+ or −)

	Inorganic		Organic	
Soil property	Extractable	Fixed	Extractable	Stable
1. pH	(−)		(−)	(+)
2. Organic matter		(+)	(+)	(−)
3. Extr. Al	(−)		(−)	
4. Extr. Fe	(−)		(−)	
5. Clay	−	(+)	−	(+)
6. Silt	(−)		−	

( ) = significant quadratic terms in regression

There are weak negative relationships (Table 13) between the percentages of soil extractable inorganic

Table 13. Relationships (R^2) between the different forms of phosphorus found in surface soils in Lake District woodlands. (Amounts of the different forms were expressed as percentages of total phosphorus)

a. R^2 values

	Forms of phosphorus			
	Extractable inorganic (Ext. Pi)	Fixed inorganic (Fixed Pi)	Extractable organic (Ext. Po)	Stable organic (Stable Po)
Ext. Pi	1			
Fixed Pi	0·13*	1		
Ext. Po	0·09^{ns}	0·05	1	
Stable Po	0·11*	0·79**	0·29**	1
Total P	0·07^{ns}	0·61**	0·004^{ns}	0·03^{ns}

* and ** = R^2 significant at probabilities of 0·05 and 0·01 respectively
ns = not significant at probability of 0·05

b. nature of relationships (+ or −)

	Extractable inorganic	Fixed inorganic	Extractable organic	Stable organic
Ext. Pi				
Fixed Pi	(−)			
Ext. Po				
Stable Po	(−)	−	−	
Total P		(+)		

( ) = significant quadratic terms in regression phosphorus and those of (i) fixed inorganic and (ii) stable organic fractions in soils (Table 13). The relationships between the percentages of fixed inorganic and extractable organic phosphorus with phosphorus in the stable organic form are similarly negative, but more strongly so. Broadly speaking, these relationships suggest that other forms of phosphorus decrease as stable organic phosphorus accumulates during pedogenesis. Although the percentage of phosphorus in the fixed inorganic form increases as amounts of total phosphorus increase, those of other fractions do not seem to vary significantly with total phosphorus.

Availability of phosphorus in soils

Plants can only take up phosphorus in an inorganic form and only from soil solution. Concentrations of inorganic phosphorus in soil solution are low and therefore the solution phosphorus must be replenished as plants absorb phosphorus from solution.

Amounts of inorganic phosphorus, extractable in Olsen's bicarbonate solution, are often good indicators of the availability of phosphorus, particularly in agricultural soils, for plant uptake (Olsen *et al.* 1954; Cooke 1967; Ryden & Syers 1977). However, with Lake District woodland soils, inorganic phosphorus is a less valuable indicator, possibly because these soils have varying fixation capacities which modify the release of different fractions of available phosphorus during extraction with bicarbonate, and because the availability of phosphorus depends on the mineralisation of organic phosphorus to a considerable extent (Figure 16). Instead, greater success in measuring available phosphorus content has been obtained with a method in which the surface-absorbed, but exchangeable, pool of phosphorus has been assayed by using an isotopic ^{32}P technique (Harrison 1975); this method suggests that 0·2 to 2% of total phosphorus in Lake District woodland soil is 'available'. (Relationships between bicarbonate extractable inorganic P and isotopically exchangeable P are discussed by Ryden and Syers 1977.) Despite appreciable within-woodland variation (coefficients of variation of 50–150%), it has been possible to show that amounts of available phosphorus are statistically different in soils of individual woodlands (Harrison 1979). Amounts of available phosphorus are directly related to soil pH ($r^2 = 0{\cdot}42$); they also vary seasonally by having larger amounts in spring and summer than during winter (Harrison 1979). The seasonal effect, attributable to temperature, suggests that phosphorus is made available by microbiological/enzymic processes involved with the mineralisation of organically bound phosphorus (see later).

Digressing slightly from the main theme of this review, it is important to remember that the uptake of phosphorus depends on plant factors, such as the plant's phosphorus requirement, its rooting habit and the development of mycorrhizas, in addition to the availability of soil phosphorus. For this reason, a plant bioassay has been developed for assessing phosphorus availability, recognising that this availability integrates soil and plant factors (Harrison & Helliwell 1979). This bioassay relies on root responses to test solutions of phosphate. When birch and sycamore seedlings were placed for 15 min in a 5×10^{-6}M phosphate solution (containing 5×10^{-4}M calcium sulphate and 20 microcuries ^{32}P as orthophosphate), there was a negative exponential relationship between (i) phosphorus uptake (in pg P mg root^{-1} 15 min^{-1}) from the test solution and (ii) the concentrations of phosphorus previously available to the test seedlings during propagation in sand culture (Harrison & Helliwell 1979). Plants grown in unamended soils, prior to being bioassayed, took up more ^{32}P-labelled phosphorus than plants grown in soils with added phosphorus. In other experiments, saplings, grown in 25 different soils for 2 years before being assayed, responded by taking up ^{32}P-labelled phosphorus in a manner negatively related to the estimates of available phosphorus (and phosphatase activity). The results so far obtained suggest that this bioassay may facilitate work on phosphorus nutrition, particularly when growing plants in nutrient-deficient soils, and it may also aid the assessment of sites for forestry.

As plants remove phosphorus from the available pool, it is generally replenished, but the slow rate of replenishment in many woodland soils is the factor restricting plant uptake. Replenishment is largely achieved in these Lake District soils by the mineralisation or hydrolysis of organcally bound phosphorus with the release of orthophosphate into the 'pool' of available phosphorus—a complex of processes (Figure 16). The rate of mineralisation of organic phosphorus, probably the fraction extractable in Olsen's bicarbonate solution (Harrison in press), is inferred from the rate of hydrolysis of ^{32}P-labelled ribonucleic acid. Mineralisation is largely governed by soil pH, extractable calcium and moisture contents, soil respiration rate, and phosphatase activity (Harrison in press). As with amounts of available phosphorus, rates of mineralisation of labile organic phosphorus vary with season, being faster in spring than autumn (Harrison in press), a similarity of effect going some way to explain the dependence of amounts of available phosphorus on the mineralisation of labile organic phosphorus. It is further corroborated by the (i) negative relationship between amounts of available (isotopic exchange) and extractable organic phosphorus and (ii) the positive relationship between amounts of available phosphorus concent and rates of labile organic phosphorus mineralisation (Harrison in press).

Fixed inorganic and stable organic phosphorus may contribute to the replenishment of the 'pool' of available phosphorus, but the amounts contributed are likely to be small. Fixed inorganic phosphorus may aid replenishment by shifts in the physical equilibrium between fixed and soil solution phosphorus. Stable organic phosphorus may be mineralised, possibly by phytases, but only slowly because most occurs as inositol hexaphosphate (phytin) which is rendered insoluble in these mostly acid soils by iron and aluminium (Harrison 1970; Jackman & Black 1951).

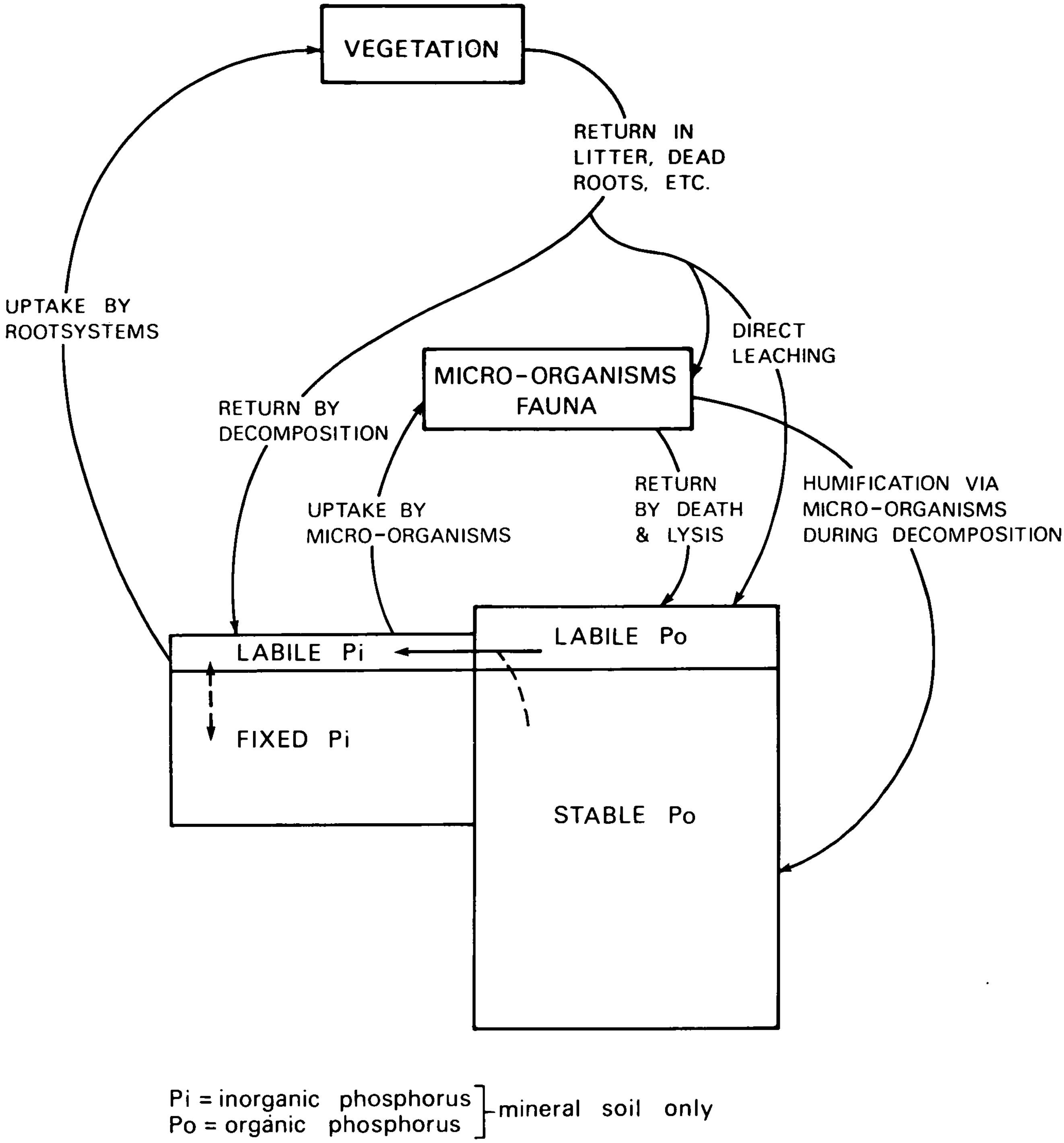
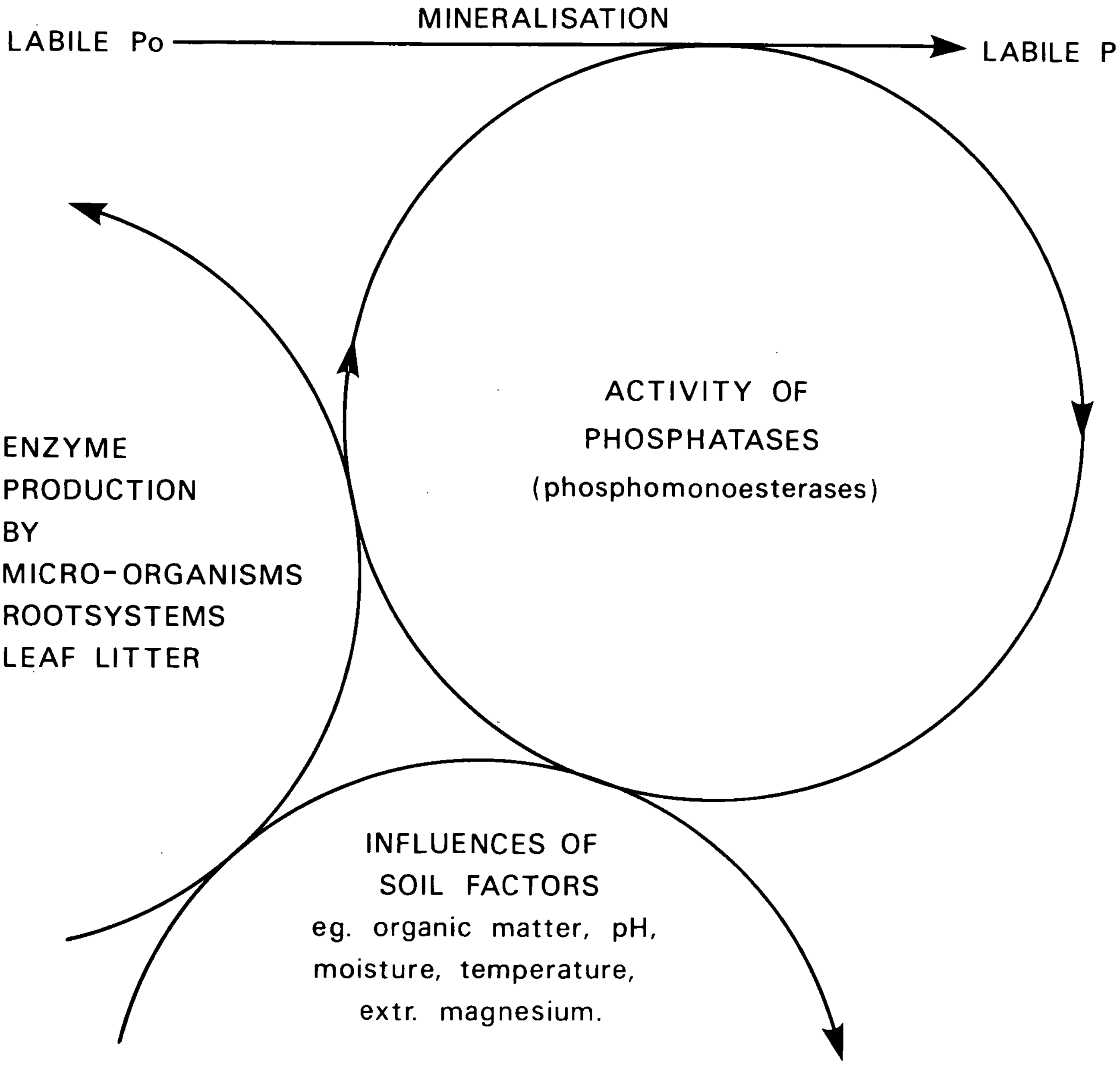


Figure 16 Simplified woodland phosphorus cycle.

Phosphatase activity in soils

The enzymic activity of free phosphates, originating from soil microbes and plant roots and litter, mediates the mineralisation in soils of labile bicarbonate soluble organic phosphorus to inorganic phosphorus (Figure 17). It is strongly and positively related to the amounts of soil moisture and organic matter – probably by being bound as humoprotein complexes, the enzymes being thereby protected from decomposition. Phosphatase activity is also positively related to amounts of magnesium extractable with neutral ammonium acetate, but negatively related to extractable calcium ions which occur in large concentrations in soils of high pH; magnesium is a natural activator and calcium a competitive inhibitor of phosphatases. While rates of mineralisation and the amounts of labile organic phosphorus are both strongly related to soil pH, there is a complex relation between pH and phosphatase activity (weakly negative) possibly because of mixtures of enzyme type (isoenzymes) with different pH optima – acid (pH 5 to 6), neutral (pH 7) and alkaline (pH>8) (Figure 18). The activity of phosphatases varies seasonally (Harrison & Pearce 1979) and, when effects of soil temperature on their activity were taken into account, the seasonal pattern of phosphatase activity mirrored seasonal changes in the amounts of available soil phosphorus (Figure 19).



Pi = inorganic phosphorus, Po = organic phosphorus.

Figure 17 Scheme showing relation of soil factors to phosphatase activity and organic phosphorus mineralization.

Relationships between soil phosphorus and plant uptake

Trees and ground vegetation take up 0·8 to 1·3 g P m^{-2} yr^{-1} from soils in 2 Lake District woodlands (Brown 1974; Harrison 1978), but these quantities are less than potential uptake, as the restricted availability of phosphorus is limiting tree growth. The restricted availability of phosphorus in these soils is due to a high proportion of the relatively low concentrations per unit volume being locked up in organic forms. In the top 25 cm of soil, where most of the fine roots grow, amounts of available phosphorus range from 0·4 to 1·5 g P m^{-2}, averaging 0·35 P m^{-2}. These amounts are continuously being sustained by recycled phosphorus returning to soil from decaying roots, branches and leaf litter, and in stem and leaf leachates, so enabling the annual demand made by plants, namely 0·8 to 1·3 g P m^{-2}, to be met (Harrison 1978). Most of the recycled phosphorus passes through the labile fraction of the top 5 cm of soil, with the recycled organic phosphorus being mineralised by phosphatase enzymes before becoming available for uptake by plants.

These estimates suggest that the labile inorganic 'pool' turns over between 2 and 20 times a year in relation to plant demand for phosphorus. However, these estimates do not take into account the turnover due to the demand for phosphorus by the soil microbial and faunal populations (Figures 16 and 19; Cole *et al.* 1978; Sharpley & Syers 1977), additional to that returned to soil in plant materials. The total demand for phosphorus by microbes and fauna is in the order of 2 to 3 times the amount of P required for primary production in the vegetation (Heal & MacLean 1975). Such a demand indicates direct competition between the microbial population and plants for available phosphorus (Barber 1967, 1973). Hence, the real turnover rates of the labile inorganic phosphorus may be between 4 and 60 times a year, depending on the soil conditions.

Of the annual uptake of phosphorus by woodland vegetation, approximately 10% is retained by trees (Harrison 1978), the remainder, 0·7 to 1·15 g P m^{-2}, being recycled. The losses in cycling phosphorus due to tree production are probably replaced by phosphorus (i) enriching incident precipitation (rain), but the likely input of 0·035 g P $m^{-2}yr^{-1}$ after deducting losses of 0·024 g P m^{-2} in drainage gives a possible net input of only 0·01 g P m^{-2}, (ii) derived from fixed inorganic and stable organic forms to an, as yet, unknown extent, and (iii) originating from rocks and stone weathering within the soil profile.

In summary, the availability of phosphorus in Lake District woodland soils, ie the sum of their available phosphorus content, and its replenishment through mineralisation of organic phosphorus recycled plant litters, is largely determined by soil pH and calcium status; both available phosphorus content and the rate

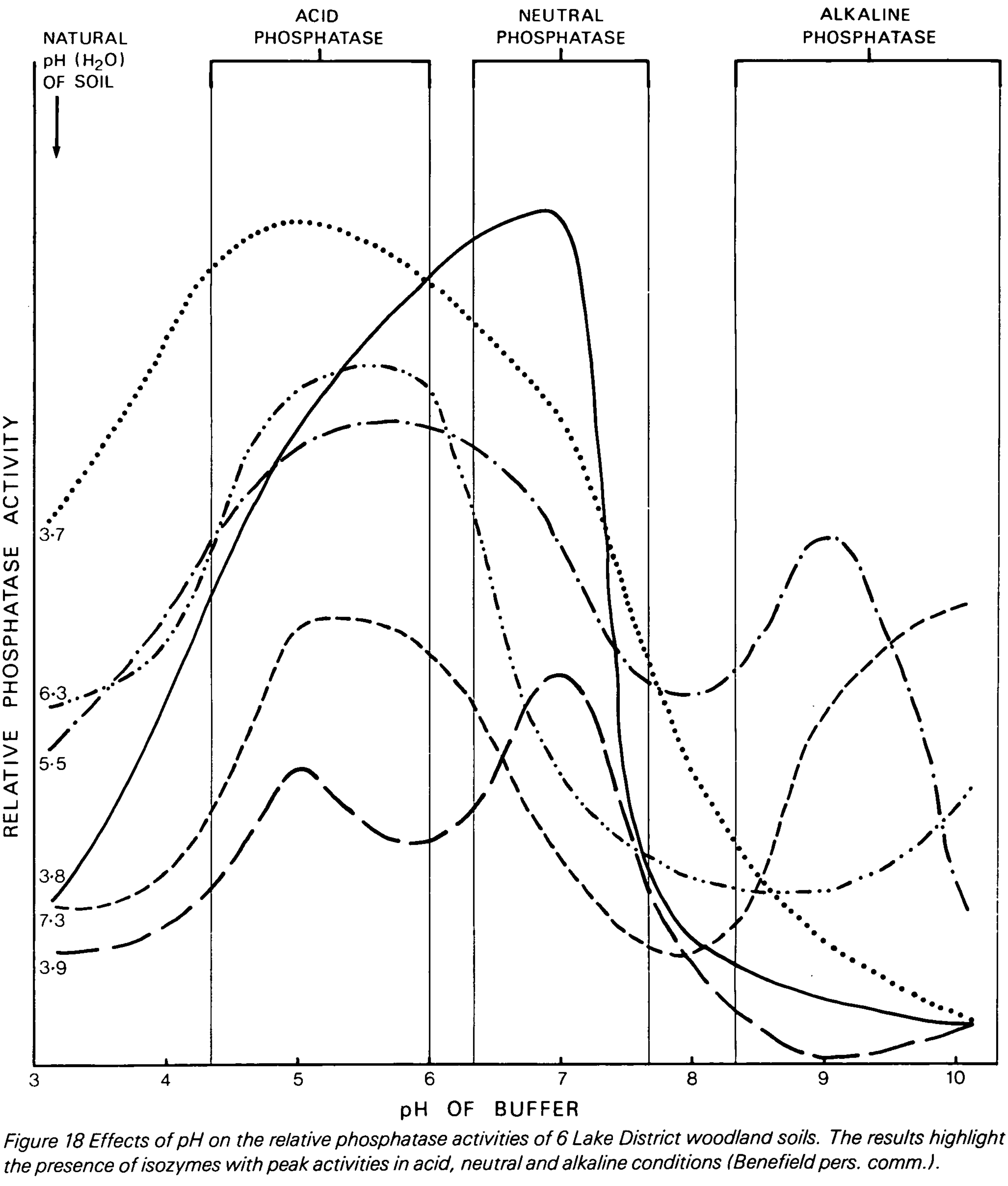


Figure 18 Effects of pH on the relative phosphatase activities of 6 Lake District woodland soils. The results highlight the presence of isozymes with peak activities in acid, neutral and alkaline conditions (Benefield pers. comm.).

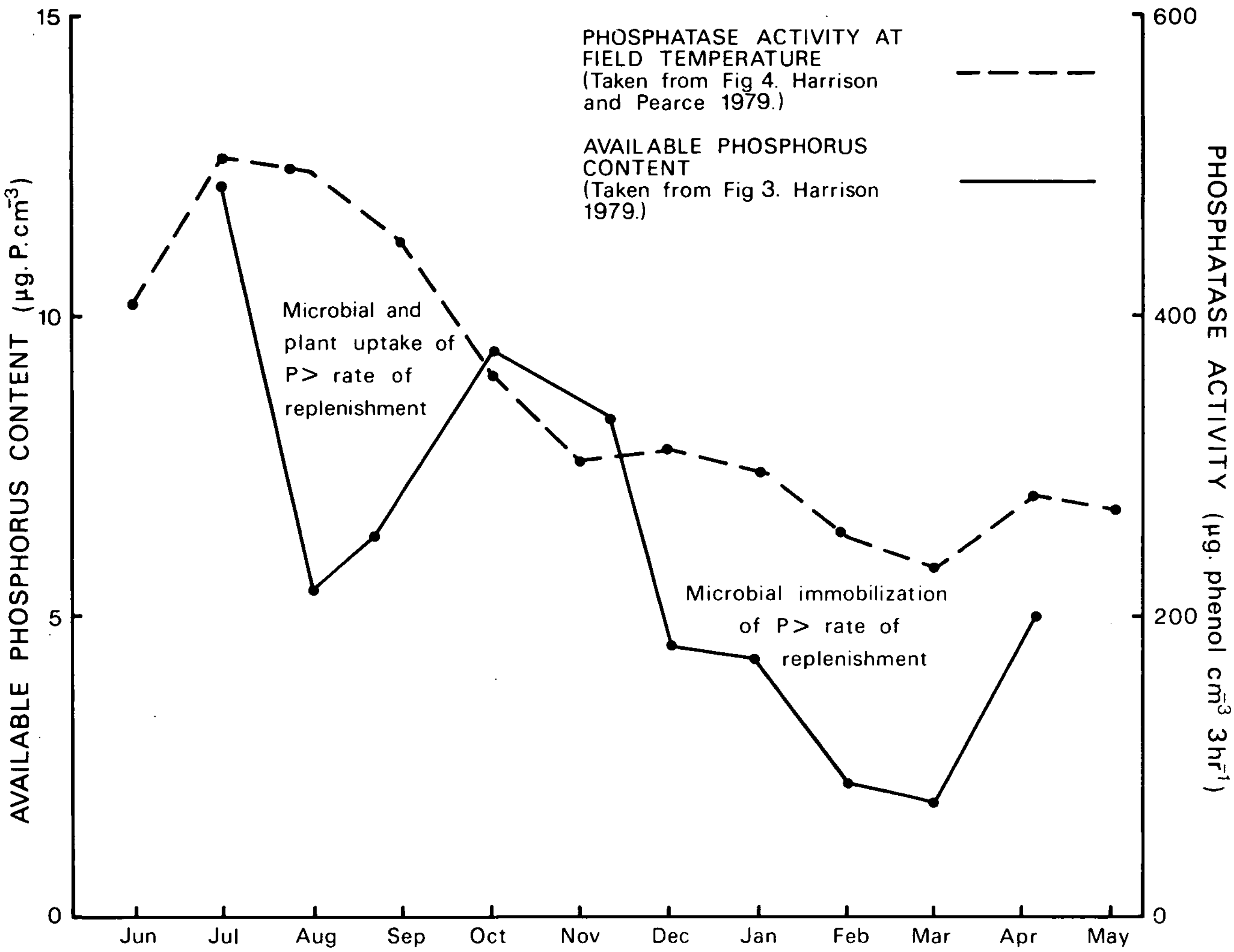


Figure 19 Seasonal changes in the relationship between phosphatase activity and amounts of available phosphorus in woodland soils of the Lake District.

of organic phosphorus mineralisation increase about 10-fold over the pH range 3 to 8.

A. F. Harrison

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NATURE CONSERVATION PROBLEMS IN SOUTH-EAST EUROPE

Attitudes to the conservation of nature in central and western Europe differ to a remarkable extent from country to country. These attitudes are determined by several factors such as standards of living, cultural values, traditional attitudes to wildlife, education, legislation for nature protection and its enforcement, and the strength of public feeling for the preservation of hunting rights. In general, the bias in favour of nature conservation is strongest in the north and west of Europe and weakest in the south and east. The consequent disparity of effort to protect nature has worried the International Union for the Conservation of Nature and Natural Resources (IUCN) which has recently published a factual survey of how nature conservation is organised and supported in most of the western countries of Europe (Poore & Ambroes 1981). However, neither Yugoslavia nor Greece, which are described here, could be included in this work. These countries together with southern Italy, Sicily, Sardinia and Corsica were visited during a 3 month tour in late 1980 under a Churchill Fellowship, when a comparative study of the organisaton of nature conservation was made.

Yugoslavia

This country is divided into 6 autonomous Republics, each responsible for establishing its own National Parks, nature reserves and promoting conservation work. Each Republic has an Institute for Nature Protection, whose Director is responsible to the Environmental Protection Committee or Committee for Education and Culture of the Republic government. Institute staff usually include biologists, geologists and lawyers, while the Director may be a forester or civil engineer. The main effort of the conservation work is directed to the National Parks, which are regarded as the most important wildlife protection areas. In the whole country, there are 16 National Parks (each with a Director and staff), the most recent being the Kornati Islands on the Adriatic coast of Croatia, established in August 1980. The principal feature of most Parks is extensive natural forest, some of which, it is claimed, has never been exploited, and large vertebrates such as red and roe deer, brown bear, wolf, lynx, wild boar and large birds of prey are often present. The Parks are expected to serve 3 main purposes: 1. a zone (usually about 10% of the total area) is set aside for tourist facilities such as hotels, camp sites, restaurants, picnic and recreation area; 2. the most important regions for wildlife are made into 'strict nature reserves' where no work is permitted, although public access is allowed; 3. in the remainder of the Park, controlled timber felling, grazing and other activities are organised to produce an income. All Parks must earn enough money to cover their expenses, although some financial support is provided by the Republic governments in special cases. The ability to earn money varies greatly from Park to Park, the most remarkable being the Plitvice Lakes NP where 1 300 people are employed in the hotels, restaurants, camp sites, bus and boating services, as guides and wardens, etc. All these facilities are owned by the Park which takes a proportion of the profits. Some of the money is made available for biological survey and research, but other Parks with a low income are unable to support such work.

Apart from National Parks, there are about 170 nature reserves and numerous Regional Parks, Protected Landscapes and Natural Monuments. A complete inventory of these sites, with details of their biological interest, has been published for Slovenia, but not the other Republics.

Greece

Unlike Yugoslavia where there is a good deal of public sympathy and support for nature conservation, Greece has considerable difficulty in overcoming public indifference. This may be the reason why the government has not been persuaded to provide more than minimal financial support for nature conservation. The chief agency is the State Forest Service which has a National Parks Division staffed by 3 people. However, the Ministry of Planning and Co-ordination has a Department which advises the Minister on environmental matters and is able to promote support for nature conservation and liaise with international conservation organisations.

Although state resources are poor, nature conservation is strongly supported by a voluntary body, the Hellenic Society for the Protection of Nature, which has done excellent work in the field of public relations, survey and advising the government. However, it does not own or manage nature reserves. There is no WWF National Appeal in Greece, nor a national ornithological society.

There are 10 areas designated as National Parks, but only one has staff. Two may have to be 'demoted' because uncontrolled building developments and other activities have changed the nature of the area. The other National Parks are all situated in mountainous areas where there are few permanent residents and conflict with other activities is low. There are 3 other categories of protected area—Aesthetic Forests (19), Protected Wetlands (11), and Natural Monuments (32). The first may consist of state or privately owned forests, but the level of protection is often insufficient to prevent activities detrimental to the conservation interest. Many of the Wetlands are important breeding sites for rare aquatic birds or as resting and feeding areas for migratory species, but control of shooting and other activities which disturb the birds is very difficult. Tourist activities on beaches and along attractive coastlines have increased considerably in recent years and these activities, together with the hostile attitude of fishermen, have been responsible for a reduction in the number of breeding sites of the loggerhead turtle and the monk seal which is now very rare throughout its range. Natural Monuments are usually small sites, a rock, tree, waterfall, etc, and mainly of cultural and historical interest.

Although the organisational aspects of nature conservation in Greece have made slow progress, the country is still extremely rich in wildlife and has more species of birds of prey than any other country in western Europe; the wolf, jackal, brown bear and wild boar survive in its mountains and forests; and the flora, which includes 675 endemic taxa, is the richest in Europe. Each year, this richness of wildlife attracts numbers of foreign scientists and university parties who often do ecological work of considerable conservation interest. The results of their work may or may not be published in the home country, but too often the results do not get back to Greek conservationists who could make use of them. A bibliography of this work is urgently needed. IUCN has also recognised the importance of obtaining up-to-date information on endangered biotopes and wildlife species and has promoted several projects in collaboration with the Greek authorities. The National Parks Division has, so far, had little success in persuading the universities to encourage students to interest themselves in conservation ecology, but this may be because grant aid is not available.

General comment

The gap between academic studies in biology and fieldwork on conservation ecology seems to be considerable in both countries. This is partly because university teaching follows traditional lines (although there are notable exceptions in Yugoslavia) and partly because there is insufficient funding. Greece has the advantage of close contacts with IUCN who can help to promote joint studies by Greek and foreign scientists and membership of the EEC may help in the future. Yugoslavia has little contact with international conservation agencies and, because each Republic goes its own way, there is evidence of isolation from ideas and events elsewhere in Europe and also from scientific conservation literature in other languages. In both countries, it was very difficult to obtain precise information about the fauna and flora of protected areas and the status of endangered species, with the possible exception of flowering plants and the large vertebrates in some instances. A biological survey to produce a 'Conservation Review' is a high priority, particularly in Greece where environmental change has been most marked and may accelerate as EEC funds for economic development become available. In nearly all the Grade I conservation areas, traditional rural activities continue, particularly silvicultural work, and grazing by sheep, goats and cattle. These activities are undoubtedly beneficial in some instances, for example where plants need open-ground conditions, but their precise effect on the fauna and flora does not seem to have been studied as a research project, nor does there appear to be an awareness that such information is important for wildlife management.

E. A. G. Duffey

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Research of the Institute in 1980

Introduction

As in previous years, the main section of the Report describes some of the research projects being undertaken within the Institute, while the full list of project titles is given in Section IV. These relatively short accounts have been grouped according to the Subdivision of the Project Leader, and fall into the 3 main Divisions of the Institute.

Within the Animal Ecology Division, 6 short accounts describe some of the work of the Subdivision of Invertebrate Ecology, followed by a further 6 reports of research within the Subdivision of Vertebrate Ecology, and 8 contributions from members of the Subdivision of Animal Function. Within the Plant Ecology Division, a slightly longer set of contributions are given. Seven reports describe the work of the Subdivision of Plant Biology, followed by 9 contributions from the Subdivision of Plant Community Ecology, and 8 accounts from the Subdivision of Soil Science. The 3 Subdivisions of the Scientific Services Division—Data and Information, Chemistry and Instrumentation, and the Culture Centre of Algae and Protozoa—each present their reports in 2 parts. The first part gives a general review of their service functions during 1980, while the second part describes individual research projects being done by members of the Subdivision.

Invertebrate Ecology

PREDATION ON ZOOPLANKTON BY YOUNG PERCH

Loch Leven in Kinross-shire, Scotland, is an ideal place to study the interaction between a fish predator, perch, and its principal prey, because it is a shallow, highly productive (eutrophic) lake with 3 dominant species of crustacean zooplankton occurring commonly over the loch in detectable numbers at all times of the year. In the shallower waters around the perimeter of the loch, there are shoals of juvenile perch from June until the following spring. Documentary and observational evidence indicated that, for at least part of their early life, perch preyed upon these Crustacea. Although the planktonic feeding period of perch had been recorded as of short duration (Furness 1979), samples from Loch Leven in the first year of the study showed that crustacean zooplankton formed practically the entire diet all through the first summer and into the winter. Subsequent samples of fish, caught through the winter and early spring, showed their food to be dominated by the same species. The study has therefore analysed changes in food composition and quantity, related these to growth and linked them to a continuous assessment of the abundance of crustacean zooplankton in the loch. The plankton has been sampled weekly at 2 stations, an integrated sample being collected from the surface to either 3 or 4 m depth and representing the zooplankton from either 24 or 31 litres of water. The numbers of the dominant species per 25 litres have had the following ranges:

Cyclops strenuus abyssorum	$0{\cdot}26 \times 10^3$ to $1{\cdot}56 \times 10^3$
Diaptomus gracilis	$0{\cdot}013 \times 10^3$ to $0{\cdot}54 \times 10^3$
Daphnia hyalina	$0{\cdot}013 \times 10^3$ to $1{\cdot}73 \times 10^3$

The seasonal patterns of abundance have varied from species to species, and the maxima and minima may vary from year to year by a factor of 5 or more.

The numbers of perch in their first year (0-class) are more difficult to estimate because of their non-random distribution, and they may fluctuate with variations in the abundance of the spawning stock, success of hatching, and/or post-hatching mortality. Although the natural mortality is believed to decrease exponentially with age, abnormal environmental conditions, disease, or changes in predation pressure can alter this relationship. Subjective assessments made during trapping, and by observing shoals, suggest that shoals may consist of more than 1×10^4 fish, even in the late summer, and that there may be dozens of these shoals all round the perimeter of the loch.

The final objective of the study is to understand the fluctuations in abundance and to model the interaction of perch and zooplankton. The primary requirements have been to determine the seasonal extent of feeding on the crustacean zooplankton and to discover whether feeding was indiscriminate (opportunistic) or selective, individualistic or common to a shoal, and to know how the diet changed quantitatively with age (size), and qualitatively wtih changes in the composition of the zooplankton. In later stages, the periodicity of feeding, or some measure of the daily food intake, will be of importance.

Two approaches have been used so far to answer the above queries: the analysis of stomach contents in samples of fish taken through the season at time intervals sufficiently close to keep the growth increment small, and experimental feeding of individual fish under measured conditions in the laboratory. A third approach, the shaping of plankton populations by controlled predation in semi-natural conditions, will follow in the near future.

In the months June, July and August, the species present in high numbers was also the dominant food item (Table 14). In September, *Diaptomus* was present at its highest level (71 specimens/25 l) and was the most commonly taken food item despite the fact that *Cyclops* was present at a density 15 times greater. This would seem to confirm the experimental finding of Furness (1979) that *Diaptomus* is a preferred food item of young perch. However, in the succeeding months,

Table 14. The % composition of the zooplankton samples (P) and the stomach contents (S) of 0-class perch from June to December. The dominant components are underlined.

	June		July		Aug		Sept		Oct		Nov		Dec	
	P	S	P	S	P	S	P	S	P	S	P	S	P	S
Cyclops abyssorum	79	77	5	29	92	65	84	29	19	61	38	61	42	1
Diaptomus gracilis	1	12	1	8	3	24	5	46	3	14	10	10	12	0
Daphnia hyalina	20	11	92	63	5	10	11	25	68	26	52	30	46	99
Total Nos/25 l	1028	–	320	–	1066	–	1343	–	506	–	696	–	279	–

Cyclops was favoured over *Daphnia* in October and November, while in December, despite *Diaptomus* being present at nearly half of its maximum density (31 specimens/25 l and both *Cyclops* and *Daphnia* being present in low numbers relative to their maxima, the latter was eaten almost exclusively (Figure 20). On the 2 occasions when *Daphnia* was the dominant food item, the total numbers of crustacean zooplankton were very low.

On the present evidence, it is difficult to decide if this division into 2 periods according to the relationship between food and plankton is a valid one. However, growth in fish, such as perch, can be divided into 'stanzas' (Kuznetsov 1972), and these can be characterised by different behaviour patterns. Differences in feeding behaviour have been noticed between fish of 2 cm and fish of 3 cm under similar experimental conditions.

Further evidence of prey selection, combined with rates of ingestion, were provided by experimental feeding in the laboratory. In 2 such experiments, *Cyclops* was evidently the preferred food, being taken in some 17–18% higher numbers than would occur if feeding on all species was random (Table 15). Where *Daphnia*

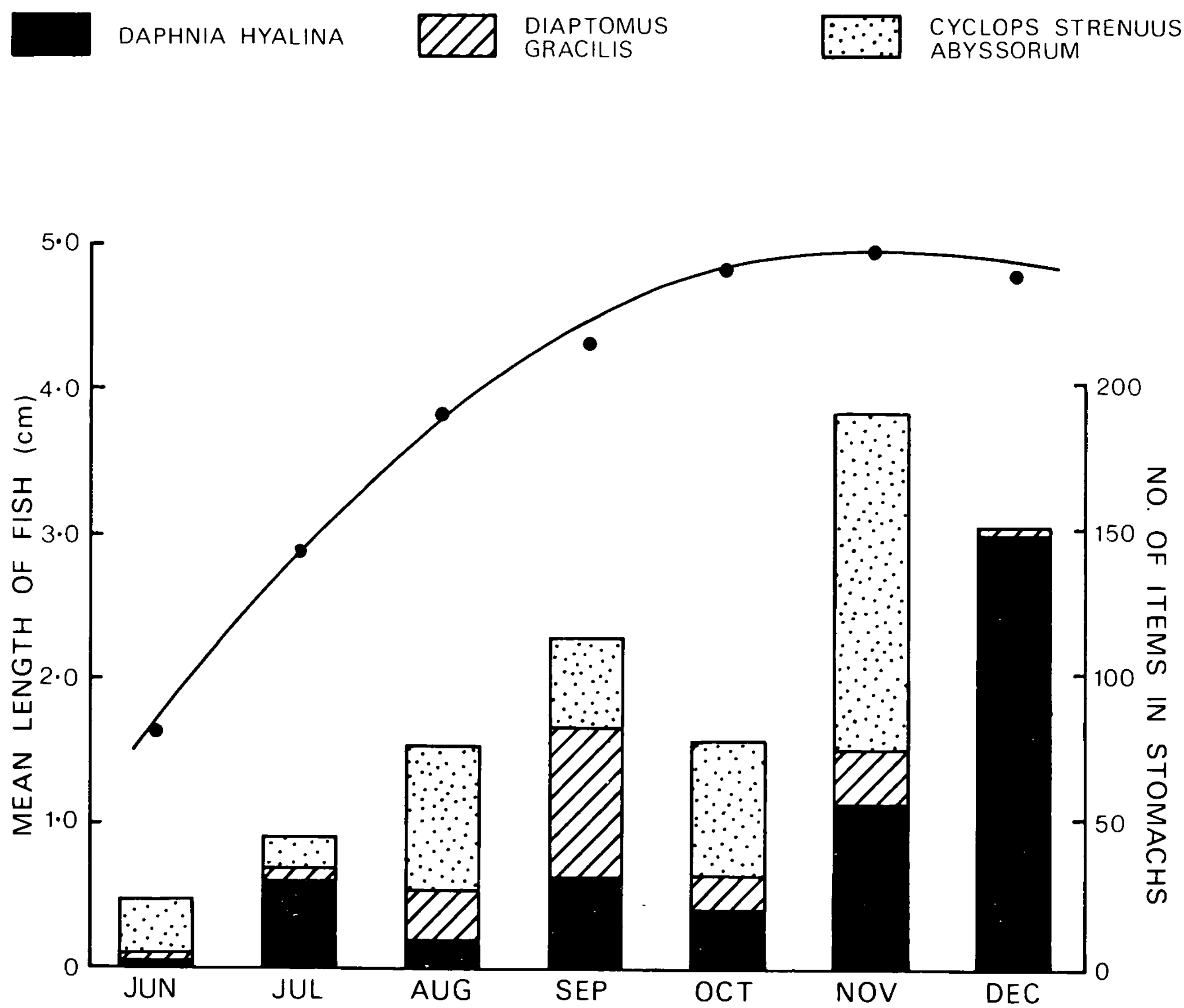

Figure 20 Growth curve of young perch and the composition and quantity of food from their stomachs in selected samples at approximately monthly intervals.

Table 15. % composition of zooplankton (P) and stomach contents (S) in laboratory feeding experiments with 0-class perch (Total length 22·5 mm).

	1. % composition		2. % composition	
	P	S	P	S
Cyclops abyssorum	72·5	90·6	60·0	76·9
Diaptomus gracilis	5·9	1·9	2·9	0
Daphnia hyalina	21·6	7·5	37·1	23·1
Total Nos	153	53	105	26

was present in higher proportions, ie where it was encountered more frequently, a higher proportion was eaten.

Experiments were also made to record 'strikes', the ingestion of a food item successfully or otherwise, with some identification of the food organisms taken. One interesting observation made during these experiments was that, in a number of cases, *Daphnia* was taken either first, or within the first burst of feeding activity. After that, *Cyclops* was taken almost exclusively and *Daphnia* was either ignored or, if taken, was invariably rejected. However, in some cases towards the end of the experiment, an occasional *Daphnia* was selected and eaten.

As these analyses and experiments proceed, a picture of the feeding biology of the young perch is emerging, which can be linked with the available knowledge of plankton biology. The end product of all these studies will be a contribution towards a numerical model of the Loch Leven ecosystem.

D. H. Jones

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THE REDISCOVERY OF *ERESUS NIGER*

Before its rediscovery in 1969, the spider *Eresus niger* was known in Britain from only 6 males and one female, collected between 1816 and 1906. The original sites, all near Bournemouth, have now been lost to urban development. In 1979, 2 males were collected at one site in pitfall traps during a survey of Dorset heathlands commissioned by the Nature Conservancy Council as part of its programme of research into nature conservation. In the spring of 1980, it was established that there are several small colonies at this site, and a few individuals were found at a second site about 600 m away. The male is the most spectacularly coloured of all British spiders, having a bright red abdomen with 4 black spots, and has long been sought after by collectors. Because of this fact, and its extreme localisation and small population, the species is to be added to Schedule 1 of the Conservation of Wild Creatures and Wild Plants Act 1975. The species is widespread throughout southern Europe and north Africa, but rare in more northern countries.

Some preliminary observations of the species were made during 1980, both in the field and in captivity, and it is proposed to extend this research in 1981 in order to improve our understanding of the habitat requirements of the species, and to discover whether colonies can be expanded by appropriate management of the habitat. Studies on population dynamics, food consumption and general biology, and experiments in habitat management will be included.

Eresus niger is a fairly large, robust spider, the adult female, which is black, being about 15 mm long, and the brightly coloured male (Cover photograph) about 9 mm long. The adult male wanders actively in search of females in bright sunshine, but the females and all young stages live in silk-lined tubes (up to 10 cm deep) in the ground. This tube is extended above ground into a small flat web, beneath which the spider lies in wait for prey. All food remains are deposited on the outside of the web, thus aiding the analysis of food consumption. The prey of adult females and larger juveniles consists mainly of beetles, heather beetles *(Lochmaea suturalis)* in particular, but occasionally some larger beetles and bugs are taken. It is thought that adult males probably do not feed, while the food of the young is unknown. They probably take 3 years to reach maturity. The male enters the female's burrow to mate, and the eggs (about 80–90 in number) are laid in a flattened silk egg-sac, which the female holds at the top of the burrow during the day. After emergence, the young remain in the female's burrow for a time before dispersal, but at present it is not clear how soon after emergence dispersal occurs, or whether the young feed on the body of the dead female. It would appear that the young do not usually travel far from their mother's burrow, because small mixed-age colonies are formed, usually occupying bare or lichen-covered patches among heather. The ages of individuals can be determined by the diameters of their burrows in early spring, when they show the greatest disparity in size between different age groups. It is hoped that existing colonies may expand, and new colonies may be formed, as a result of the artificial creation of new areas of bare ground adjacent to existing colonies and elsewhere.

P. Merrett

THE POPULATION BIOLOGY OF *SCOLYTUS INTRICATUS*

The oak bark-beetle *(Scolytus intricatus)* is indigenous to the United Kingdom and other western European countries. It is considered a likely potential vector of *Ceratocystis fagacearum*, the fungus which causes oak wilt, should this enter Europe from the United States

and infect native oaks. Initial studies on the biology of *S. intricatus* have related its life history to the life cycle of *C. fagacearum* and confirmed the likelihood of it being able to transmit fungus (Yates in press). More recent studies have concentrated on the population biology and dynamics of *S. intricatus*.
of *S. intricatus*.

The life history of S. intricatus

Scolytus intricatus breeds in the cambial region of the bark of dying oak. From late June to September, the female excavates (Cover photograph), across the grain of the wood, a maternal gallery along the sides of which the eggs are laid. Eggs hatch after about 14 days and the larvae eat the phloem, leaving characteristic feeding galleries. Larvae overwinter beneath the bark and pupate in spring after further growth. Newly emerged adults leave the bark during June by chewing their way to the surface, so leaving distinct exit holes. A proportion, if not all, of the emergent adults may feed on the twigs of live oaks either before or during dispersal. New breeding sites are thought to be located by 'pioneer' males which, having found a suitable site, then attract the rest of the breeding population by the production of an aggregation pheromone.

Population studies

Age-specific life tables are being constructed for populations of *S. intricatus* from Monks Wood NNR, Cambridgeshire, and Alice Holt Forest, Farnham, Surrey, using data collected by retrospective sampling of logs after the beetles have bred and their progeny emerged. Careful examination of the maternal and larval galleries in the bark allows the number and survival of the immature stages to be determined. Some mortality can be attributed to agents by detection of characteristic remains in larval galleries, for example the pupal cases and emergence holes of the parasitoid hymenopteran *Entedon ergias*, whose larvae are endoparasitic on both the egg and larval stages of *S. intricatus*. Although large proportions of the mortality could not be directly attributed to identifiable agents, the life table for the Monks Wood population, 1978–79, does indicate at which stage mortality is greatest (Table 16). Egg mortality, the highest mortality occurring in any of the immature stages, was thought to be the result of infertility and predation. The low mortality in first and second instar larvae compared to that in later instars was probably the result of their comparatively shorter instar duration. Larvae dying in these 2 instars were probably killed by undetermined predators and pathogens or by intraspecific competition. Because it is likely that invertebrate predators beneath the bark remain dormant during winter, much of the relatively constant winter mortality unaccounted for in the third and fourth instars may be caused by freezing. Deaths of third and fourth instar larvae caused by endoparasites, particularly *E. ergias*, probably occurred before overwintering and, in later instars, during spring when larval feeding and growth resumed. Rising temperatures in spring may have caused an increase in deaths by predation and pathogens which, in addition to those caused by endoparasites, are thought to be responsible for the high proportion of deaths in fifth and sixth instar larvae. The comparatively low mortality of pupae and teneral adults (ie beetles in which the cuticle is still hardening) is thought to be the result of death during moulting and failure to emerge from the bark. Because many of the mortality agents remain unidentified, subsequent life tables are being supplemented by information gained from sub-samples of the live population taken at the time of egg-laying and pre- and post-winter larval development.

Table 16. Life table for the oak bark-beetle *(Scolytus intricatus)* in Monks Wood NNR during 1978–79.

Age class	No entering stage	Cause of death	% dying		Accumulated % dying
Eggs	300	Unknown		28·3	28·3
Larvae					
I instar	215	Unknown		6·1	32·7
II	202	Unknown		9·4	39·0
III	183	Unknown	10·9		
		Entedon ergias	2·7		
		Other parasites	0·6		
				14·2	47·7
IV	157	Unknown	10·8		
		E. ergias	3·8		
		Other parasites	0·6		
				15·3	55·7
V and VI	133	Unknown	13·5		
		Other parasites	7·5		
				21·0	65·0
Pupae	105	Unknown		3·8	66·3
Teneral adults	101	Unknown		4·9	68·0
Adults emerging	96				

Female *S. intricatus* lay eggs individually in niches along the sides of the maternal gallery in which, after ovipositing is complete, they die. There are very few occasions when maternal galleries do not contain the dead female, so it can be assumed that only one egg batch/female is laid and, by counting the egg niches, each female's fecundity can be estimated directly. Analyses of samples from both field and laboratory-reared populations have indicated that little of the variation in the fecundity of *S. intricatus* can be explained by variation in the size of the female, and that maximum potential fecundity is rarely reached in the field. For example, the mean number of eggs/female laid in the 1978 generation in Monks Wood was 19, while females of similar size laid up to 60 eggs in the laboratory. The condition of the breeding log, particularly its nutritive quality, may contribute to this variation. Although it has been found that it is not obligatory for egg development for females to feed on live twigs, the effect of such feeding on fecundity may also be important. Because identification of the factors causing such variation in fecundity is of obvious importance to the understanding of the dynamics of the populations, both sources of variation are currently being studied.

The survival of the immature stages of *S. intricatus* (32% in 1978–79 Monks Wood population, Table 16) is very high compared with that of most other insects. However, it is probable that considerable losses in the adult population occur between emergence and aggregation on a new host log, either by failure to locate new hosts or by mortality of the dispersing population. Furthermore, the dispersal stage of *S. intricatus* has important implications if the beetle becomes a vector of oak wilt, as its effectiveness in spreading the disease will depend on its dispersal. For these reasons, experiments are being planned to investigate aspects of dispersal behaviour, particularly that occurring in response to the availablity of suitable dead wood for breeding.

M. G. Yates

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MANAGEMENT OF SCRUB AT CASTOR HANGLANDS NATIONAL NATURE RESERVE

The seral communities of secondary scrub are ephemeral because succession to woodland is a natural change. Active management is needed if these scrub communities are to be conserved on nature reserves or elsewhere (Ward 1979). One method which has been suggested is the rotational management of different plots, where each plot is allowed to progress to the late scrub stage, and then cleared to allow the seral stages to begin again. Several plots may be cut at intervals to demonstrate the different stages of development at the same time (Cover photograph).

A full-scale field trial of rotational management is now in progress at Castor Hanglands NNR. The practical management is the responsibility of the Nature Conservancy Council, and observations on the trial are being made by ITE. At Castor Hanglands, the mature scrub is now changing into secondary woodland, and clearance is needed to allow the scrub to develop again. When the scheme is fully operational, it is planned to have 15 plots, each of just over 0·25 ha. Eight plots have already been cut, the first in 1973.

The scrub on the reserve apparently invaded the grassland some 35 years ago, as judged from ring counts of the woody plants now present. It was thought, therefore, that the new scrub after clearance should be allowed to originate from a form of grassland, and not be dominated too quickly by regrowth from cut stumps. Management for production of grassland and for reduction of regrowth has been applied by cutting in July and September for 4 years after clearance. The succession has then been allowed to proceed unmanaged. This was done for the first 5 plots; but the cutting regime was subsequently altered to cutting once in late September. Regrowth was still reduced, but the loss of seed caused by cutting early successional plants in midsummer was avoided. It was important to prevent depletion of seed in the soil, as buried seed of some of the early pioneers is thought to persist until the next clearance.

The success of this scheme for scrub management must be judged on whether the species in the mature scrub habitat on the reserve reappear and eventually reproduce in the new successional communities. So far, the scheme has been successful. The number of flowering plants recorded in the first 7 years of the trial is 248, which compares favourably with the total of some 440 spp for the reserve as a whole. Fifty-five new species, mostly annuals and casuals, have been added to the reserve list as a result of this management. In each plot of 50 × 50 m, the mean total number of species was 99, range 80–124 (Table 17), but the number of species has tended to rise to its highest level

Table 17. The numbers of species of flowering plants recorded in the plots at Castor Hanglands (plot size 50 × 50 m; plot 1 omitted because of sampling differences)

Year	Plot Number					
	2	3	4	5	6	7
1975	82					
1976	93	85				
1977	105	109	88			
1978	80	88	124	102		
1979	92	109	101	111	102	
1980	80	106	98	96	115	114

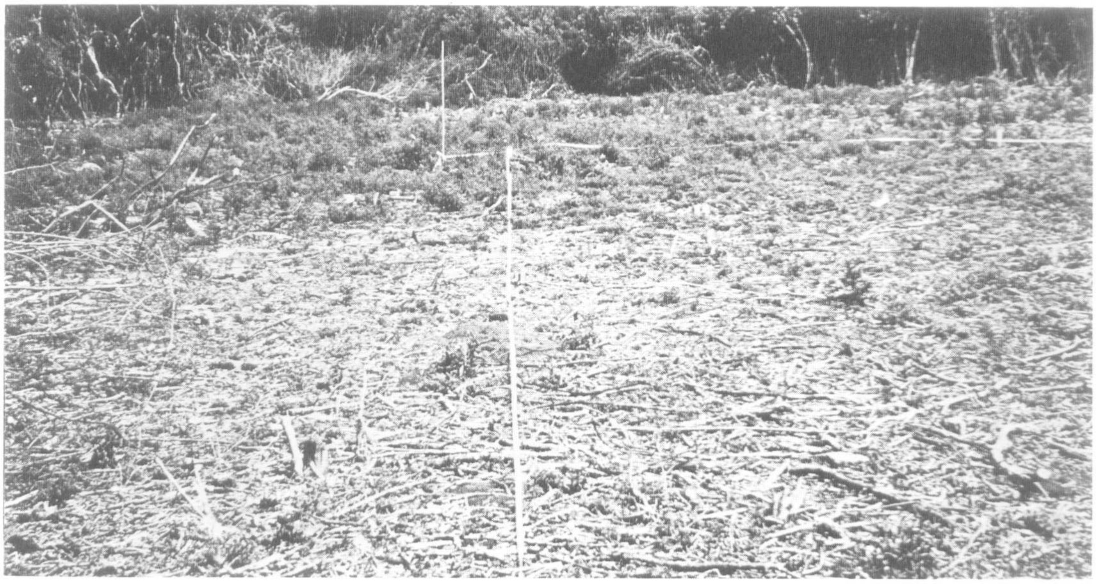

Plate 13—One year after clearance July 1976. Bareground debris from the scrub clearance and scattered plants of Prunus spinosa *and* Cirsium *spp.*

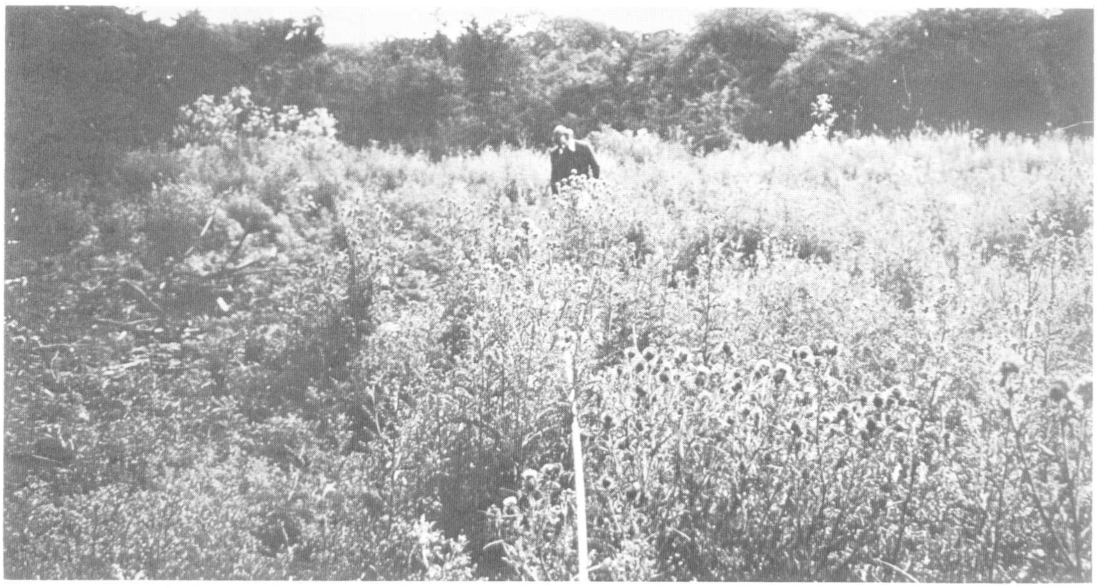

Plate 14—Two years after clearance July 1977. Tall herb vegetation with Cirsium *spp. dominant.*

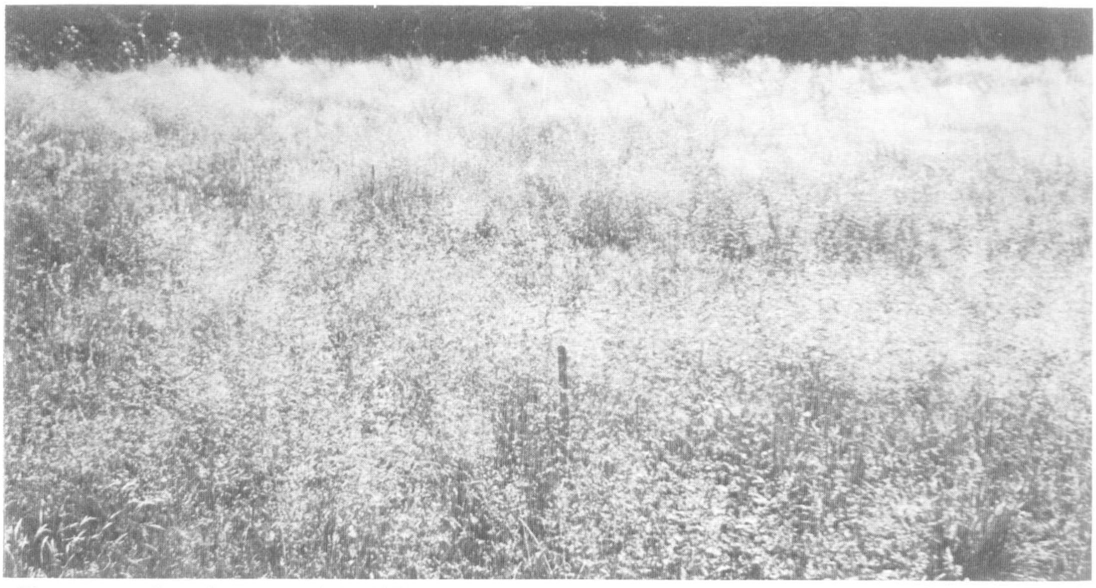

Plate 15—Five years after clearance July 1980. Tall grasses dominant (note 1 m rule on transect line); Deschampsia cespitosa *and* Holcus lanatus *are the commonest species.*

Common caption: Plot 3, transect B, Castor Hanglands National Nature Reserve.
Photograph L. K. Ward.

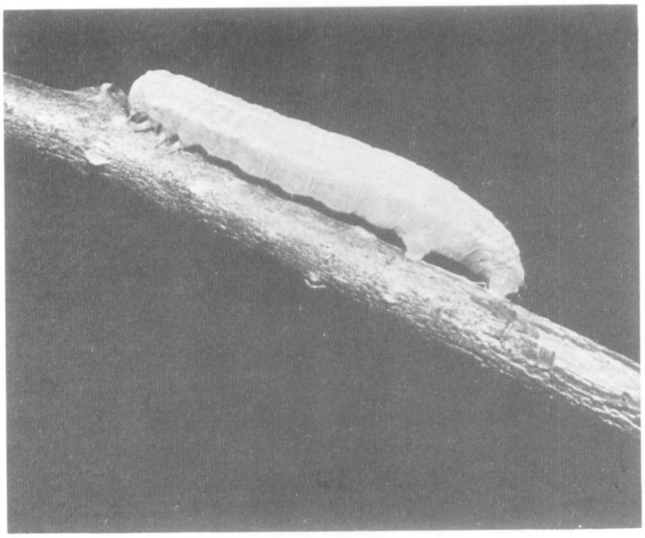

Plate 16—Operophtera brumata *L.*

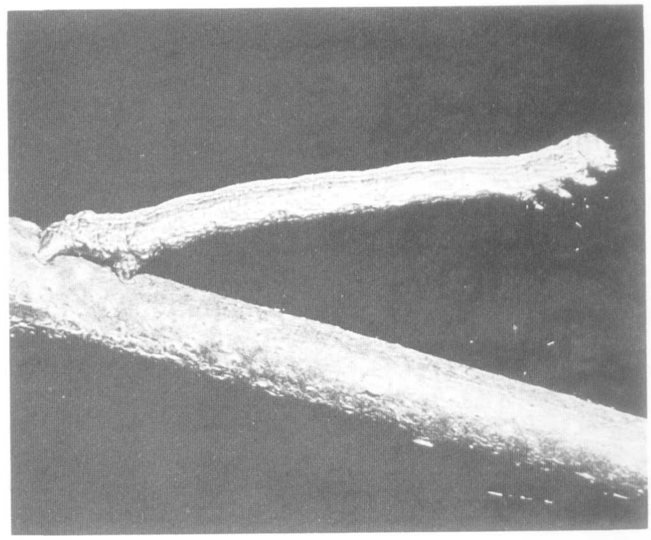

Plate 17—Agriopus *spp.*

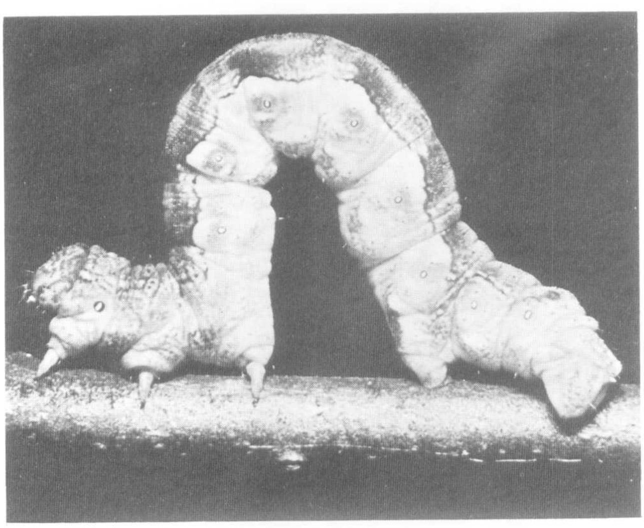

Plate 18—Erannis defoliaria *(Clerek).*

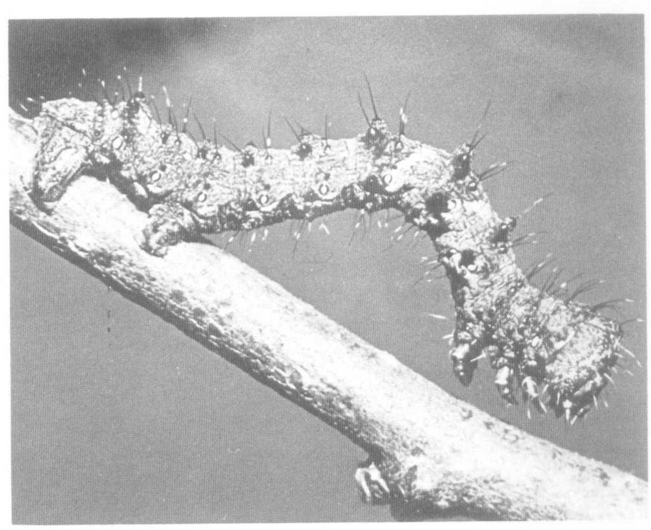

Plate 19—Apocheima pilosaria *(Denis & Schiff).*

Common caption: Lepidopterous larvae feeding on Nothofagus.
Photographs R. C. Welch.

in the second year after clearance. Nearly all of the 19 woody plants originally present have appeared again as seedlings, or have persisted as regrowths in the plots. *Crataegus monogyna, Fraxinus excelsior, Rhamnus catharticus, Rosa* spp, *Rubus* spp, and *Sambucus nigra* are well represented as seedlings, whereas *Prunus spinosa* and *Acer campestre* have mostly persisted as regrowth. *Ulex europaeus* germinated in high numbers from buried seed on some plots, although it is not now represented in the mature scrub. *Euonymus europaeus* has produced only a very few seedlings, while *Ligustrum vulgare,* which is uncommon in the mature scrub, has not been recorded as either a seedling or a regrowth.

The plots have little vegetation after clearance, but they quickly become covered (Plates 13 and 14). There has been marked variation, however, in the dominant species present after clearance. Those that have been particularly well represented in the first 2 years are *Cirsium arvense, C. vulgare, Glechoma hederacea, Ranunculus repens, Rumex sanguineus* and *Senecio viscosus.* On some plots,. *Poa trivialis, Prunus spinosa* and *Mercurialis perennis* survived in some numbers. Later, *Holcus lanatus, Agrostis stolonifera* and especially *Deschampsia cespitosa* became dominant (Plate 15). *Calamagrostis epigejos* has increased on the oldest plots and is expected to become dominant, or co-dominant, in the wetter patches. The woody plants, which will be later dominants, re present, but are inconspicuous beneath the tall grasses. A few woody species, including *Fraxinus, Quercus* and *Crataegus,* have continued to invade as seedlings after the first 2 or 3 years. *Crataegus* is less frequent in the new plots than in the mature scrub.

The total number of woody plants invading or showing regrowth on the different plots has been extremely variable. In the first year following clearance, the numbers in sample transects ranged from 4032 to 248/50 m^2 (Figure 21). This variability is thought to be due to variations in weather between years. After the invasion of woody plants as seedlings, or as regrowths, in the first year, the numbers have tended to fall continuously, but they have not yet reached the density of 150 rooting stems/50 m^2 which was recorded for the original uncut scrub.

The length of time for which the scrub should be allowed to progress towards woodland is uncertain. Originally, it was thought that patchy scrub with grassland species still present at the time of cutting was desirable. However, the present clearance of closed canopy scrub with little in the field layer has shown how rapidly many individuals and species appear from buried seeds, or other sources. This exploitation of the bared ground by early pioneers is now considered to be an important feature of management, as it provides a habitat for these species which is not normally present on the reserve. The time necessary for the developing scrub at Castor to reach the stage where the canopy closes, and the field layer is nearly eliminated, is about 25–30 years. It has, therefore, been suggested that 28 years should elapse before the plots are cleared again.

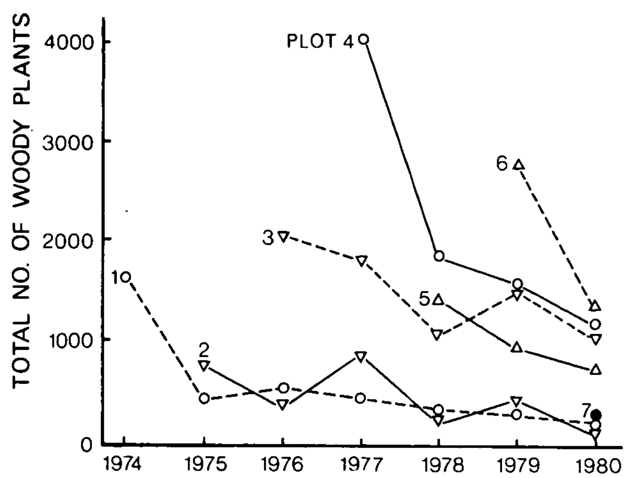

Figure 21 The total numbers of woody plants invading the 7 cleared plots at Castor Hanglands NNR (counted in July on 4 random transects of ½ × 25 m; figures for Plot 1 less reliable because of sampling differences).

Lena K. Ward

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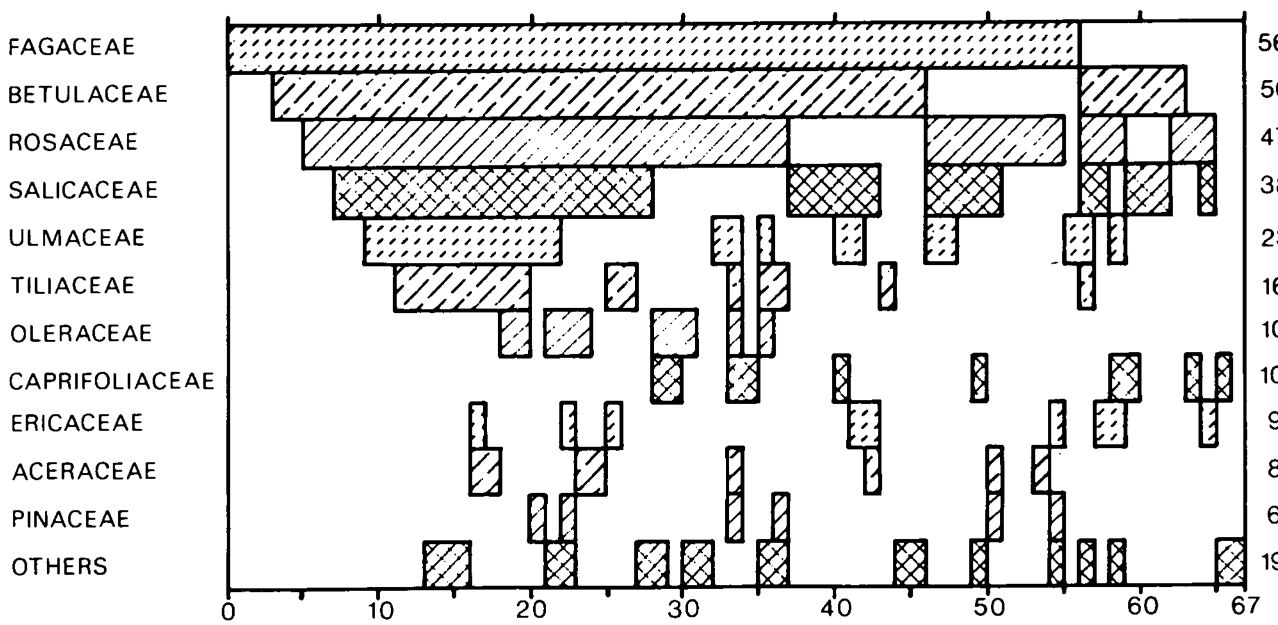
THE INSECT FAUNA OF *NOTHOFAGUS*

The family Fagaceae is represented in Britain by 3 native species, 2 oaks (*Quercus robur* and *Q. petraea* and the common beech (*Fagus sylvatica*). The sweet or Spanish chestnut (*Castanea sativa*), although widely distributed and particularly common in south-east England, was introduced during Roman times (Mitchell 1980). Southern beech (*Nothofagus*) has a natural distribution restricted to the southern hemisphere where 40 species are known from South America and Australasia (Stewart 1979). Two deciduous tree species of *Nothofagus* from Chile show great potential as fast-growing hardwoods in Britain. *N. obliqua* was first introduced in 1849, but the oldest surviving trees date from 1902 (Tuley 1980), whilst *N. procera* was introduced in 1913. The earliest Forestry Commission plantings of both species were at Bedgebury, Kent, in 1930, but during 1955-6 106 trial plots totalling 24·8 ha were established in 76 forests throughout Britain. Not until 1976 was a further large quantity of seed of *N. procera* imported from Chile, and this importation coincided with substantial collections of *N. obliqua* seed in Britain. These were distributed to forest nurseries and extensive planting was expected. At that time, the ability of native species of insect to colonise these introductions was unknown.

In 1978, *N. procera* and *N. obliqua* planted in Thetford and Alton Forests between 1953 and 1959 were sampled for insects, particular attention being paid to phytophagous species. As *Nothofagus* is in the same subfamily as *Fagus*, it might be expected that insects known to feed on that species would most readily accept *Nothofagus* as an alternative host plant. However, *Fagus* has a relatively poor insect fauna, whereas *Quercus* (*robur* and *petraea*) has a far larger number of associated insects than any other British tree (Southwood 1961). Of the 26 species of larval Lepidoptera recorded on *Nothofagus* in 1978, 24 are known to feed on *Quercus*, 9 on *Fagus* and one on *Castanea* (Welch in press). Some of these larvae have been recorded from up to 12 alternative hosts without any indication as to which are the preferred, or most common, food plants. In Britain, the family Betulaceae completes the order Fagales, with 3 species of *Betula*, and one each of *Corylus*, *Carpinus* and *Alnus*. In this study, 24 species of lepidopterous larvae had at least one member of the Betulaceae as an alternative host, with 21 species recorded feeding on *Betula*. The Rosaceae were the next most common alternative hosts, especially *Crataegus* (18 spp) and *Prunus* (17). *Salix* spp (Salicaceae) were also hosts for 17 of the larvae which fed on *Nothofagus*.

During 1979, *N. procera* and *N. obliqua* were sampled more extensively at 5 sites in the Forest of Dean, at Westonbirt Arboretum and Leyhill Open Prison (Tortworth Court), Gloucestershire, and in the Chilterns Forest, Buckinghamshire. Between May and September, 67 species of larval Lepidoptera were collected and reared in the laboratory to prove that they could complete their development on *Nothofagus*, and these observations were supported by the presence of mature larvae in the later field samples. These 67 species of larvae have been recorded from at least 65 species of tree or woody plant (many hosts are recorded to genus only), belonging to 27 families. Figure 22 shows the 11 most common alternative host families upon which these species of Lepidoptera are known to feed. Thus, of the 56 species known to feed on members of the Fagaceae, 3 species are restricted to trees of this family; 2 species feed only on plants in the Fagaceae or Betulaceae; a further 2 species have members of both these families, plus Rosaceae as alternative food plants; and so on across the figure to one species previously recorded from members of the Caprifoliaceae and one or more other families, and one species whose known hosts are all herbaceous plants. Figure 23 shows similar details for the 3 families providing the most commonly recorded alternative host



horizontal blocks = total no. of Lepidoptera spp. feeding on plants of a given family
vertical columns = no. of major plant families fed upon by each species

other families =		
	Aquifoliaceae	Lauraceae
	Araliaceae	Leguminosae
	Berbaridaceae	Loranthaceae
	Buxaceae	Myricaceae
	Coruaceae	Platanaceae
	Cupressaceae	Saxifragaceae
	Eleagnaceae	Taxaceae
	Hippocastanaceae	Vitaceae

Figure 22 Families of alternative host plants of 67 species of larval Lepidoptera known to feed on Nothofagus procera *and* N. obliqua.

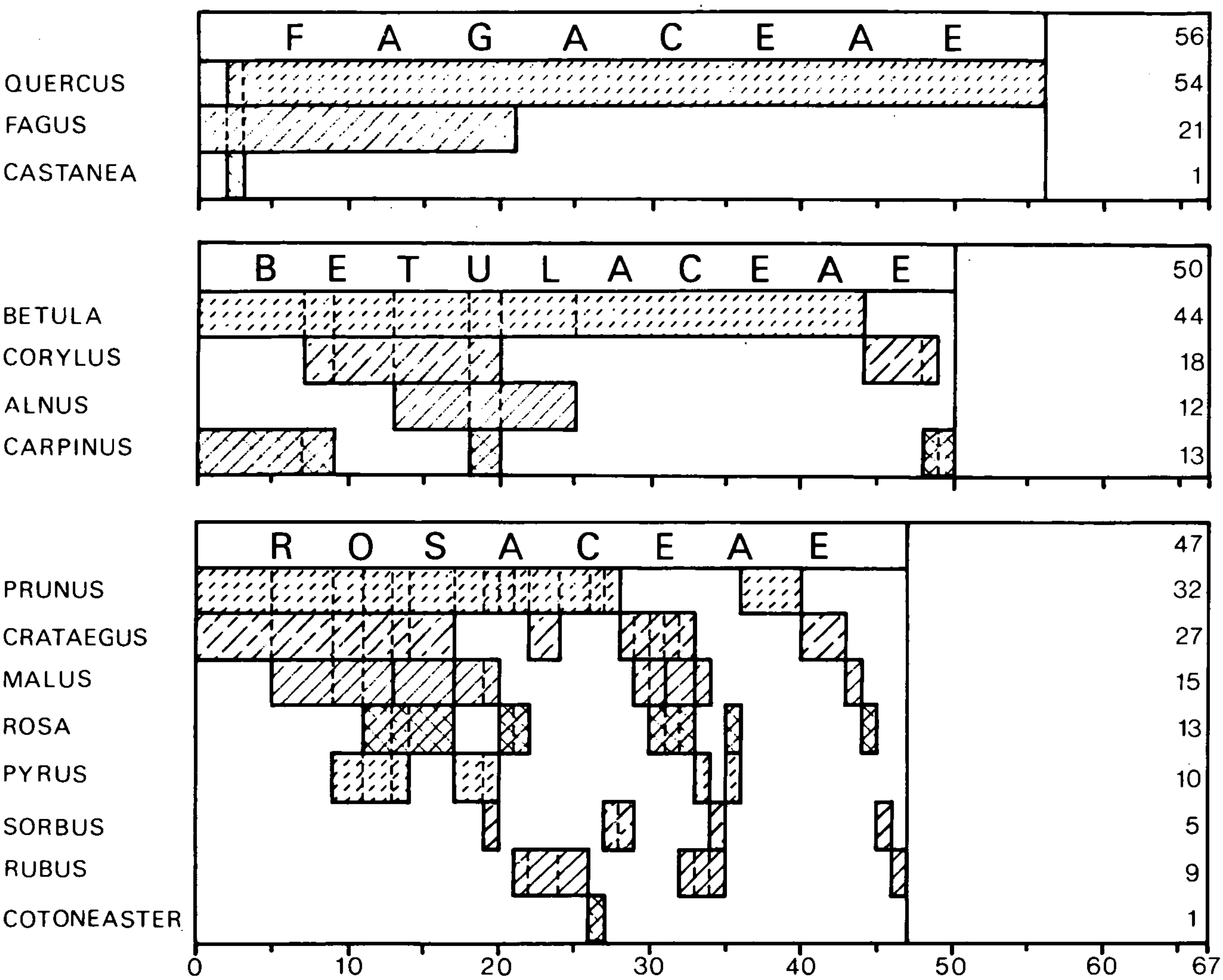


Figure 23 Frequency of alternative host plants of 67 species of Nothofagus*-feeding larval Lepidoptera in the 3 major families.*

plants. Of those known to feed on members of the Fagaceae, all but 2 have *Quercus robur* or *Q. petraea* as a host plant, 2 of the 21 species feeding on *Fagus sylvatica* feed on no other member of this family, whilst the single species with *Castanea sativa* as a host plant is also known to feed on *Fagus* and *Quercus* species. Although it will be seen that 35 species utilise *Quercus* only within this family, reference to Figure 22 shows 3 species feeding exclusively on Fagaceae. Thus, most of these have known alternative hosts in one or more other families. However, as was shown with the 1978 samples, 96% (63 spp) of the larvae found feeding on *Nothofagus* have at least one alternative host plant in the order Fagales.

In 1980, sampling was restricted to sites in the Forest of Dean. *N. procera* was sampled in 2 compartments at Flaxley and *N. obliqua* at Speech House Arboretum. In addition, comparative samples of insects were taken at these and other localities from *Quercus robur, Q. petraea, Fagus sylvatica* and *Castanea sativa.* Defoliating larval Lepidoptera were locally abundant during 1980, and the most numerous species collected were *Operophtera brumata* (Plate 16), *Agriopus* spp (Plate 17), *Erannis defoliaria* (Plate 18) and *Apocheima pilosaria* (Plate 19). It is evident that the most lepidopterous larvae found feeding on *Nothofagus* in Britain have *Quercus* as a natural food plant.

The occurrence of larvae of Lepidoptera on introduced trees appears to have been previously under-estimated. Southwood (1961) lists 5 species of micro-lepidoptera associated with *Castanea*, whilst K. Noble (pers. comm.) adds 2 macro-lepidoptera. The current year's samples have added an additional 23 species of larvae. Some of these may have fallen from neighbouring oaks but, even allowing for those, it is obvious that *Castanea* has been under-recorded in the past.

In addition to the larval Lepidoptera, other groups of phytophagous insects are being studied, but identification of all samples is not yet complete. Of the 11 species of leafhoppers (Homoptera, Typhlocybinae) so far identified, one is associated with *Fagus* and *Carpinus*, one is polyphagous, and one is more common on *Fagus* than *Quercus*, but the remaining species are all known to have *Quercus* as their only, or preferred, food plant. Claridge and Wilson (1979) regarded one of these, *Eurhadina kirschbaumi*, as showing "a very clear preference for *Q. petraea* and may be effectively specific to it". It is, therfore, of considerable interest that this should be one of the species to colonise *Nothofagus*. Phytophagous leaf-feeding weevils (Coleoptera, Curculionidae) occur commonly in foliage samples and, to date, 8 species have been recognised. Examination of cut logs and dead standing trees has revealed an extensive sub-cortical fauna. Species having wood-boring larvae include 3 Cerambycidae, 3 Scolytidae and one Anobiidae.

From this work, it has become apparent that *N. procera* and *N. obliqua* have acquired an extensive and varied insect fauna during the relatively short period that they have grown in Britain.

R. C. Welch

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RECOVERY OF POPULATIONS OF GRASSLAND INVERTEBRATES FROM ANNUAL MOWING

Management of grasslands is necessary for their survival, and has a wide range of effects on populations of invertebrate animals. The effects of grazing, both continuous and seasonal, cutting, burning and the application of fertilisers have been studied, but the changes in invertebrate populations which occur following cessation of these methods of management have not previously been examined in detail. From 1973 to 1975, the effects of cutting on invertebrates, particularly Hemiptera, were studied in a field experiment at Castor Hanglands NNR (Morris 1976; Morris & Lakhani 1979). Four treatments, cutting in May (M), in July (J), both May and July (B), and no cutting (control, C) were applied in a randomised block design on an *Arrhenatherum*-dominated grassland growing on Oolitic limestone. The fauna was sampled at fortnightly to monthly intervals with a vacuum insect net. Sampling at this intensity was not possible after 1975, but, in 1976, 1977 and 1978, 3 samples were taken fortnightly in August, when numbers and species of adult Auchenorhyncha (Hemiptera) are at a maximum. None of the experimental plots was cut or otherwise treated after July 1975. Vegetation structure is an important factor influencing the composition and abundance of the grassland fauna of Auchenorhyncha. By 1978, no significant differences between the height of the vegetation in the different plots at Castor Hanglands could be detected.

Total numbers of adult Auchenorhyncha in the 3 August samples, which fell from 9926 to 5381 from 1973 to 1975, were further reduced in 1976 to 4147, but rose to 7066 in 1977 and 16266 in 1978. The proportion of these totals which was taken from the control (untreated) plots was 41–50% in 1973–1975, but fell from 47% to 29% from 1976 to 1978. Contrasts between all treatments for N (total adult Auchenorhyncha in the 3 August samples), except between J and B, were significant at the 0·05 level in 1976. In 1977, only the contrast between J and C was significant, and in 1978 no significant differences between treatments were recorded.

The numbers of species (S) represented on the J and B plots were smaller than those on the C plots from 1973 to 1975 and continued at a low level in 1976 (Figure 24). The M plots were intermediate between J and B on the one hand and C on the other, but closer to the latter. Contrasts of S between all treatments except J–B were significant at P<0·05 in 1976. In 1977, the numbers of species on the treated plots increased markedly and mean values for S in 1978 were higher, though only slightly and not significantly so, on the treated plots compared with the controls. No significant effects of the 'treatments' were recorded in 1977 or 1978.

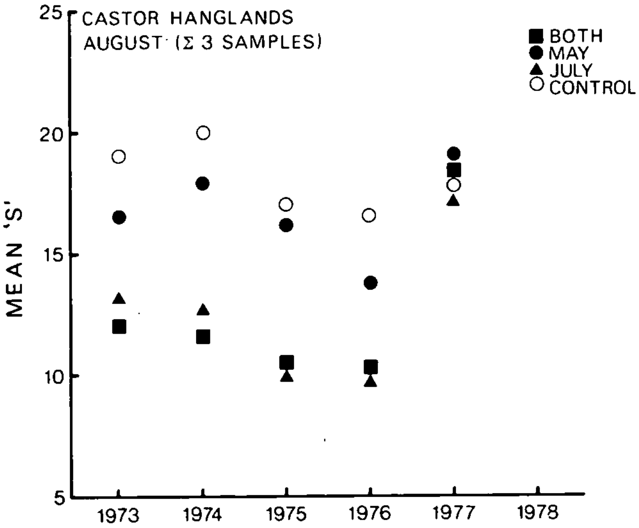

Figure 24 The mean number of species of Auchenorynchа (S) recorded from different treatments in August of each year (1973-78).

During the period of annual cutting, values of the Brilloin index of species diversity (D) tended to be significantly lower on the J and B plots compared with the control ones (C) (Morris & Lakhani 1979). No significant contrasts in D occurred between treatments in 1976 or 1977 for the August samples taken together, but in 1978 the values of D were significantly (P<0·05) higher on the J and B plots than on the controls (C). As values of S were only slightly lower on the C plots compared with the others, this difference is because of the greater equitability of species on the J and B plots at that time.

Significant effects (P<0·05) of the treatments in reducing numbers of adults were recorded on the pooled data for August on 11 species of Auchenorhyncha in 1976. In 1977, the number of species had fallen slightly to 8, but no species was significantly less numerous on any of the treated plots in 1978. In 1976, one species, *Psammotettix confinis*, was significantly more abundant on the treated plots than on the controls, and, in 1977, the same was true for *P. confinis* and *P. cepalotes* taken together, though not separately. In 1978, no significant effects were recorded on *Psammotettix* species.

The results show a slow recovery of the Auchenorhyncha fauna of cut grassland, but the lack of any apparent recovery of species abundance in 1976 may have been affected by the abnormally hot and dry weather in that year. The recovery of species richness (S) in 1977 contrasts with the fact that 8 species were still significantly less abundant on the treated plots in the same year, as does the maintenance of high values of S in 1978 with significantly increased values of D on the J and B plots over the controls (C). The results suggest that management, as a method of rejuvenation or renewal, is advantageous even for the fauna of tall grassland, always provided that periods of at least 3 years are allowed for recovery from the deleterious effects of mowing. The invertebrate fauna of grassland, therefore, contrasts markedly with the vegetation in its much slower response to cessation of management and its need for relatively long periods of freedom from disturbance. The considerations are important in the formulation of management for nature reserves.

M. G. Morris

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Vertebrate Ecology

DIET OF INDIVIDUAL OYSTERCATCHERS ON THE EXE ESTUARY

While the main aim of a project on oystercatchers (*Haematopus ostralegus*) wintering on the Exe Estuary is to study their role in the population dynamics of the mussel (ITE Annual Report 1978), we have uncovered an interesting aspect of the birds' feeding ecology which involves a number of other prey species. Individual oystercatchers have a limited diet compared with the full range of prey species, numbering 7 molluscs, 2 worms and 1 crustacean, eaten by the population as a whole. This limited diet is partly because individuals feed in the same habitat, and even the same precise locality, for long periods. For example, many birds are found only on the mud-flats within the estuary, so their diet at low water consists almost entirely of the ragworm (*Nereis*) and clam (*Scrobicularia*), the predominant macro-invertebrates occurring in these areas. Surprisingly, however, individuals feeding in one habitat may consistently select different kinds of food. This selection is most obvious on the mussel beds, where birds feeding side-by-side throughout the winter may eat quite different things. Most eat only mussels, but some concentrate throughout the winter on cockles, or periwinkles, or a mixture of *Nereis* and *Scrobicularia*.

Birds with dissimilar diets at low water may also behave differently at high water. Although some birds that eat mussels or periwinkles at low water do feed in the fields at high tide, the majority do not. Only one third of mussel-eaters have ever been seen in the fields at high water, and then infrequently. Similarly, none of the few birds which eat cockles has been seen in the fields. In contrast, all the birds eating *Nereis* and *Scrobicularia* have been seen in the fields, and are seen there more frequently than birds specialising on other prey. These birds are usually to be found at the main roosts.

Differences in the diets of individuals can, in part, be related to differences in their ages. Age counts at low water show that most birds feeding on the mussel beds are adults and that juveniles are more common in other places. It seems that most adults eat mussels and the younger birds more often specialise on other kinds of prey. However, it is also clear that not all adults eat mussels and that some juveniles do. While there is a general trend for diet to change with age, considerable individual differences do occur within each age class.

The change in diet with age may arise because individuals turn to mussels as they mature, or because young birds leave the estuary after one or 2 years and are replaced by other birds with different diets. The former hypothesis seems more likely because many individuals have been seen to change their diet during the first 2 years or so of life. We do not yet know why more birds eat mussels as they mature. Perhaps it takes much experience of eating bivalves to deal with mussels successfully, or it may be because adults steal so many mussels from the juveniles that young birds give up and try other foods.

J. D. Goss-Custard, Sarah E. A. Le V. dit Durell, S. McGrorty and C. J. Reading

BADGER POPULATIONS AND THEIR FOOD

The relationship between the population density and distribution of badgers, on the one hand, and the biomass and dispersion of their main foods, on the other, has been studied since 1975. We are also trying to understand the role of social behaviour in this relationship. Badgers provide an interesting opportunity to study the relative importance of various features of the environment on mammalian social organisation. The information we are collecting should also be relevant to the management of badgers, which is important in areas where badgers may transmit bovine tuberculosis to cattle.

Badger diet was studied in 6 areas in Scotland with apparently very different habitats. More than 2000 samples of faeces were analysed, and the results were similar in all the different places. Earthworms (*Lumbricus* spp) were by far the most important food, being eaten frequently and in large quantities (Figure 25). Badgers also ate insects, cereals, roots (*Conopodium* tubers), rabbits, and various other foods, but none of these was nearly as important as earthworms, either because these other foods were eaten infrequently, or in small quantities, or both. For several of the food items we could measure variations in availability in time and between study areas, and there were good correlations between the occurrence of the various foods in the badger diet and their availability. The one striking exception was earthworms, which appeared in faeces at a frequency independent of their availability. A likely explanation for this is that badgers change their foraging strategy to counteract fluctuations in earthworm availability; details of this hypothesis are being investigated. Badgers appear to specialise on earthworms, but to eat other foods in proportion to their availability.

In the second stage of this project, the effect of earthworms on badger populations was studied. Earthworm biomass was estimated using formalin sampling; *Lumbricus* (mostly *L. terrestris*) was patchily distributed in all study areas, and was most readily available to badgers on short grassland and in broad-leaved woods. Badgers live in groups ('clans'), each occupying an exclusive range. The size of these ranges was measured using radio-location and a bait-marking technique. In this last method, colour markers were fed to badgers from different setts, and the markers were recovered from latrines situated on the boundaries of the clan ranges. Simultaneously, the number of badgers in each clan was estimated by injecting a few animals with an isotope which they excreted in their faeces. The proportion of labelled faeces in a range was used to indicate the number of badgers present.

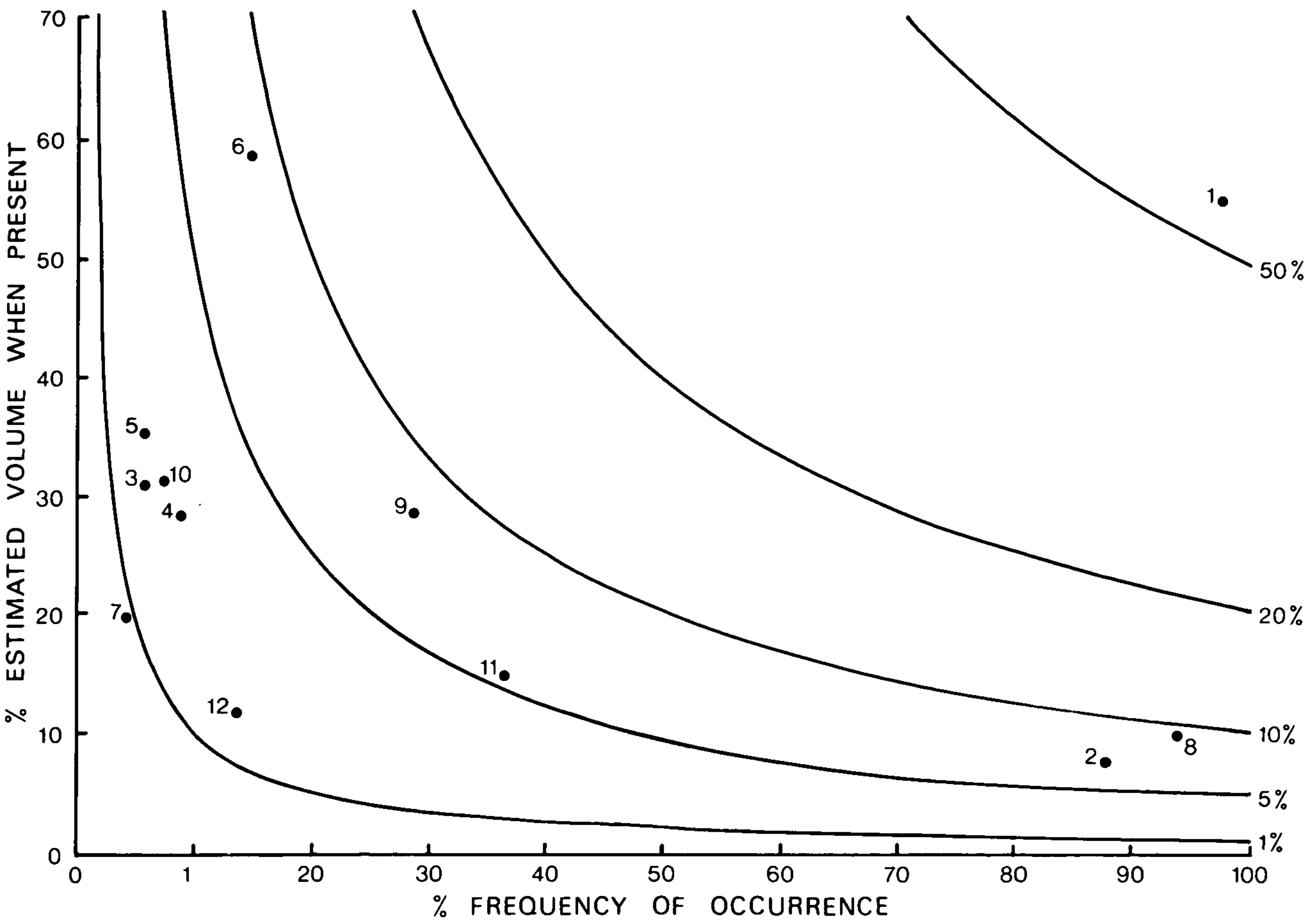

Figure 25 The food of Scottish badgers: frequency of occurrence of food categories in badger faeces (n = 2,059), with the estimated volume of each in the diet of the badger for only those occasions when they were eaten. The product of these 2 parameters is the volume of each food in the overall diet of the badger (curved lines).
*1 = earthworms, 2 = insects, 3 = amphibians, 4 = birds, 5 = small mammals, 6 = rabbits, 7 = carrion, 8 = leaves, 9 = cereals, 10 = fruits, 11 = roots (*Conopodium*), 12 = fungi.*

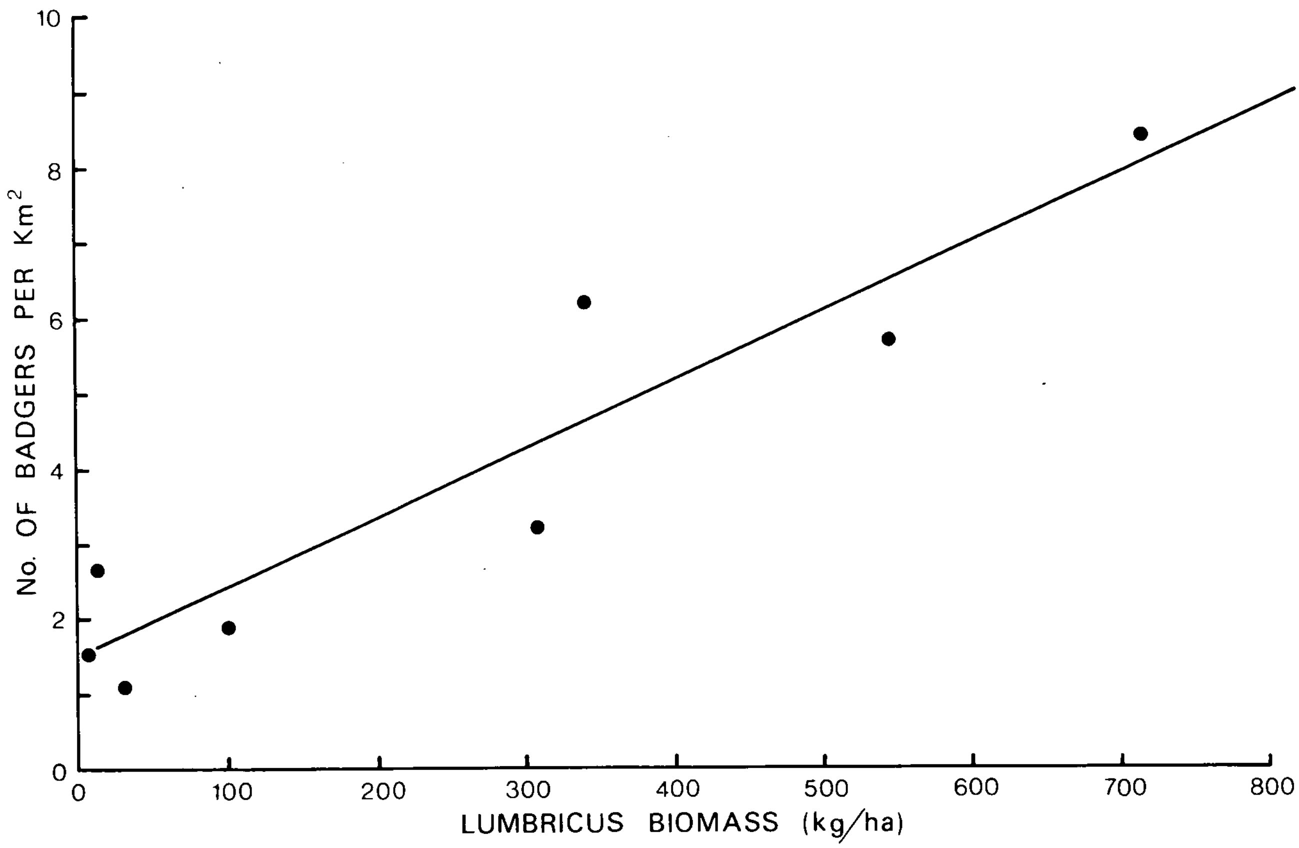

*Figure 26 The relation between badger density and the biomass of earthworms (*Lumbricus *spp)* $Y = 0{\cdot}09X + 1{\cdot}5$; $r = 0{\cdot}93$.

The number of badgers per clan is not related to the size of the clan range, but to the earthworm biomass in the range. The size of the range is correlated with the distance between high worm concentrations or "patches", but not with worm biomass. The overall effect of this relationship is that there is a close correlation between the density of badgers and the biomass of earthworms in the area (Figure 26). The mechanism whereby badger group size can be adjusted to available food in the range is being investigated at present.

H. Kruuk and T. Parish

EFFECT OF LARGE CARNIVORES ON LIVESTOCK IN NORTHERN KENYA

(This work was commissioned by UNESCO as part of the integrated project on Arid Lands in their Man and the Biosphere Programme)

Nomadic tribes in the semi-deserts of northern Kenya lose sheep, goats, cattle and camels to predators, such as spotted hyaenas, lions and others. To protect themselves and their livestock, the people build enclosures ('bomas') of various thorny shrubs and trees. This boma building contributes to the serious desertification of the area by the gradual removal of trees and shrub. The project attempted to estimate the amount of predation on livestock and the effectiveness of the protection afforded by the boma. It was done by interviewing herdsmen of 4 different tribes in one study area of 20 000 km^2, and by independently estimating the numbers of predators and their consumption of livestock. Annual rates of predation vary between 2–10% of the numbers of livestock. Lions take mostly cattle, spotted hyaenas mostly sheep and goats, and the other predators only sheep and goats. Most livestock are killed in day-time when grazing (72% of kills)—only spotted hyaenas kill more often at night, and 90% of all kills are made outside the protection of a boma. There are clear differences between tribes in extent of losses sustained through predation inside the boma; these differences are associated with variation in boma structure (Plates 20 and 21). Other differences in losses of livestock are probably caused by the presence or absence of dogs.

Recommendations were made to UNESCO for experiments with alternative materials for boma construction and for the use of pesticides to prolong the useful life of bomas by combating ticks, and for research on the use of dogs.

H. Kruuk

EXPERIMENTAL DRIVE-COUNTS OF DEER IN A WOODLAND ENCLOSURE

This report considers the results and experience gained from experimental drive-counts of red deer (*Cervus elaphus*) and roe deer (*Capreolus capreolus*) in a woodland enclosure (Enclosure No. 9) on the Beinn Eighe National Nature Reserve, Wester Ross. The aim was to determine how accurately the numbers of deer could be counted in an area of thick cover using groups of people as 'beaters'. This experiment was part of a continuing project concerned with methods of assessing red deer populations in woodland habitats (ITE Annual Report 1979). The idea was to introduce a known number of red deer into Enclosure No. 9, after removing any roe deer present. Being relatively small (20 ha) and with thick cover, this enclosure seemed especially suitable for preliminary work on drive-counting.

Enclosure No. 9 lies on the lower slopes of the reserve, on rough ground with an average slope of about 20° (maximum over 30°). The ground vegetation is mostly *Calluna* and *Molinia* up to 0·9 m high, with taller *Myrica gale* bushes in the moist hollows, and extensive patches of bracken (*Pteridium aquilinum*). The area was fenced in the middle 1960s and largely planted with Scots pine (*Pinus sylvestris*), together with patches of rowan (*Sorbus aucuparia*), alder (*Alnus glutinosa*) and willow (*Salix spp*). It now has only about 30% of open ground, the rest being thick cover, ie offering good concealment for deer. The deer fence (2 m high) is in very good condition and shows no signs of penetration by deer.

No red deer were present until some were introduced for the purposes of this study, but, in spring 1979, there were 3 recognizable roe bucks (with antlers) and 3 different doe-like individuals. No doubt, some roe deer had been present since the time of planting. The 3 bucks were shot in late April 1979, but it was not practicable to shoot the others. One of these turned out to be a young buck which developed its first antlers in spring 1980. From May 1979 to September 1980, therefore, 3 roe deer were present. These deer were unmarked, and determining their numbers depended on the maximum which could be accounted for in a large number of sightings. In early May 1979, 6 individually marked red deer (3 young stags and 3 hinds) were put into the enclosure, and they showed no adverse effects in adapting to their new environment. A calf born in mid June 1979 brought the total number up to 7 red deer. One hind died in early April 1980, but another calf born in June 1980 brought the total to 7 again.

Casual sightings, in the course of other work in the enclosure, included far more red deer than roe deer. Although there were twice as many red deer as roe deer present, the ratio in casual sightings was about 20 red/1 roe. Whereas casual sightings made over a few consecutive days usually accounted for all red deer present, it was rare to see all the roe; the maximum number of roe was recorded in only 5 out of 60 visits of several hours at a time. This was partly because the roe deer, being much smaller than the red deer, were more easily concealed by the taller ground vegetation as well as by the tree cover. Also, when disturbed, the roe deer tended to run quickly to the nearest patch of cover, whereas the red deer moved away more slowly, often pausing on open ground.

The first drive-counts to assess the roe deer, in March and April 1979, were planned differently from the rest (Table 18). These counts involved teams of beaters inside the enclosure, together with observers at vantage points outside. The deer were driven towards the open ground so that they could be seen and tallied by the observers. This method of drive-counting is applicable only to those woodland areas with sufficient open ground and suitable vantage points, and, perhaps not surprisingly, it gave better results for roe deer than the method used later. The main drive-counts, after the red deer were introduced, used all the available people as beaters, ie without the advantage of extra observers. In these counts, the people walked in line through the enclosure and tallied any deer which they passed. This approach is potentially the most useful, as it is applicable to thick woodlands with little or no open ground and no convenient vantage points.

Table 18. Results of drive counts

Period	People	Spacing (m apart)	Number of counts	Red deer Present	Red deer Counted	Roe deer Present	Roe deer Counted
*March '79	8 +		1	0	0	6	5–6
*April '79	11 +		1	0	0	6	4–6
				6 introduced in May '79		3 shot in late April '79	
July '79	7	44	2	7**	6,3	3	0,0
	6	50	2	7	6,5	3	0,0
Aug. '79	4	70	2	7	4,2	3	0,0
	6	50	2	7	(0,0)	3	(0,0)
Oct. '79	10	32	2	7	6,6	3	2,2–3
April '80	12	27	8	6**	6,(0),5,5 6,(3),5,6	3	0,(2),1,0 1,(0),0,2
July '80	15	22	4	7**	6,6,(3),6	3	2,1,(1),2
	13	25	6	7	0,3,6,7 (0),5	3	1,0,1,1 (0),3
	12	27	2	7	(3,2)	3	(1,3)

Notes:— *Special counts using beaters (8–11 people), and observers outside the enclosure.
**Changes due to births and deaths indicated in text.
( )Counts affected by radio-failure, heavy rain or line breakdown.

After the red deer had been introduced, 30 counts were made using all the available people as beaters. Of this number, 8 counts were recorded as being unsatisfactory, mainly because people lost contact with each other during a drive. Heavy rain sometimes resulted in poor communication, and hence failure in control. As might be expected, the results of the counts which went according to plan were generally better than those which did not, ie 'good' counts detected an average of 74% of the red deer and 30% of the roe deer, and 'bad' counts 21% of the red deer and 29% of the roe. Similarly, those counts with larger numbers of people (closely spaced) tended to detect higher proportions of the deer present than those with fewer people (widely spaced). For example, taking only those 'good' counts with 10 or more people (16 counts), 79% of the red deer were detected compared to 41% of the roe deer. The roe deer were obviously much more difficult to detect and count than the red deer. It is of interest to note that the individual red deer most frequently missed were the calves, perhaps because, like the roe deer, they were appreciably smaller than the adult red deer. The adult red deer were, in fact, counted correctly in 13 out of 16 counts in April and July 1980. There were, however, 2 rather poor results for red deer amongst the 'good' counts in July 1980, with 13 people 25 m apart. These poor results were due to red deer breaking through the line of beaters in areas of exceptionally thick cover; these deer were heard, but not seen. Presumably the roe deer were able to do this more often.

The main conclusion from this study is that drive-counting can be effective for large animals like red deer, even in areas of thick cover, but is apparently less effective for smaller animals like roe deer. It is tempting to believe that more people in this study would have meant a consistently higher rate in detecting the deer, especially the roe. Nonetheless, with good planning and closely spaced people, the chances are that few deer will be missed, though perhaps higher proportions of the smaller species. The success of a drive-count must depend on clear briefing beforehand, and on the maintenance of control throughout. The latter depends on good communication and on the ability of people to keep in touch with their neighbours. Brightly coloured clothing and pre-arranged stopping points were found helpful in these experimental drives. First-hand experience of these practicalities was one useful outcome of this study.

We thank NCC (North West Scotland Region) for research facilities at Beinn Eighe, and the Senior Warden (Edwin Cross) for much help. We are also grateful to the 43 volunteers who helped in different counts.

B. Mitchell and D. McCowan

OTTER DISPERSAL AND BREEDING IN A RIVER SYSTEM IN ABERDEENSHIRE

This project aims to collect further information on 2 ideas resulting from earlier studies of otters (*Lutra lutra*) (Cover photograph). The first was that a main river, the River Dee, is used more by otters than its tributaries, and the second was that breeding is influenced by the severity of the winter weather. In addition, we aim to obtain information on patterns of rearing young throughout the year. In the absence of marked animals, our interpretations are tentative, but the appearance of small footprints which were previously absent is taken to show the arrival of a new otter family with young.

Most work is being done at 2 adjacent undisturbed lochs on Muir of Dinnet NNR, Aberdeenshire, which are close to and drain into the River Dee and have some similarities to a tributary of the main river. In this area, otters are thought to be born far up small tributaries, to stay near their birth place till they are weaned, and then to move to good feeding places near (eg the lochs), or on, the main river, where they stay until they are 7 – 12 months old. Subsequently, they disperse along the main river or into other river systems.

Table 19 gives data on the numbers of otter faeces (spraints) found on unit distances (2 km) of the River Dee and some of its tributaries. The number of spraints found on the River Dee changed between years. In some months, the density of spraints per 2 km stretch was higher than in others (Jenkins & Burrows 1980), but there was no obvious trend. Usually, more spraints were found on the main river than on its tributaries, and, on all 4 tributaries examined, there was a marked tendency for an increase in summer or, especially, in autumn. Perhaps otters then tend to disperse up the tributaries, or to feed there on spawning salmonids.

In 1974–78, rearing success of otters at the Dinnet Lochs and neighbouring River Dee varied between years. In 1975 and 1976, there was a rapid succession of families each year, with 2–3 in January–July (Figure 27), but there was only one family in this period in both 1977 and 1978 (Jenkins 1980). In addition, young born in autumn or early winter 1974 (B) and 1975 (E) and (F) survived through the winter, but others, born in October 1976 (J), August 1977 (M), and September 1978 (Q), disappeared when 3–4 months old. Family (N), in March 1977, was not seen till well grown and stayed for a very short period. About 9 young were reared in the first 20 months up to July 1976, but only about 8 in the next 30 months. The first 2 winters were relatively mild with little ice or snow, but in 1976/77, 1977/78 and 1978/79, the 2 lochs were frozen almost completely for up to 3 months, and long stretches of the river were frozen also. It seems likely that the difference between the 2 sets of years arose because young born in late summer or autumn survived mild winters, but disappeared in hard ones.

Table 19. Numbers of spraints and standard errors of means on 2 km stretches of the River Dee and some of its tributaries (both banks were examined).

	River Dee 1977		River Dee 1978		Gairn 1977		Muick 1977+/78*		Tanar 1977+/78*		Feugh 1980	
	No	SE	No	SE	No	SE	No	SE	No	SE	No	SE
Winter	10·9	3·3	14·3	4·4			2·8	0·5+	2·0	1·4+		
			13·0	2·2								
Spring	9·6	2·2	13·2	2·4	1·6	1·4	4·3	1·0+	3·3	1·0+		
	8·1	1·7	9·1	2·0					0			
Summer	9·5	1·7	6·7	1·4	2·0	1·2	7·5	4·2*	2·5	1·0*	3·1	1·3
											3·7	0·8
Autumn	9·8	2·0	15·5	2·8	8·4	1·2	6·8	4·0+	6·5	4·9*	5·3	1·0
							5·5	2·2	7·5	5·5		

The main method of study used from July 1979 has been to search for otter footprints on mud patches on otter pathways. Measurements of these prints give an indication of the age of the otters, those in the range of 3·0–5·0 cm indicating the presence of one or more young. We also count spraints deposited on the runs. This is done each month except in fresh snow, when spraints are obscured. More spraints were found when footprints showed that young otters were present (Figure 27).

In 1979/80, the lochs were completely frozen for only 1 – 2 weeks in both November and January–February, and again at the end of March. There was little ice at any time on the river. In comparison to the 3 previous years, the winter was mild.

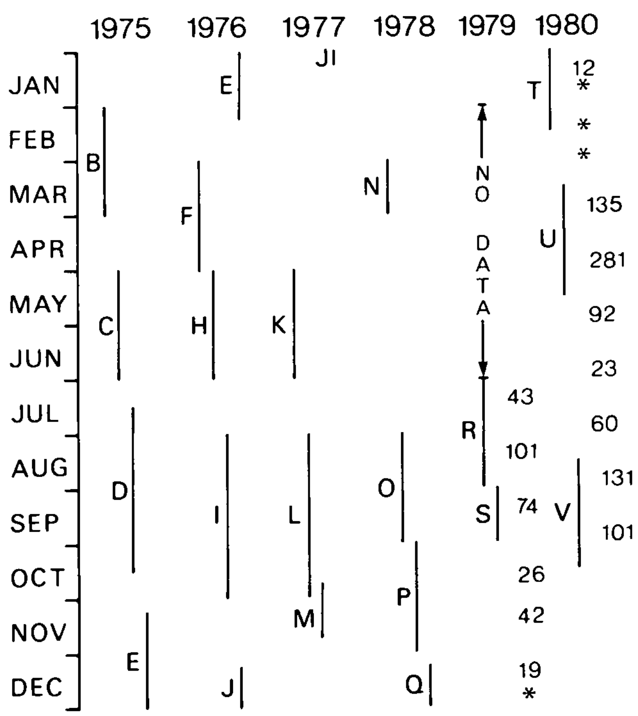

Figure 27 Otter families recorded from fore footprints measuring 4·0 – 5·0 cm, or seen at a corresponding size (B, C, K), at Dinnet lochs, and from July 1979 nos. of spraints recorded on monthly surveys plus months with too much snow (*) to record spraints.

In 1979, one family with 2 big young was present in July and August (R), and an additional new family with young appeared in September (S) (Figure 27). The bigger ones were born about April, and the others about June–July. No young were recorded in October–December, but 2 groups were tracked in snow in January. These were 2 larger animals (possible one of the families recorded earlier (R) or (S)), and also an adult with 2 small young (T). The latter were born about October. The scarcity of spraints in October–December, when there was hard frost but no concealing snow, suggests that otter cubs were not continuously present at the lochs in that period, and they may have gone to the river. In 1980, no young were recorded in February, but 2 families were present in April. One family then had 1–2 small young (U) and the other had 2 big young. Presumably the latter were the smaller ones noted in January (T), which had gone to the River Dee when the lochs were frozen. The small young recorded in April would have been born about January. From this, 2 families probably survived through the 1979/80 winter, one family born about October and the other born about January. Another new family (V) was noted in September.

Figure 27 shows that half-grown young were present through January or February in 1975, 1976 and 1980, but not after the first few days of January 1977, or in January or February 1978, or in January 1979. The new data from 1979/80 support the idea that young otters born in late summer or autumn can survive in mild winters in Deeside, but probably not in cold ones, when the lochs are frozen for long periods. Since families (R) or (S) and (T) disappeared from the lochs when these were frozen, but may have reappeared subsequently, the critical factor for the survival of young otters may be whether the river is frozen concurrently with the lochs. This may partly explain the importance of the river for otters as compared with the tributaries.

D. Jenkins and Rosemary J. Harper

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Acknowledgements
Our studies on otters owe a great deal to help with methodology from colleagues in Aberdeen (Dr M. Gorman, with radio-isotopes) and Exeter Universities (Mr I. Linn, Miss M. Wise, with work on otter foods).

FLUORIDE LEVELS IN FOXES

Work in 1980 was aimed at discovering the levels of fluoride in foxes from various parts of the country. Only by having such information for the whole country is it possible to talk about 'normal' levels and 'raised' levels at particular sites. This work is an extension of a more intensive study of fluoride pathways being carried out around an aluminium smelter at Holyhead, Anglesey. It was convenient to study foxes, as staff of the Ministry of Agriculture, Fisheries and Food and others had already collected quantities of bones during other investigations, and kindly made their material available.

Fluoride is known to accumulate in bone throughout an animal's life, so long as it continues to be ingested, so that a knowledge of the animal's age may be important. Most bones had been aged by counting incremental lines in tooth sections from the same animals, except for some of the material from Holyhead and Aberdeen which was not aged.

Bone was examined from 182 foxes of known age, and from 46 whose ages were not known. These foxes came from the areas shown in Table 20. The part chosen for analysis was the angular apophysis, a protrusion of bone on the rear angle of each lower jaw. This protrusion can be easily removed from one side, leaving most of the skull virtually intact for subsequent study.

Table 20. Numbers, ages and fluoride content of bones of foxes from various parts of Britain

Source of Foxes	No. of foxes			Fluoride in PPM in bone	
	Aged	Unaged	Mean age months	Mean	Adjusted mean
Cardigan	12	0	27·7	494	450
Montgomery	10	0	28·5	612	510
Pembroke	29	0	28·6	549	521
Radnor	14	0	23·9	550	533
Carmarthen	12	0	33·5	575	545
Brecon	26	0	28·1	537	581
Anglesey (excluding Holyhead)	52	–	16·6	476	555
	–	21	–	567	–
Holyhead	0	6	–	1787	–
Aberdeen	0	19	–	283	–
Surrey	27	0	31·5	927	889
Totals	182	46	–	–	–

A first examination of the data showed that fluoride content increased logarithmically with age, so that age must obviously be taken into account when comparing mean fluoride levels between different samples. If samples were sufficiently large, however, they tended to have similar mean ages so that, when mean fluoride levels were adjusted for age, the changes in value were only small (Table 20). If it is assumed that samples for which individual ages were not known had a similar age structure to those whose ages were known, then the mean fluoride levels could be compared directly with the other samples. Obviously more samples of known age are required so that those of unknown age can be discounted.

The results show that there was little difference in the fluoride content of bones from the various parts of Wales, except, as might be expected, for the area immediately around the aluminium smelter at Holyhead. Here, levels were at least 3 times as high as elsewhere. The low figure from Aberdeen was not surprising in view of its predominantly rural setting remote from industry. What was surprising was the high figure from Surrey, which might have been expected to be similar to the mainland Welsh counties. The cause of this high value is not known.

K. C. Walton

Animal Function

CAUSES OF MORTALITY IN SPARROWHAWKS

Between 1963 and 1979, carcasses of 341 sparrowhawks (*Accipiter nisus*) were examined at Monks Wood Experimental Station in an attempt to find the cause of death. The carcasses were sent by members of the public, in response to advertisements placed periodically in national bird journals. All carcasses were requested, irrespective of region and form of death. The main objective was to obtain tissue for analysis of pesticide residues (see Bell & Newton, page 65), but, in addition, an autopsy was performed on each carcass, taking account of any notes from the sender on the circumstances of death. This procedure provided information on the causes of mortality in this species, and their frequency through the year. From most specimens, liver samples were subsequently analysed to determine the concentrations of DDE (from the insecticide DDT), PCBs (from industrial polychlorinated biphenyls), and HEOD (from the insecticides aldrin and dieldrin). This report gives the results of the *post mortem* examinations, but mentions analytical results only briefly, as these have recently been reviewed in detail by Cooke *et al.* (1979). The following points emerged:

1. The numbers of carcasses received each year increased from 1963 into the 1970s (Figure 28). This increase almost certainly resulted from the known rise in sparrowhawk numbers over this

Figure 28 Numbers of sparrowhawk carcasses received for analysis of pesticide residues, 1963-79.

period, and the recolonisation of areas from which birds had been eliminated by pesticide poisoning in previous years. These changes in status followed from successive restrictions in the use of organochlorine pesticides, particularly aldrin and dieldrin. Increased numbers of hawks in the countryside meant that more were likely to be found dead by bird-watchers and others who contributed carcasses. The numbers of other species in the scheme did not increase in this way, but their numbers in the environment were reduced less to begin with.

2. The sex ratio in the sample was 194 hens:137 cocks, a deviation from unity that was statistically significant ($\chi^2 = 4{\cdot}9$, $P<0{\cdot}05$). Hens predominated in most months, both among adult and among first-year birds, even in June when most hens would have been on nests and immune to the commoner kinds of recorded mortality. As expected, however, the age composition of the sample changed greatly during the year, with juveniles predominating in late summer and early autumn, and adults during most of the rest of the year. The most likely explanation of the distorted sex ratio is the known habitat difference between the sexes; hens spend less time in woodland, and more time around farmland and villages, than do cocks, and would thus be more likely to die in places where they could be found by people.

3. Combining the records from different years, particularly large numbers of carcasses were received in the months August – September, and even larger numbers in March – April (Figure 29). The August – September peak was due almost entirely to juveniles, but both juveniles and adults contributed to the spring peak. The autumn peak covered the time when juveniles had just left their natal territories and were learning to fend for themselves, while the spring peak covered the times when the song bird prey of sparrowhawks were scarcest. Thus, the lowest level in most resident prey species occurs in April each year, just before the start of breeding, while most winter visitors have left and most summer migrants have not yet arrived. The spring peak in numbers of hawk carcasses received occurred despite the fact that hawk numbers would have reached their own seasonal low at this time. The carcasses received in spring were not only of starved birds – though the numbers of these did reach a peak in those months – but also included birds which had died from other causes. Perhaps food shortage predisposed the birds to various kinds of death.

4. No less than 48% of the sparrowhawks appeared to have died from accidents of some kind – 34% from collisions with buildings or wires, 7% from collisions with vehicles, and 7% from other kinds of injury. Considering the hunting technique of the species, these accidents were not surprising, but these forms of mortality are likely to be taking a serious toll, as the growth in road traffic, overhead wires, buildings and other human development continues.
In addition, although the sparrowhawk was under full legal protection throughout the period considered here, at least 37 (11%) of birds had been shot. This form of mortality was presumably under-estimated, as most people who knowingly shoot a protected species would take steps to prevent their action coming to light. The remaining deaths were attributed to haemorrhages (14%), disease (4%), starvation (9%) and unknown causes (14%). Haemorrhaged birds usually show widespread internal bleeding, especially around the brain, heart, lungs and foregut, that was not obviously due to injury.

5. In order to investigate the organochlorine concentrations in birds which had died in different ways, we examined the proportion of individuals in each death category whose livers contained more than 10 ppm HEOD, or more than 100 ppm DDE (no bird had more than 100 ppm PCB). These levels are often taken as indicative of death from these compounds. Significant variation in residue levels occurred among the different death categories, with the haemorrhaged and 'cause unknown' groups containing more birds that were heavily contaminated with these compounds than the rest (Table 21). It seems likely that haemorrhages were a frequent symptom of organochlorine poisoning (see also Cooke *et al.* 1979). Further circumstantial evidence for the link between HEOD and haemorrhages is that most cases were from areas of high dieldrin usage, and occurred in late winter and spring when dieldrin-dressed grain was sown; in addition, the numbers declined in frequency after

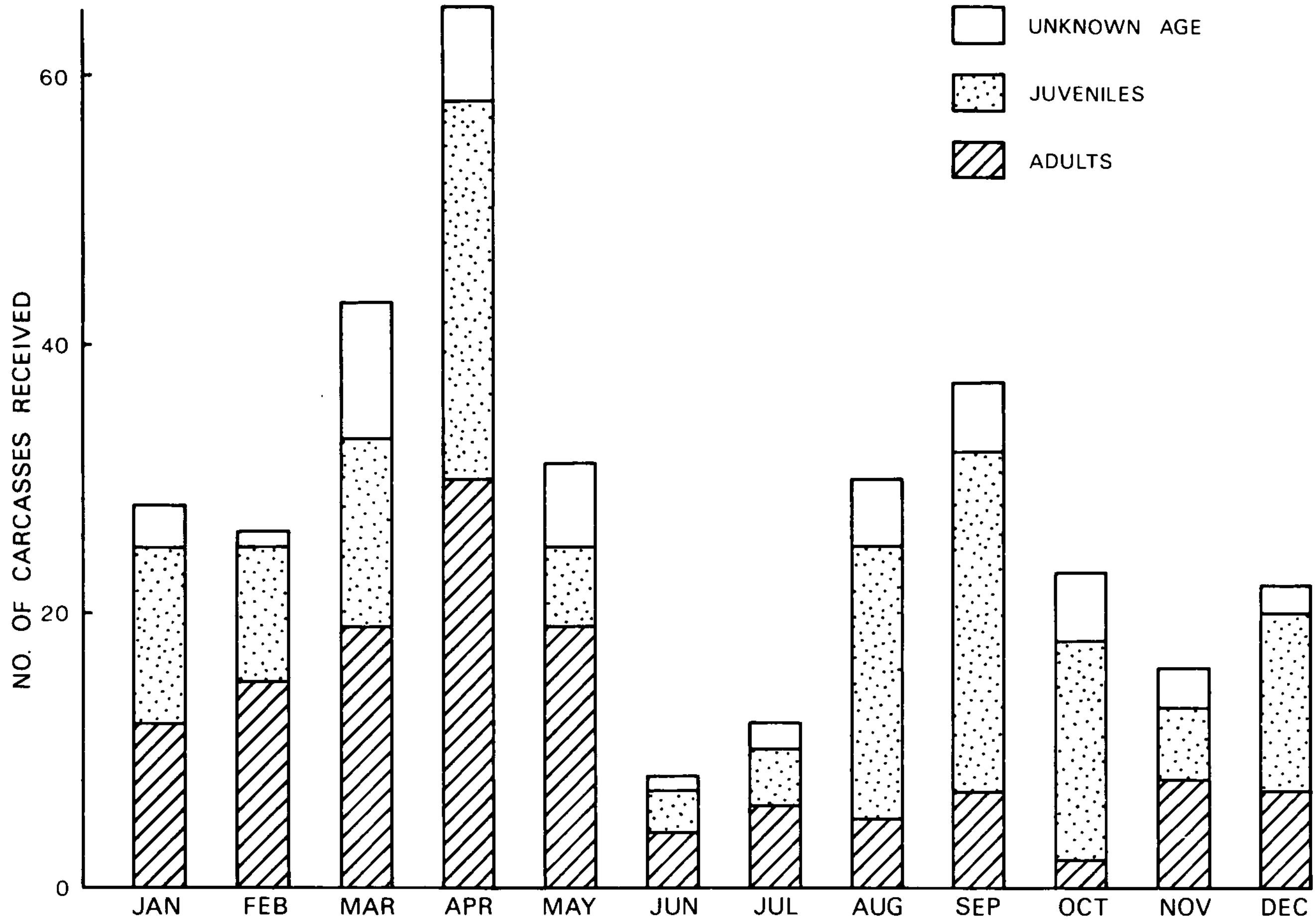

Figure 29 Numbers of carcasses of first-year and adult sparrowhawks received in different months, years combined.

1975, when the use of dieldrin as a seed dressing was further restricted. Many of the birds whose cause of death was not diagnosed on *post mortem* examination also had high concentrations of HEOD in their liver, which suggests that many such birds had been poisoned by this pesticide, though without showing signs of haemorrhage.

There is, of course, no reason to suppose that the proportions of various kinds of death recorded were representative of the population as a whole. Samples received were inevitably biased towards mortality associated with human activities, or occurring near human habitation. Certain natural kinds of death, such as predation, were much less likely to be recorded by people, and, in those circumstances, carcasses were unlikely to have been obtained. The same bias applies to ring recoveries, so it was not surprising that the British recoveries also indicated that a large proportion of sparrowhawk deaths were due to collisions or other accidents (Glue 1971).

Table 21. Causes of death, and concentrations of DDE and HEOD in the livers of sparrowhawks received for autopsy, 1963–79.

Supposed cause of death	Numbers received	% of total	Number analysed for organochlorine residues	Number & % with liver concentrations exceeding 100 ppm DDE No	100 ppm DDE %	10 ppm HEOD No	10 ppm HEOD %
Collision	116	34	104	0	0	1	1
Road casualty	25	7	20	2	10	1	5
Other injury	23	7	23	1	4	0	0
Shot	37	11	32	2	6	0	0
Haemorrhage	47	14	46	7	15	8	17
Disease	15	4	15	0	0	0	0
Starvation	29	9	25	4	16	1	4
Unknown	49	14	40	1	3	6	15

Note: Significant variation in the proportion of highly contaminated birds occurred among categories: for DDE, $\chi^2_6 = 21{\cdot}6$, $P<0{\cdot}001$; for HEOD, $\chi^2_6 = 27{\cdot}3$, $P<0{\cdot}001$.

This study of mortality forms part of a much wider programme on pesticide levels in birds of prey, and on factors which influence their numbers and breeding success.

I. Newton and A. A. Bell

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Glue, D. 1971. Ringing recovery circumstances of small birds of prey. *Bird Study,* **18,** 137–146.

RESEARCH ON KESTRELS

Research on the ecology of the kestrel (*Falco tinnunculus*) (Cover photograph) was sponsored by a NERC studentship during 1975–78. The study was conducted in the southern uplands of Scotland, an area which has largely changed from sheep farming to commercial forestry over the last 15–20 years. The young forest plantations are mainly of spruce and larch, and the growth of grasses and other ground vegetation after planting provides excellent habitat for the kestrel's main prey, the short-tailed vole (*Microtus agrestis*). Eskdalemuir Forest, near Moffat, was chosen as a study area, because it was one of the largest areas of young plantation in the region, and because small mammal members were already being monitored there as part of an existing ITE project. The aim was to study kestrels in a good vole habitat in order to assess the impact of food supply on their ecology, numbers and breeding performance.

Several aspects of kestrel ecology were examined. Diet was investigated by analysing pellets of indigestible prey remains collected at nests or roosts. Kestrel numbers were counted during drives along minor roads and forest tracks. To find home range and territory size, kestrels were trapped and individually marked with unique colour combinations of small, plastic wing tags. Breeding density and performance were also measured by finding as many nests as possible in the area each year, usually 20–40. Most kestrels in Eskdalemuir nested in disused crow nests in small woods, shelter-belts or isolated trees.

Changes in vole numbers seemed to affect kestrels in several ways:

1. Diet. Although voles were always present in at least 80% of pellets examined, they were less frequent in the diet when voles were scarce and more frequent when voles were plentiful. Other items, such as shrews, birds and invertebrates, were taken when they were abundant or when few voles were available.

2. Kestrel numbers. Most kestrels left the area in winter, and some of these birds returned to breed the following spring. Kestrels were more numerous when voles were plentiful than when voles were scarce, both in and out of the breeding season. In autumn and winter, individuals had exclusive ranges (or territories) that were larger when voles were scarcer. In summer, ranges were held by pairs and often overlapped with those of other pairs, apart from a defended area around the nest.

3. Breeding performance. Breeding was earlier and more successful in 1978, a good vole year, than in 1977, a year when voles were unusually scarce. In addition, a higher proportion of the breeding population consisted of first-year birds in 1978 than in 1977.

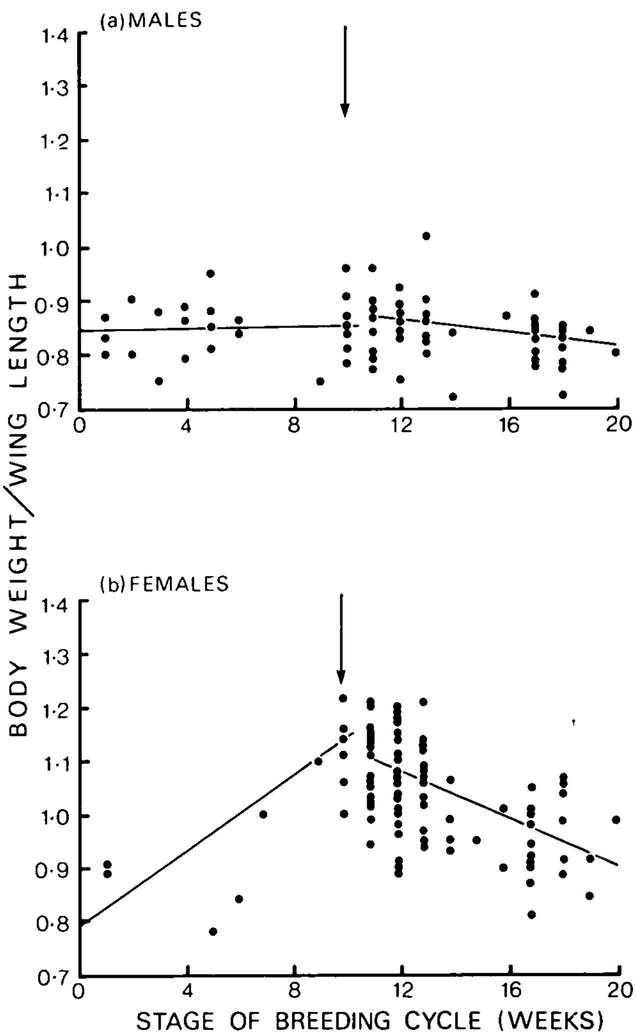


Figure 30 Changes in the body weights of trapped male and female kestrels during the breeding season. Weights are expressed as weight divided by wing length, in order to reduce some of the variation due to body size. Arrows mark the week in which the clutch was completed. Lines are linear regressions fitted to data of weeks 1–10 and 11–20.

These and other results indicate the importance of food supply, and particularly of vole numbers, in affecting the behaviour and ecology of kestrels. One aspect for further study is the seasonal change in the body weight of individuals, which may be an indication of their nutritional state. All trapped birds were weighed, and data for all years were combined to examine changes in body weight during the breeding cycle (March to July). Males showed little change throughout the breeding season, apart from a slight decline during the incubation and fledging periods (Figure 30). Females, however, seemed to gain weight rapidly prior to laying and to lose it thereafter (Figure 30). The loss in weight was not entirely due to egg-laying, as it occurred after clutch completion and was probably related to nutritional stress during the incubation and nestling periods. The rate and magnitude of weight changes may depend on how well individuals are fed and may thus relate to breeding performance. Females with 6-egg clutches were generally heavier than those with smaller clutches, at least during early incubation.

Body weights collected from trapped birds are not ideal for this type of analysis because trapping may not give a representative cross-section of the population. In particular, those birds that fail early, or are less attentive at the nest, are often missed. Furthermore, the sexes differ in their ease of capture during the breeding cycle: males are more easily caught than females prior to laying and during the late nestling period, but not during incubation. To overcome these problems, methods will be developed for weighing birds electronically without having to trap them. Such methods will allow weight changes in individuals to be followed throughout the breeding season and may yield less biased data.

A. Village

VIRUSES AND STRESS IN BIRDS

Although previous studies have isolated viruses from avian tissue, little is yet known about the ecology of avian viruses in relation to their hosts. The aim of this research is to assess the incidence and importance of viruses in a wild bird population. Initially, the starling (*Sturnus vulgaris*) is being used, as this is a pest species and easy to catch in large numbers. The work is shared between ITE and the Institute of Virology (IV), another component institute of NERC.

The first part of the project is to identify the viruses present in starlings. We have collected tissues from about 200 birds and these have been sent to IV and tested using standard virus culturing techniques. However, as yet, no virus has been positively identified. This negative result need not mean that starlings are virus-free, but simply that any viruses which the sampled birds contained were at such a low latent level that the techniques were not sensitive enough to detect them. Sick birds with a high active level of viruses are rarely found, probably because they would not survive for long in the population. Future work will concentrate on identifying viruses directly in faeces using electron microscopy. Sera from starlings will then be tested for the presence of antibodies against these viruses. This method is more likely to reveal latent infections.

The second aspect of the project is to assess the importance of viruses in bird populations. In other words, does a particular virus limit a bird's chances of survival, or of successful breeding? As has already been emphasised, sick birds are rarely found. Therefore, instead of trying to find how many starlings are killed by virus infections, we are trying to see whether sublethal viral infections cause stress in starlings. 'Stress' in this context is defined broadly as an animal's physiological responses to maintain homeostasis when challenged by changing environmental conditions. We can assess how much a starling is affected by measuring the level of a hormone, corticosterone, in its blood.

However, before we can say whether a starling is stressed, we have to determine the normal level of corticosterone in the blood, by catching starlings in the wild using mist nets or traps and taking blood samples from them. Unfortunately, this procedure is itself highly stressful and causes corticosterone levels to increase rapidly. Figure 31 shows the levels of corticosterone in 42 birds at different times after capture. It is apparent from this graph that, to assess normal corticosterone levels, the blood sample has to be taken in less than one minute after capture.

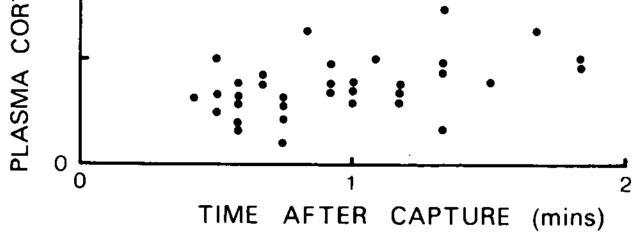


Figure 31 The level of corticosterone in the plasma of 42 starlings sampled at different times after capture in a mist net.

Corticosterone levels also change in wild birds during the year. To measure these seasonal changes, we have caught starlings in every month for a year and taken blood samples within one minute of capture. Preliminary results suggest that the levels are lowest during the autumn, rise during the winter, and remain high in actively breeding birds throughout the ensuing breeding season.

We have also kept a group of starlings in captivity and followed the changes in their corticosterone levels since capture, in order to assess the effects of captivity. These birds have been maintained under constant environmental conditions and, in due course, will be used to assess stress caused by viruses isolated from wild starlings.

A. S. Dawson

BIRDS OF PREY AND POLLUTION

The main objective of this research is the surveillance of organochlorine residues in the tissues of wild birds. These compounds are now widespread in the environment, largely resulting from their use in agriculture since the late 1940s, and now virtually every organism analysed will be found to be contaminated. A feature of the years immediately after the introduction of aldrin and dieldrin was the occurrence each spring of incidents involving massive mortality of mainly seed-eating birds—finches, pigeons and game birds, when sometimes hundreds were found dead and dying in the vicinity of newly drilled grain fields. A joint RSPB/BTO Committee on Toxic Chemicals was formed and undertook investigation and analysis of carcasses, showing that the compounds dieldrin, aldrin and heptachlor, used as seed dressings against the wheat-bulb fly, were mainly responsible. Consequently, a voluntary ban on the spring use of this group of insecticides, agreed by Government, industry and farmers, became operative from 1962, after which the large-scale mortality declined. The survey by the RSPB/BTO Joint Committee had included a wide range of bird species, and showed that many predatory birds also carried high residues of organochlorines in their tissues. Field surveys conducted during the same period confirmed that some of these species had declined markedly in abundance and, in some cases, had disappeared entirely from large areas where they were formerly common.

In 1962, the Nature Conservancy formed its Toxic Chemicals and Wildlife Section, a major part of its work being to continue monitoring the residues in predatory birds. Because of the then precarious situation of some of the species, it was decided that collection of live specimens for monitoring purposes was both impracticable and undesirable, and the only option was to rely on birds found dead. Accordingly, requests for carcasses were published periodically in the main ornithological and conservation journals, producing, on average, about 300 specimens per year.

In the early years, the scheme included virtually all of the British species, but it was soon possible to identify those most at risk, and to limit the range of species monitored to about 10. The high cost of analysis (then about £20 per tissue; currently about £120) necessitated strict adherence to the restricted list, and the monitoring programme has continued on this basis, with slight adjustments to the species included, ever since. It is now in its nineteenth year.

By using particular species of predatory birds as indicators, including both those at high risk, and others known to accumulate these chemicals, it proved possible to monitor the trends in environmental contamination by persistent organochlorine compounds and so observe the effectiveness of government control measures on their use in agriculture. At the same time, it was possible to identify at an early stage any of the listed species at risk. Partly as a result of this work, various controls have been applied over the years, and one of the most recent was the withdrawal of dieldrin as an autumn cereal seed dressing from 1975 onwards.

During the 5 years under review, the livers from some 570 birds were analysed, including those from 130 sparrowhawks (*Accipiter nisus*) and 113 kestrels (*Falco tinnunculus*), and the results for these species are given in Figures 32–35. From the trends in organochlorine use, one might expect declines in HEOD residues (from aldrin and dieldrin) during the last few years, but not necessarily in DDE residues (from DDT).

As in previous years, wide variation in organochlorine concentrations occurred among the individuals of both species. For HEOD, the data suggested a decline of residue levels in both species during the period since 1975, while, for DDE, residues seemed to decline in kestrels, but not in sparrowhawks. Only for HEOD were the downward trends statistically significant over the years concerned. It seems, therefore, that the most recent restriction in dieldrin use has been effective in reducing residue levels from this compound in kestrels and sparrowhawks.

A. A. Bell and I. Newton

DDT AND TERATOGENESIS IN FROG TADPOLES

Cooke (1970, 1972) described how frog tadpoles (*Rana temporaria*) (Cover photograph) developed abnormal behavioural and anatomical features when exposed to DDT. One of these abnormalities was the formation of a large hole in, and the subsequent loss of, part of the snout. This abnormality could not be induced before the animals had reached the stage when the hind limbs had just begun to grow. It began with a darkening and roughening of the skin surface, and was confined to this one area of the animal's body, other areas of skin remaining normal throughout. Even more peculiarly, some of the affected animals appeared to regrow the snout after losing it, although these had a characteristic 'blunt' snout.

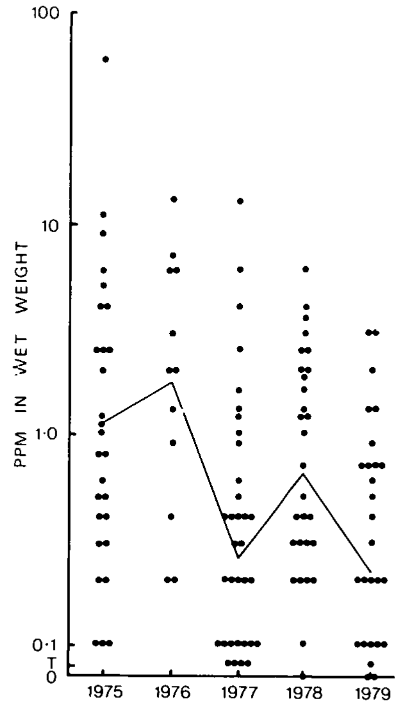


FIGURE 32 HEOD concentrations in livers of sparrowhawks, 1975–79. The 4 categories at the base of the graph refer to lowest quantifiable level, trace levels (T), and nil levels (0). With linear regression of log HEOD on year, the downward trend was statistically significant: $r = 0{\cdot}27$, $P < 0{\cdot}01$.

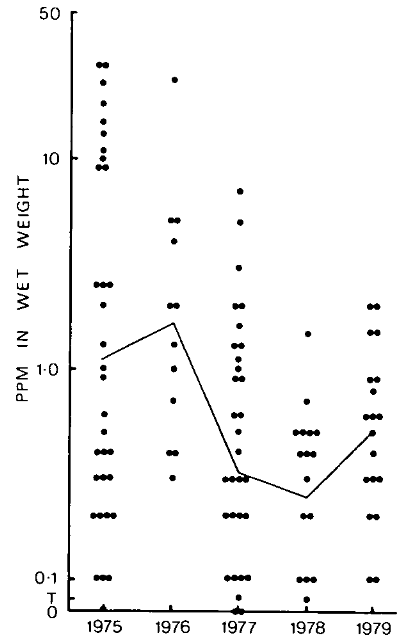


Figure 33 HEOD concentrations in livers of kestrels, 1975–79. The 3 categories at the base of the graph refer to lowest quantifiable level, trace levels (T), and nil levels (0). With linear regression of log HEOD on year, the downward trend was statistically significant: $r = 0{\cdot}24$, $P < 0{\cdot}01$.

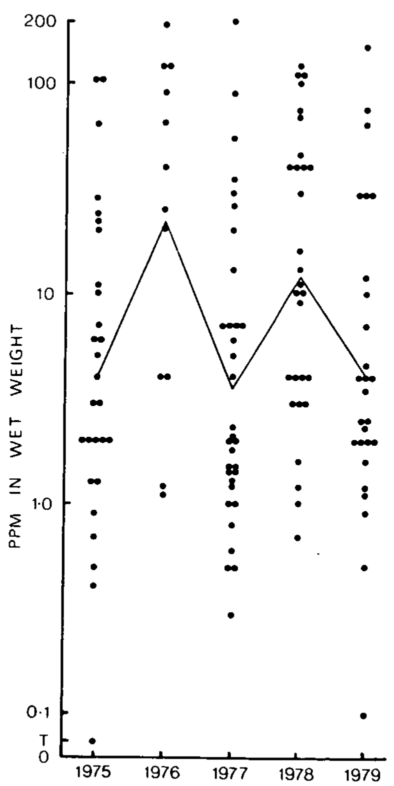


Figure 34 DDE concentrations in livers of sparrowhawks, 1975–79. The 3 categories at the base of the graph refer to lowest quantifiable level, trace levels (T), and nil levels (0). There was no statistically significant trend with time.

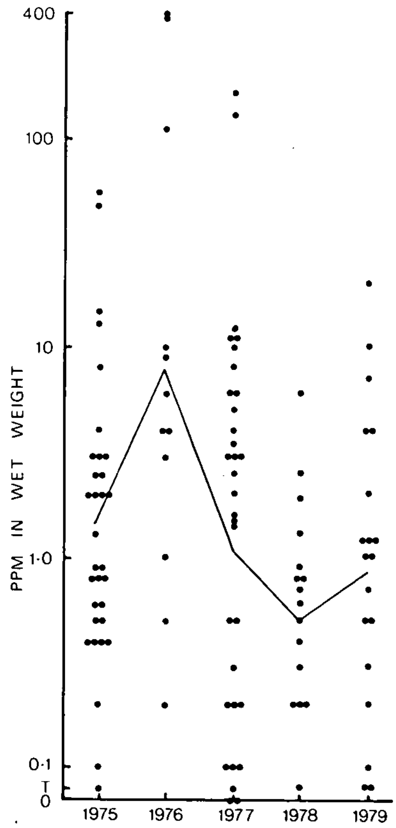


Figure 35 DDE concentrations in livers of kestrels, 1975–79. The 3 categories at the base of the graph refer to lowest quantifiable level, trace levels (T), and nil levels (0). The apparent downward trend was not statistically significant.

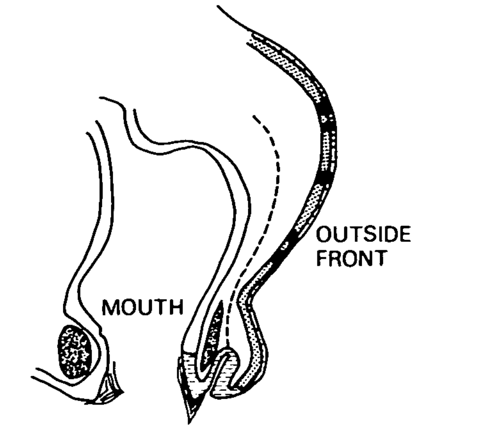


Figure 36a *Snout area of normal tadpole.*

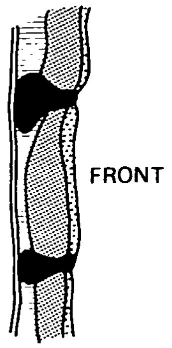


Figure 36b *Details of skin of control tadpole.*

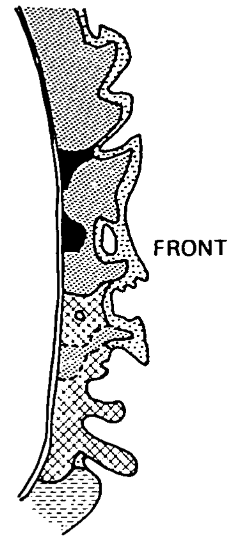


Figure 36c *Skin of DDT dosed tadpole. Note disrupted structure compared to Figure 36b.*

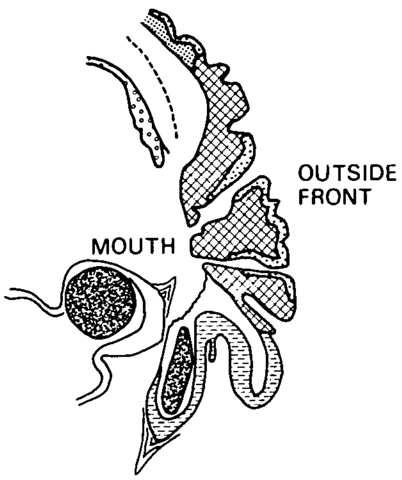
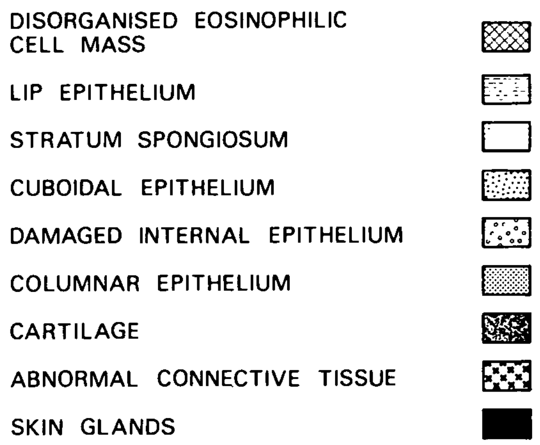


Figure 37 *Dosed tadpole snout. Holes through the skin and internal damage.*



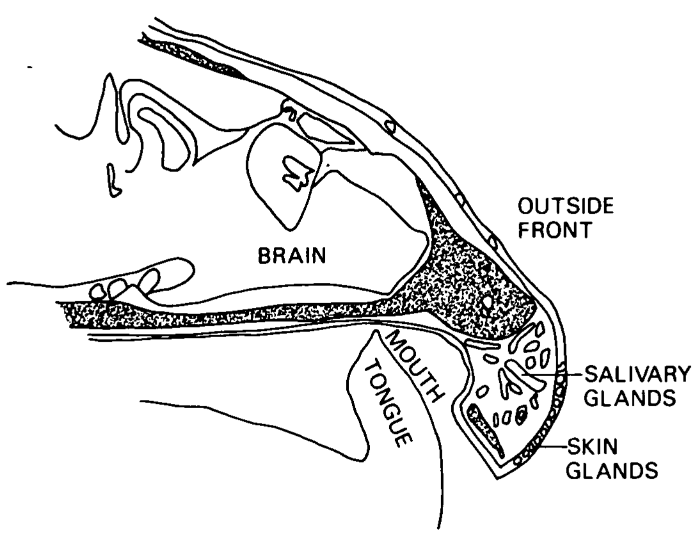


Figure 38a *Control froglet. Head end.*

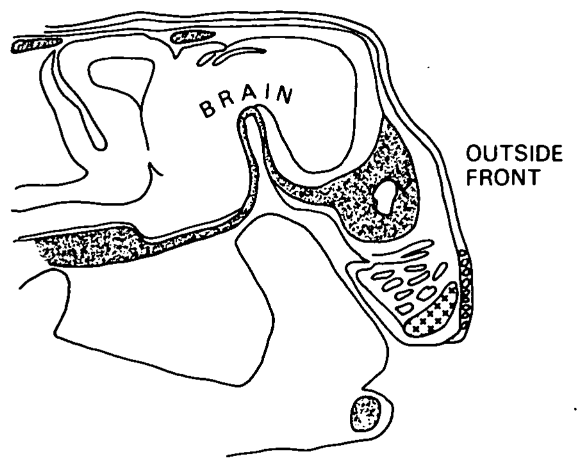


Figure 38b *DDT dosed froglet, showing brain deformation.*

Histological details of this abnormality have now been examined by light microscopy (further details in Osborn *et al.* in press). Figure 36a shows the salient features of the snout of a normal tadpole at a time when the abnormality can be induced, and Figure 36b shows the smooth appearance of the skin in such an animal. Figure 36c shows the strikingly different skin of a tadpole which had just developed a dark patch below and between the nostrils. It can be seen how disorganised the cell layers are, compared with the highly organised ones in the normal animal (Figure 36a & b). The abnormality developed until holes appeared in the skin and penetrated right through it (Figure 37).

The histological study revealed that, as well as the effect on the structure of the skin, another factor contributed to the loss of the snout. One of the behavioural abnormalities induced in tadpoles by DDT was hyperactivity and a general lack of co-ordination. These abnormalities caused the lower mandible to strike repeatedly the inside surface of the upper mandible, and some histological preparations showed the lower mandible firmly embedded in the upper. This rasping action caused such damage to the inner surfaces of the tadpole snout that both the internal epithelial and connective tissue layers were destroyed (Figure 37). Eventually the small holes in the external surface and the internal damage combined until one large hole was formed, and, soon afterwards, the bottom of the upper mandible fell away.

Froglets that developed from tadpoles which regrew the snout were compared with normal tadpoles at the same stage of development (Figure 38). Several internal abnormalities were noted, which included changes in the salivary gland and cartilage of the upper jaw. Most important, perhaps, was the pronounced kink in the base of the cranium which caused the brain to be bent and the ventricular space to be reduced. Possibly this damage to the brain contributed to the eventual death of these froglets.

We believe that the damage to skin structure began with a proliferation of either the cells which formed the mucous glands of the skin, or of skin cells themselves. Whichever was the case, the study provided further evidence that DDT can cause a disorganised proliferation of epithelial cells. It would be premature to link these results with those identifying DDT as a possible cancer causing agent, because our study was not sufficiently detailed to identify the eosinophilic cell mass that developed in the tadpole skin as a tumour, and because, in any case, a simple extrapolation from this embryonic life form to mammalian foetuses may not be justified.

D. Osborn

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MASS DEATHS OF BIRDS ON THE MERSEY ESTUARY

(This work was partly supported by NCC funds)

For a number of years, there have been reports of birds dying on the Mersey estuary in late summer. In 1979, groups of about 100 or more birds were washed ashore dead or dying on successive high tides from September through to November. Thereafter, the numbers of dead and dying birds tended to decline. In August and September 1980, a similar event occurred. Under a contract from the NCC, we investigated these problems, paying most attention to the larger 1979 incident.

In 1979, close to 2500 bodies were recovered —although the true mortality figure would have been higher by an unknown amount. Birds were washed ashore in limited sections of the estuary (Figure 39) and dunlin and black-headed gull were the main species involved. Substantial numbers of duck were also found (Table 22), and these caused concern for human health, because wildfowl are shot for food in this area.

MAFF and ITE laboratories soon established that the only identifiable toxic chemical present in amounts sufficient to affect the birds was lead. Further analyses by ITE, together with data from records at Monks Wood, which showed lead levels in waders above 1 mg kg^{-1} to be rare, suggested that lead was higher in the Mersey birds than elsewhere (Table 23).

Increasing evidence suggests that sublethal effects of lead occur when liver levels exceed 5 mg kg^{-1} in live birds, and that lead may have been the cause of death, or at least a major contributor to death, in birds with liver levels in excess of 10–20 mg kg^{-1}. It thus seemed probable that lead was the chemical which had precipitated the 1979 incident, especially as observations on sick birds and *post mortem* findings were typical of lead poisoning. For example, 2 sick birds examined by ITE had green droppings, and could not stand or hold their heads erect; and *post mortem* birds had green intestinal contents and green gall bladder contents. In addition, some 1980 birds had 'green-tainted' livers.

The petro-chemical industry produces organic forms of lead (for the anti-knock agent in petrol) on the Mersey, and it seemed possible that this industry was the source of the lead that the birds had absorbed. Industrial analysts co-operated with ITE and the North West Water Authority, and showed that much of the lead in affected birds was in an organic form. However, as yet, the exact source of the lead which the birds

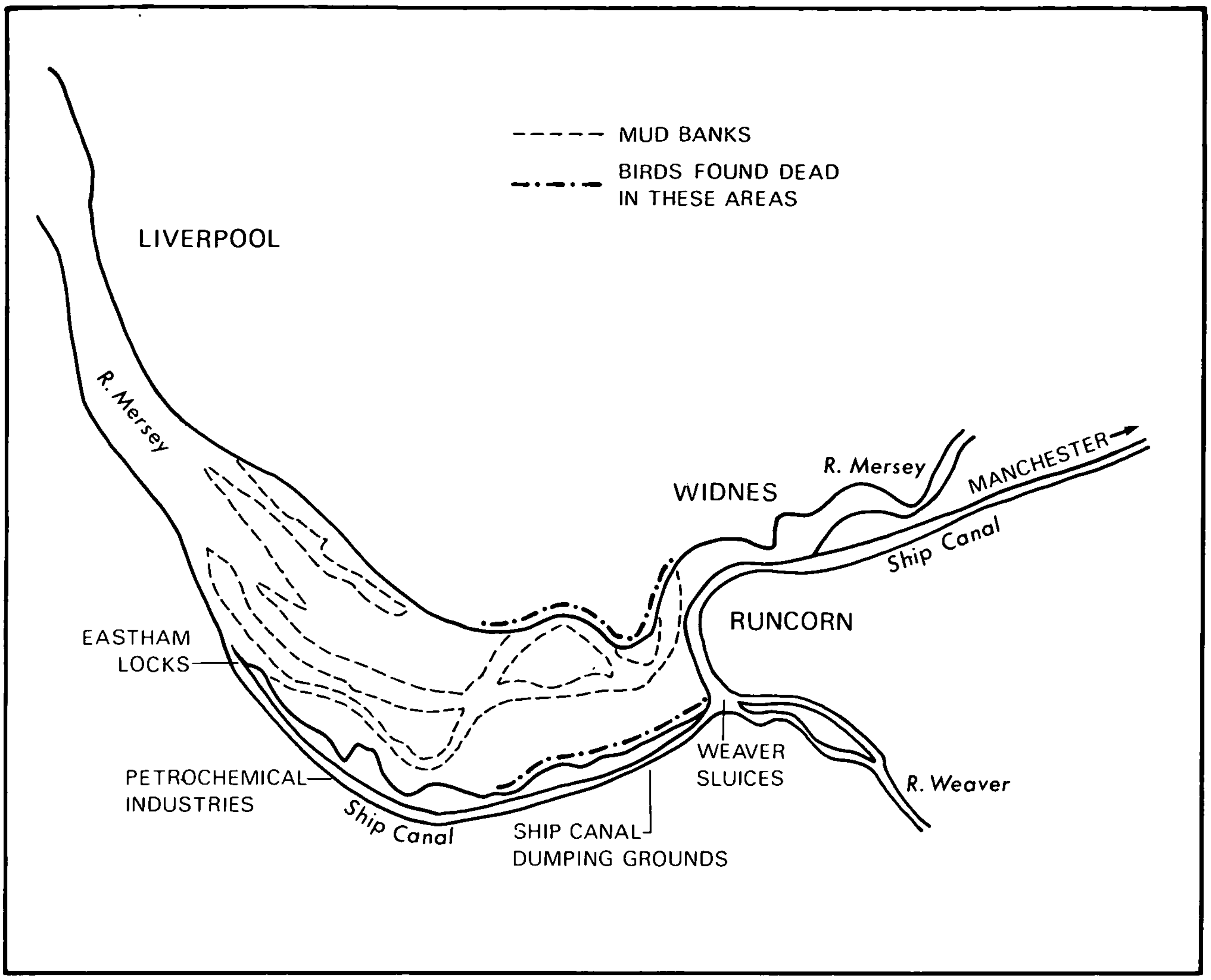


Figure 39 Sketch map of Mersey showing some relevant features.

accumulated in 1979 has not been identified. It is likely that a number of factors contributed to the large-scale incident in 1979, resulting in birds accumulating high, and often lethal, organic lead concentrations.

Some similarities were found between 1979 and 1980, when black-headed gulls were the main casualties. While lead levels in gulls were only moderately elevated, those in sick and dead wildfowl and waders were considerably higher. Again, industrial analysts found up to and over 20 mg kg^{-1} lead in the livers of waders and wildfowl found dead, much of it in organic form. ITE data for 1980 demonstrated that substantial quantities of lead (Table 24) were present in some living ducks, possibly sufficient to render them inedible, as organic lead is more toxic than inorganic lead. However, there are many complexities in the problem. For example, teal netted on 25 September 1980 contained less lead than teal shot on 7 September 1980 (shooting is not thought to cause sample contamination that cannot be easily detected; cf low lead in shot birds in Table 23). Possibly more lead was available in early September; alternatively, the netted birds may have been new arrivals to the estuary and so not exposed for any length of time.

To help resolve some of these difficulties, and to provide information which will aid in reducing the problem to an acceptable minimum, we have conducted some experimental work on the toxicity of organic lead compounds to birds. Without such information, effective controls on pollution sources cannot be properly formulated.

At the time of writing, part of this research has only just been completed, but we can report that, after 3–4 days, a daily oral dose of 25–30 mg kg^{-1} body weight tri-ethyl lead killed starlings (*Sturnus vulgaris*), whereas a tenth of this dose caused no deaths, but affected feeding patterns and possibly muscle condition. Some of the experimental birds showed symptoms similar to those of the 1979 Mersey birds. The symptoms were only present for a short period before death, which suggests that organic lead compounds are as toxic to some species of birds as are some of the more poisonous insecticides, and that sources of such compounds should be controlled.

Investigations into the Mersey mortalities are continuing under the auspices of ITE, the North West Water Authority, NCC and the Royal Society for the

Protection of Birds. It is hoped that, in 1981, sufficient data will be available to take positive action on the pollution which the recurrent mortalities have brought to light.

D. Osborn

Table 22. Total numbers of dead and sick birds of each species reported during the course of the mortality. Total numbers recorded between 15 September and 21 December 1979.[1]

		Total numbers
GULLS		
Black headed gull	*Larus ridibundus*	368
Common gull	*Larus canus*	16
Herring gull	*Larus argentatus*	29
Lesser black backed gull	*Larus fuscus*	4
Greater black backed gull	*Larus marinus*	1
Unidentified gulls		15
		433
WADERS		
Dunlin	*Calidris alpina*	1336
Redshank	*Tringa totanus*	116
Curlew	*Numenius arquata*	49
Greenshank	*Tringa nebularia*	1
Green sandpiper	*Tringa ochropus*	4
Knot	*Calidris canutus*	6
Ruff	*Philomachus pugnax*	2
Little stint	*Calidris minuta*	5
Grey plover	*Pluviatis squatorola*	5
Golden plover	*Pluviatis apricaria*	1
Lapwing	*Vanellus vanellus*	2
		1577
WILDFOWL AND OTHERS		
Teal	*Anas crecca*	48
Mallard	*Anas platyrhynchos*	34
Pintail	*Anas acuta*	37
Shelduck	*Tadorna tadorna*	16
Wigeon	*Anas penelope*	2
Mute swan	*Cygnus alor*	2
Barnacle goose	*Branta leucopsis*	1
Carrion crow	*Corcus corone*	1
Heron	*Ardea cinerea*	2
Cormorant	*Phalocrocorax carbo*	1
		144
An additional 232 unidentified birds were reported		
Total of identified waders, wildfowl and all gulls		2154
Total of unidentified species excluding gulls		232
	Total	2386

1. Data supplied by local ornithologists and wildfowlers, principally Mr R. Cockbain, collated by RSPB and NWWA.

Table 23. Lead (mg kg^{-1} wet wt) in tissues of waders (mainly dunlin and redshank) on Mersey and other estuaries.

Location	Status, Method of capture	*n*	Range of figures Liver	Muscle
Mersey[1]	Dead, 1979 Incident	5	8–31	–
Mersey[1]	Sick, 1979 Incident	6	6–11	0·6–1·5
Mersey[2]	Live, Netted 1979 Incident	4	2–8	0·6–1·3
Severn[2]	Live, Netted 1979 Incident	10	<0·02–0·6	0·02–0·1
Wash[3]	Live, Netted	19	all <0·02	–
	Monks Wood records	1	6·3	–
Tees[4]	Live, Netted	–	<2	–

Notes: 1. These birds were collected during the time when mortalities were occurring, by Mr R. Cockbain and friends.
2. Mersey birds were collected by local ornithologists in January 1980 when mortalities had almost ended. Dr P. N. Ferns, University College Cardiff, Supplied the Severn birds.
3. Data extracted from Monks Wood records.
4. Dr P. E. Evans, personal communication.

'1979 Incident' birds could not be collected at the same time of year.

Table 24. Lead (mg kg^{-1} wet wt) in tissues of wildfowl (mainly teal and mallard) from the Mersey and other estuaries.

Location	Status, Method of capture	*n*	Range of figures Liver	Muscle
Mersey[1]	Dead, sick 1979 Incident	–	10–25	c4
Medway[2]	Live, shot 1979 Incident	10	<0·02–0·6	«0·02–0·2
Mersey[3]	Live, shot and netted 1980	14	<0·2–9	«0·2–5

Notes: 1. Few wildfowl samples could be collected at the time 1979 mortalities were occurring. Several laboratories analysed a few birds and obtained the results shown, *n* cannot be given since some tissues were pooled in some laboratories.
2. Collected in association with the Royal Society for the Protection of Birds.
3. Birds collected by Frodsham Wildfowlers Club (WAGBI) and Mr R. Cockbain.

'1979 Incident' birds could not be collected at the same time of year.

SUBLETHAL EFFECTS OF CADMIUM ON VERTEBRATE KIDNEY

Increasing interest in cadmium over the past few years has arisen because this toxic element is found in animals and man, not only as a result of pollution, but also as a result of natural contamination from geological sources. In some regions, animals accumulate high concentrations of this metal in their kidneys and other tissues. One such region is north-west Scotland, and investigations into the metal content of seabirds at the internationally important St Kilda colony revealed the presence of such large amounts of cadmium as to make desirable further work on possible sublethal effects (Osborn *et al.* 1979).

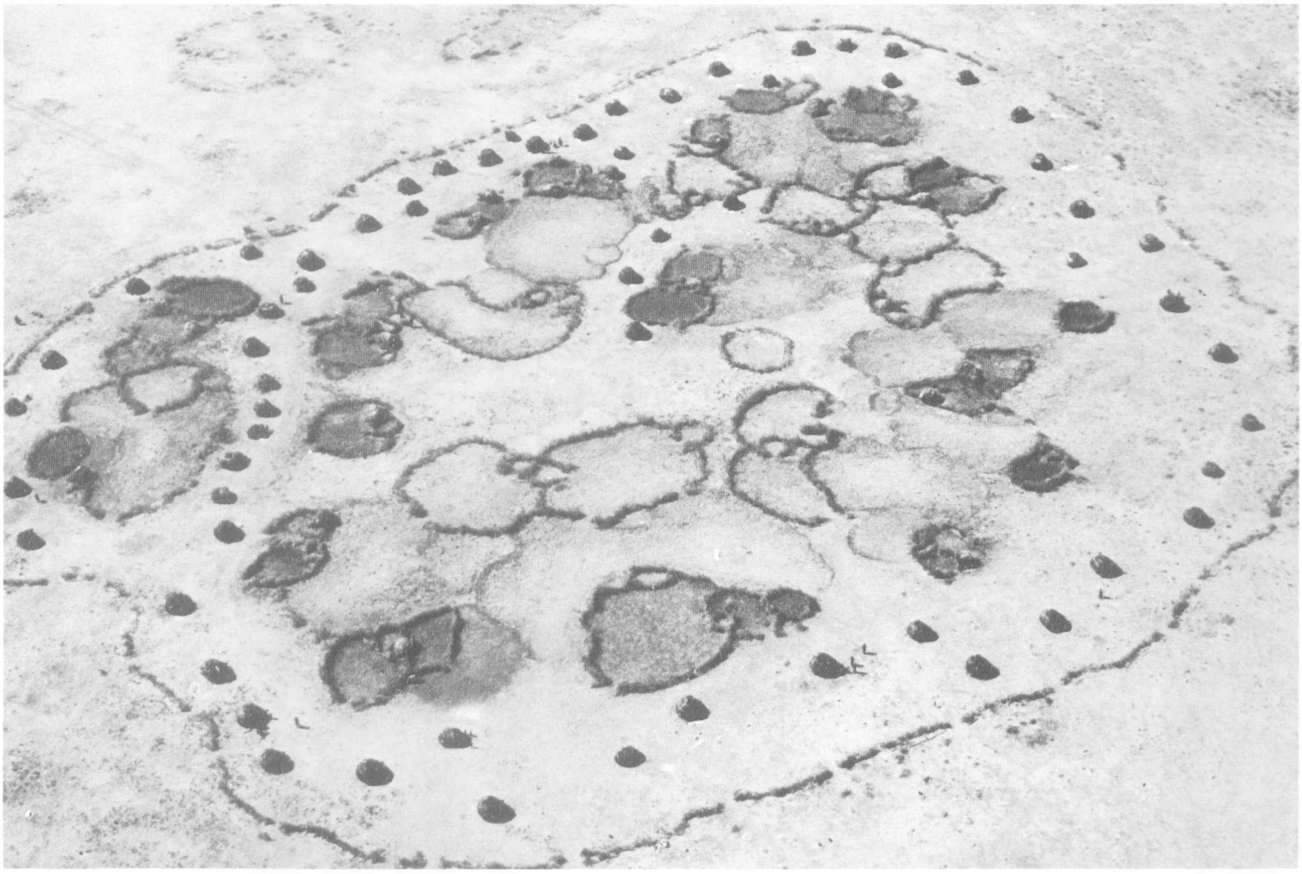


Plate 20—Aerial photograph of a village of the Rendille tribe of northern Kenya. Thorn fences are used as a protection against predation by hyaenas and lions.
Photograph H. Kruuk.

Plate 21—Village of the Sambaru tribe, northern Kenya. The more solid thorn fences protect the livestock better than those of the Rendille tribe.
Photograph H. Kruuk.

Plate 22 — Normal appearance of proximal tubule of starling kidney. Photograph D. Osborn.

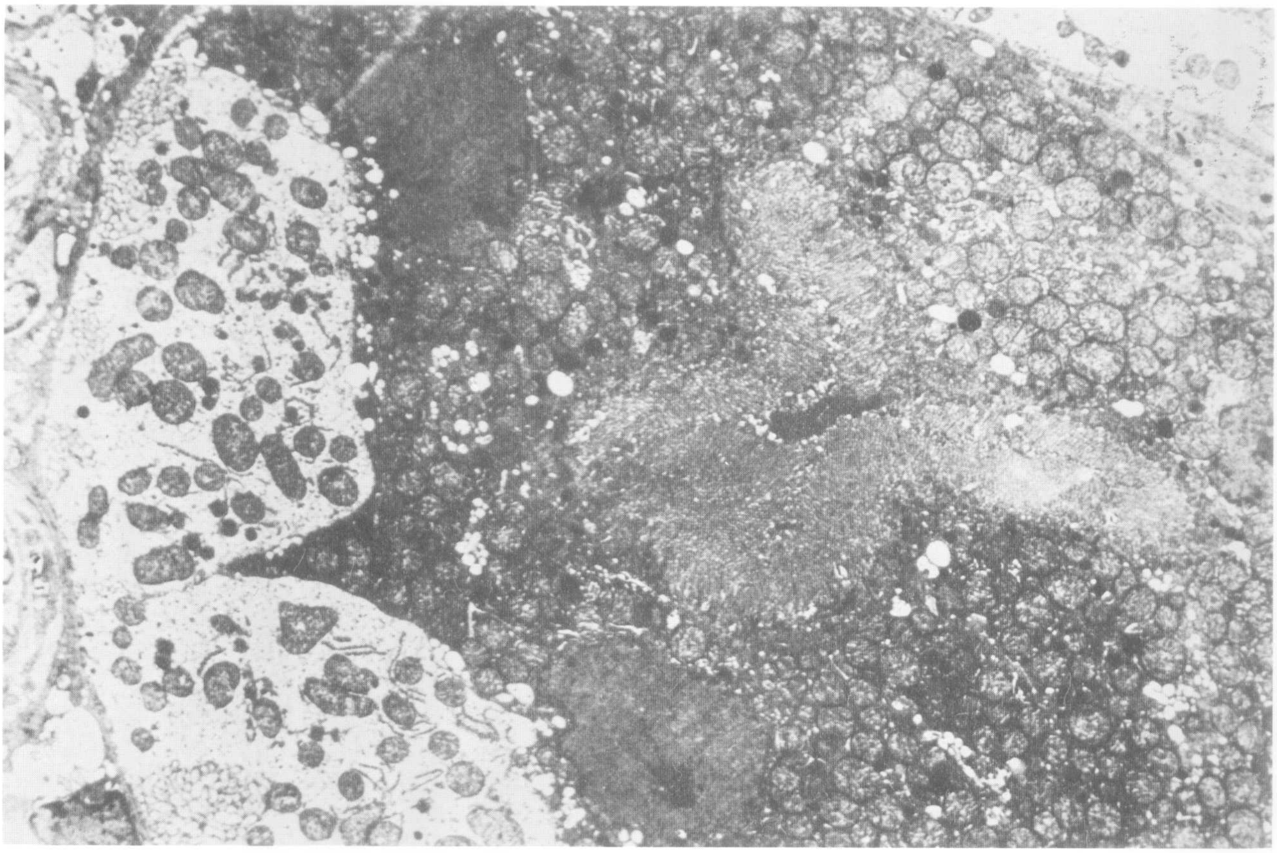


Plate 23a — Proximale tubule of cadmium-dosed starling kidney, c250 mg kg^{-1}Cd dry wt whole kidney. Tissue is extensively damaged; note increase in mitochondria, 'shut-down' nuclei in dark electron-dense cells. Note 2 new 'light' cells invading the damaged area.
Photograph D. Osborn.

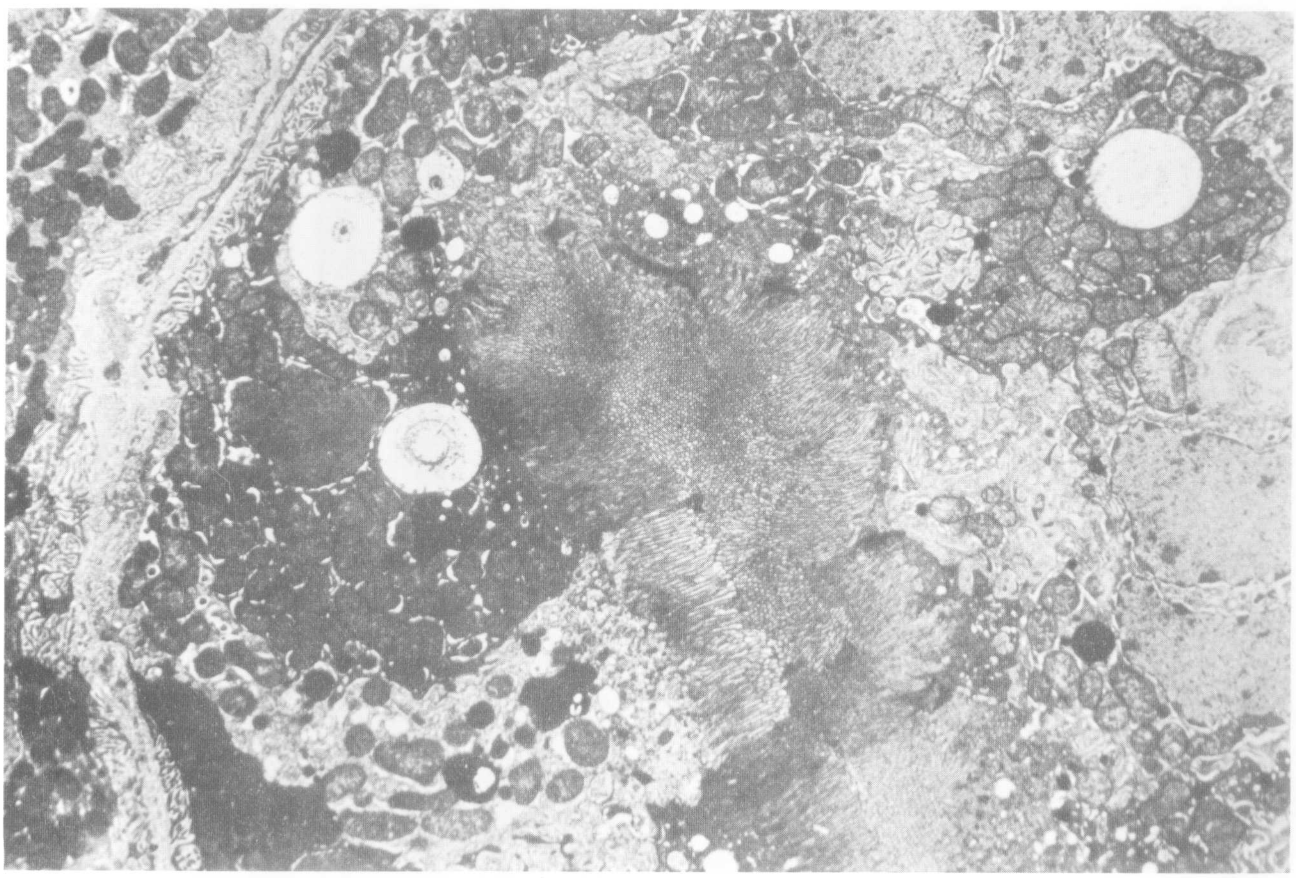


Plate 23b — Proximal tubule of Manx shearwater kidney from St. Kilda, c250 mg kg^{-6}Cd dry wt. Note similarity to Plate 23a. Two dark cells lie either side of a 'light' cell.
Photograph D. Osborn.

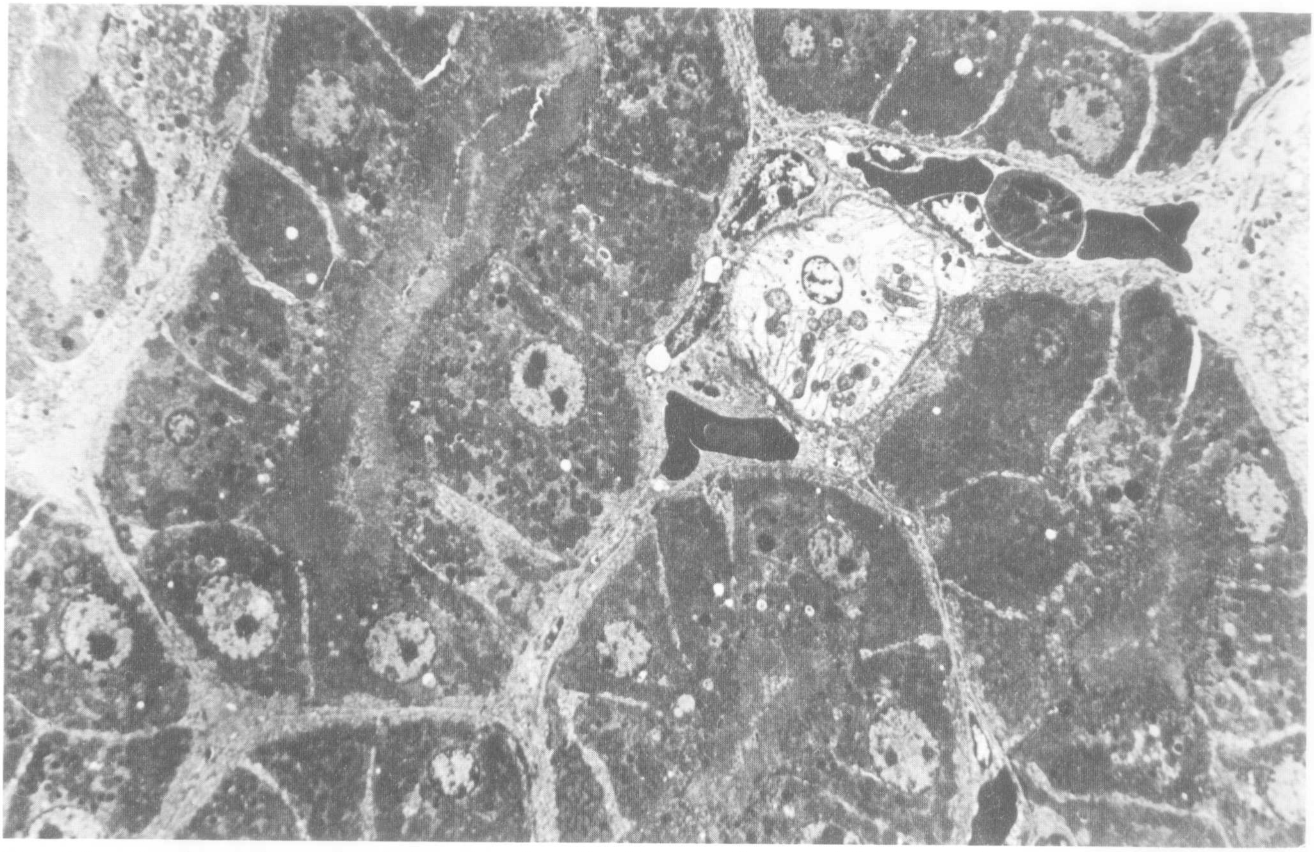


Plate 24a — Proximal tubule of cadmium-dosed starling kidney c 40 mg kg^{-1} Cd dry wt. Damage here is less than that shown in Plate 23, but loss of cellular adhesion has occurred; note the 'Spaghetti' like membrane structures at the base and between cells.
Photograph D. Osborn.

Plate 24b — Proximal tubule of puffin from St. Kilda. Identical to Plate 24a in many respects, c100 mg kg^{-1} Cd dry wt.
Photograph D. Osborn.

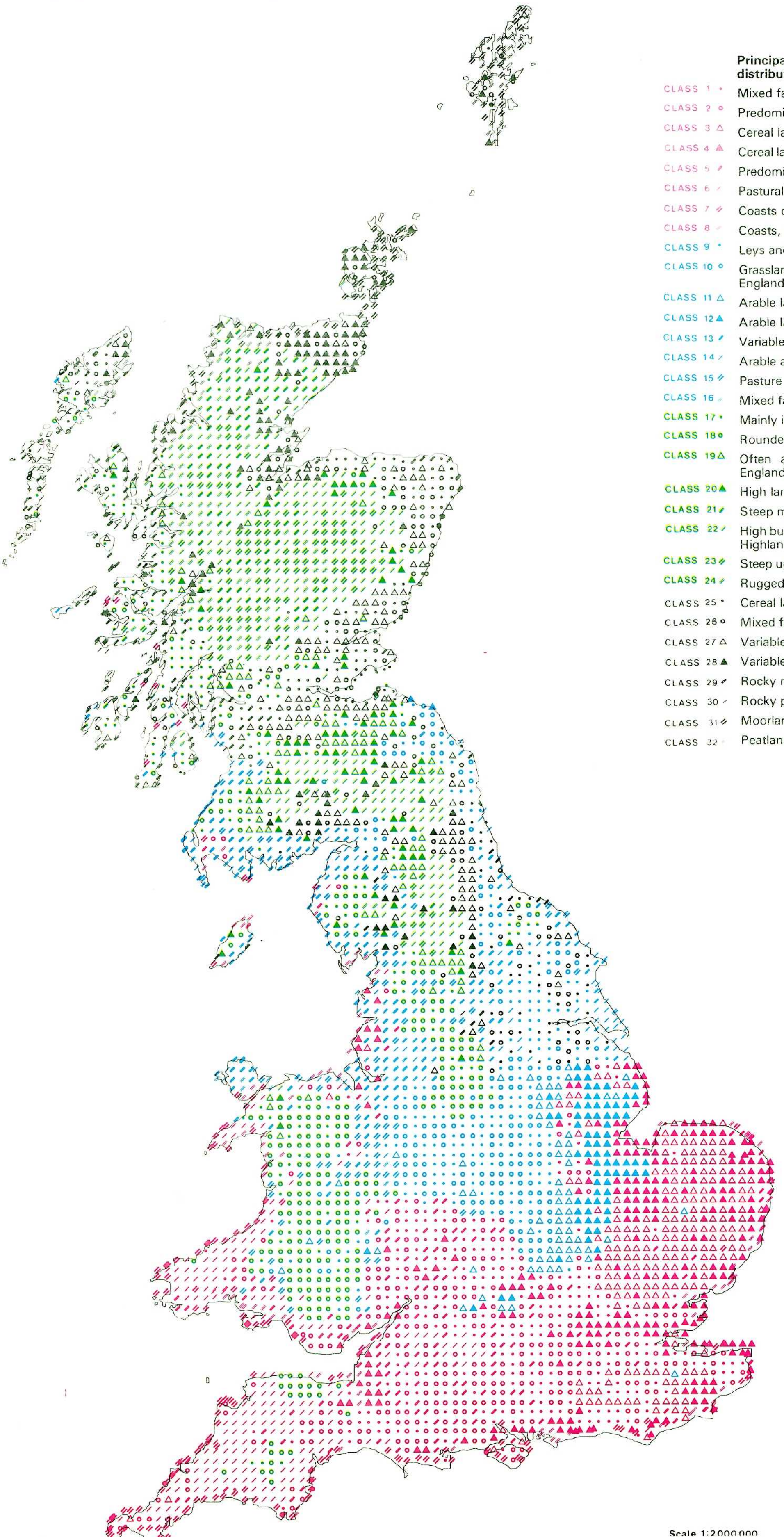
Plate 1 — Study colony on Isle of May.
Photograph M. P. Harris.

Plate 3 — Puffin with fish.
Photograph M. P. Harris.

Plate 5 — Puffin about to be released after being implanted with PCBs.
Photograph M. P. Harris.

Plate 6 — Dosed puffin after release and return to the colony.
Photograph M. P. Harris.

Sampling Survey of the United Kingdom



Land Class	Principal features of the land classes – outliers from the core distribution are frequently present.
CLASS 1 •	Mixed farmland in central and southern England
CLASS 2 ○	Predominantly arable farmland in southern England
CLASS 3 △	Cereal land in East Anglia and the edge of the Weald
CLASS 4 ▲	Cereal land with much urban development in the margins of East Anglia
CLASS 5 ⁄	Predominantly pastural land in central and south-west England
CLASS 6 ⁄	Pastural land in south-west England and south Wales
CLASS 7 ⫽	Coasts of south-west England and Wales
CLASS 8 ⁄	Coasts, mainly estuarine, of England and Scotland
CLASS 9 •	Leys and arable land, mainly of the midlands and north-east England
CLASS 10 ○	Grasslands and arable land mainly in the midlands and north-east England
CLASS 11 △	Arable land in the east and central English midlands
CLASS 12 ▲	Arable land in the east English midlands
CLASS 13 ⁄	Variable land mainly pasture, mainly in north-west England
CLASS 14 ⁄	Arable and urban land of the lowlands of northern England
CLASS 15 ⫽	Pasture and arable land in northern England and Wales
CLASS 16 ⁄	Mixed farmland in northern England and south-west Scotland
CLASS 17 •	Mainly improved upland pasture land in England and Wales
CLASS 18 ○	Rounded hills covered mainly with moorland in Western Scotland
CLASS 19 △	Often afforested uplands with moorland vegetation in northern England and southern Scotland
CLASS 20 ▲	High land with rounded slopes and grasslands in southern Scotland
CLASS 21 ⁄	Steep mountains with moorland vegetation in the Scottish Highlands
CLASS 22 ⁄	High but smooth slopes with variable vegetation in the central Scottish Highlands
CLASS 23 ⫽	Steep upper slopes covered with moorland in the north-east of Scotland
CLASS 24 ⁄	Rugged peat covered mountains in north-west Scotland
CLASS 25 •	Cereal lands in east Scotland
CLASS 26 ○	Mixed farmland in north-east England
CLASS 27 △	Variable lowlands in north-east England and east Scotland
CLASS 28 ▲	Variable lowlands in northern Scotland
CLASS 29 ⁄	Rocky moorlands along the inner west coasts of Scotland
CLASS 30 ⁄	Rocky peatlands mainly on the outer coasts of western Scotland
CLASS 31 ⫽	Moorlands in the northern Isles, Orkney and Shetland
CLASS 32 ⁄	Peatlands of Shetland and north-west Scotland

Rounded hills covered mainly with moorland in western Scotland

Often afforested uplands with moorland vegetation in northern England and southern Scotland

Map produced by the Experimental Cartography Unit

Figure 13 Geographical distribution of the 32 land classes into which Britain can be divided.

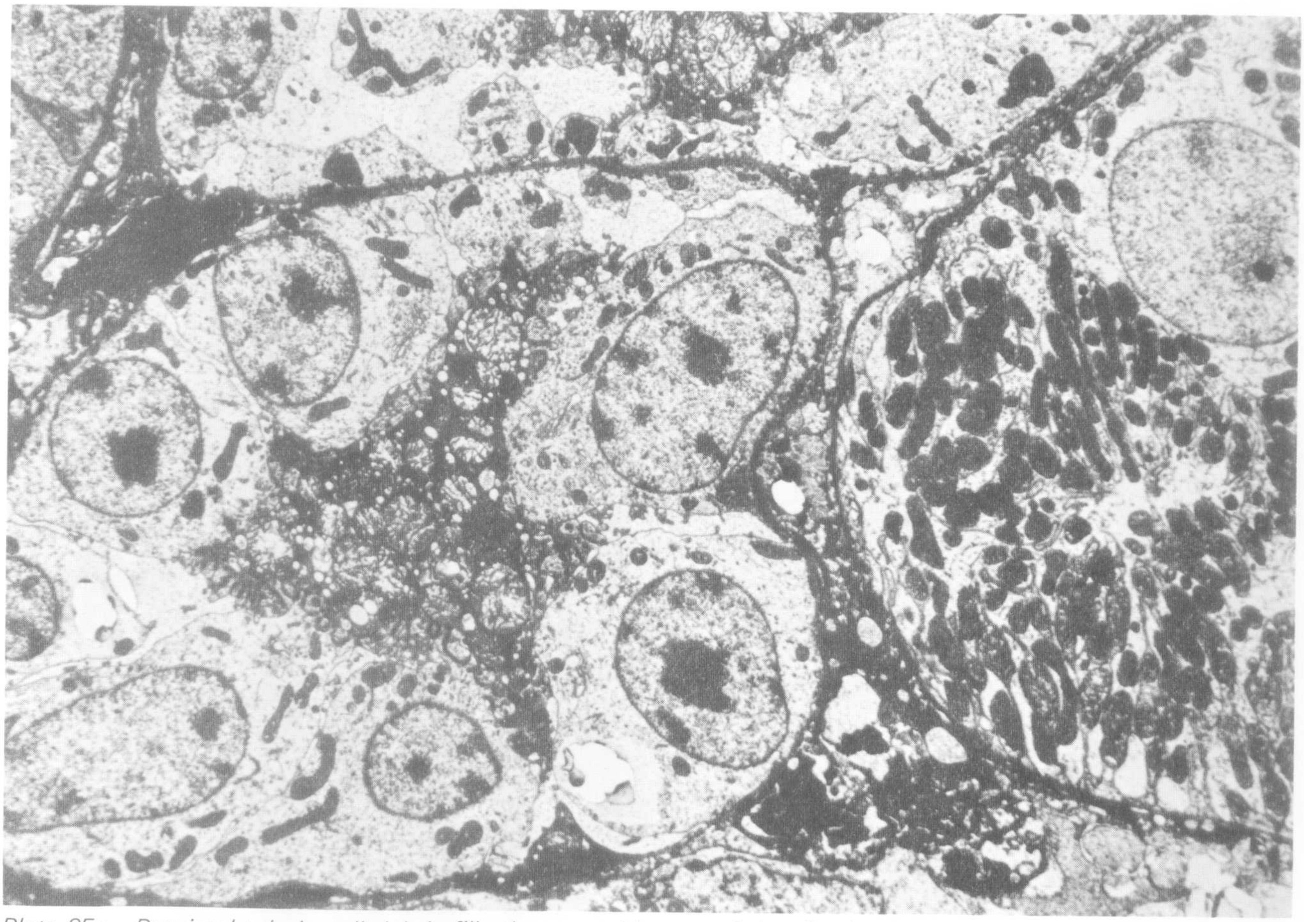


Plate 25a — Proximal tubule cell debris fills the central lumen of the distal tubule in the kidney of this cadmium-dosed starling.
Photograph D. Osborn.

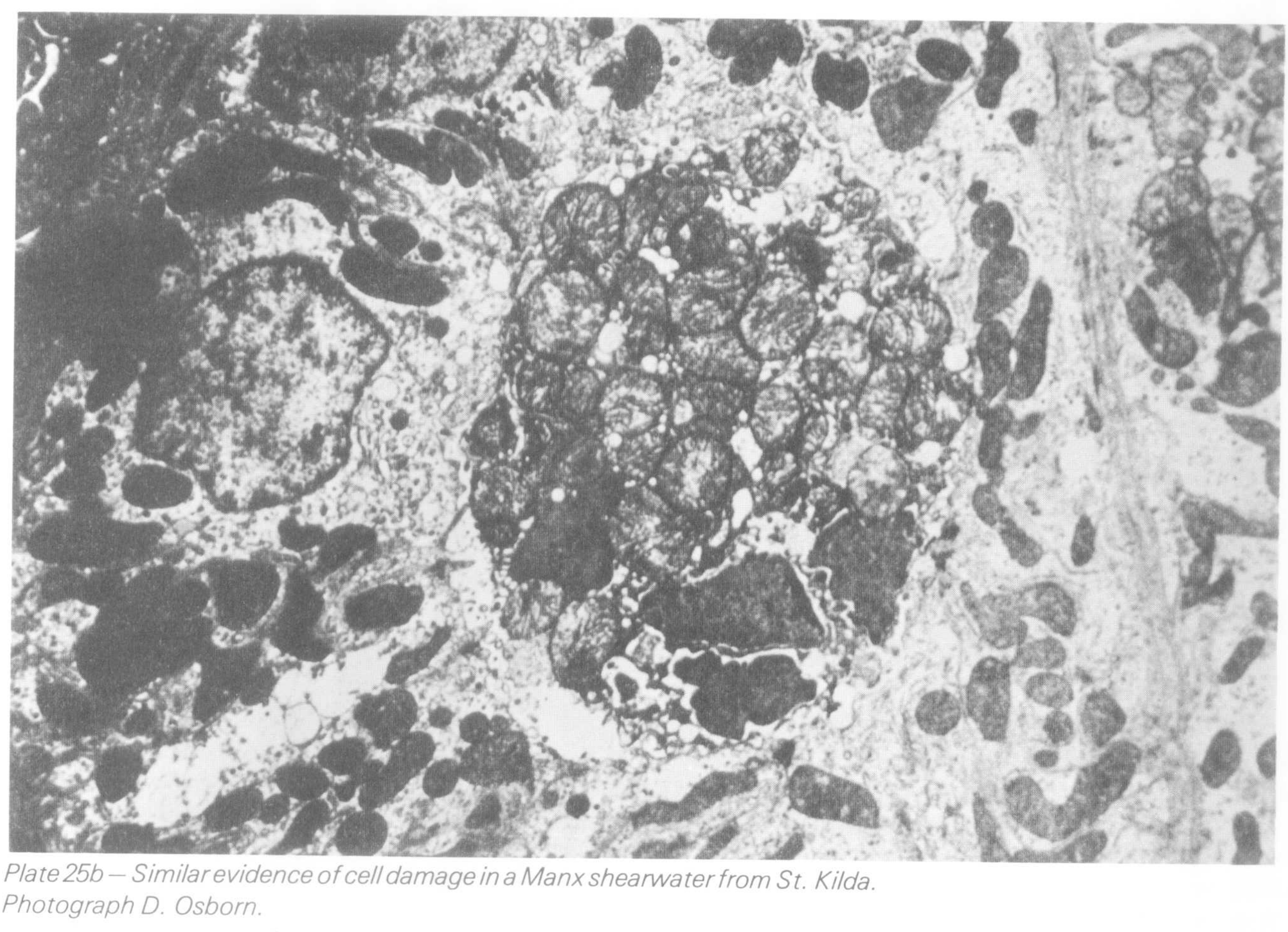


Plate 25b — Similar evidence of cell damage in a Manx shearwater from St. Kilda.
Photograph D. Osborn.

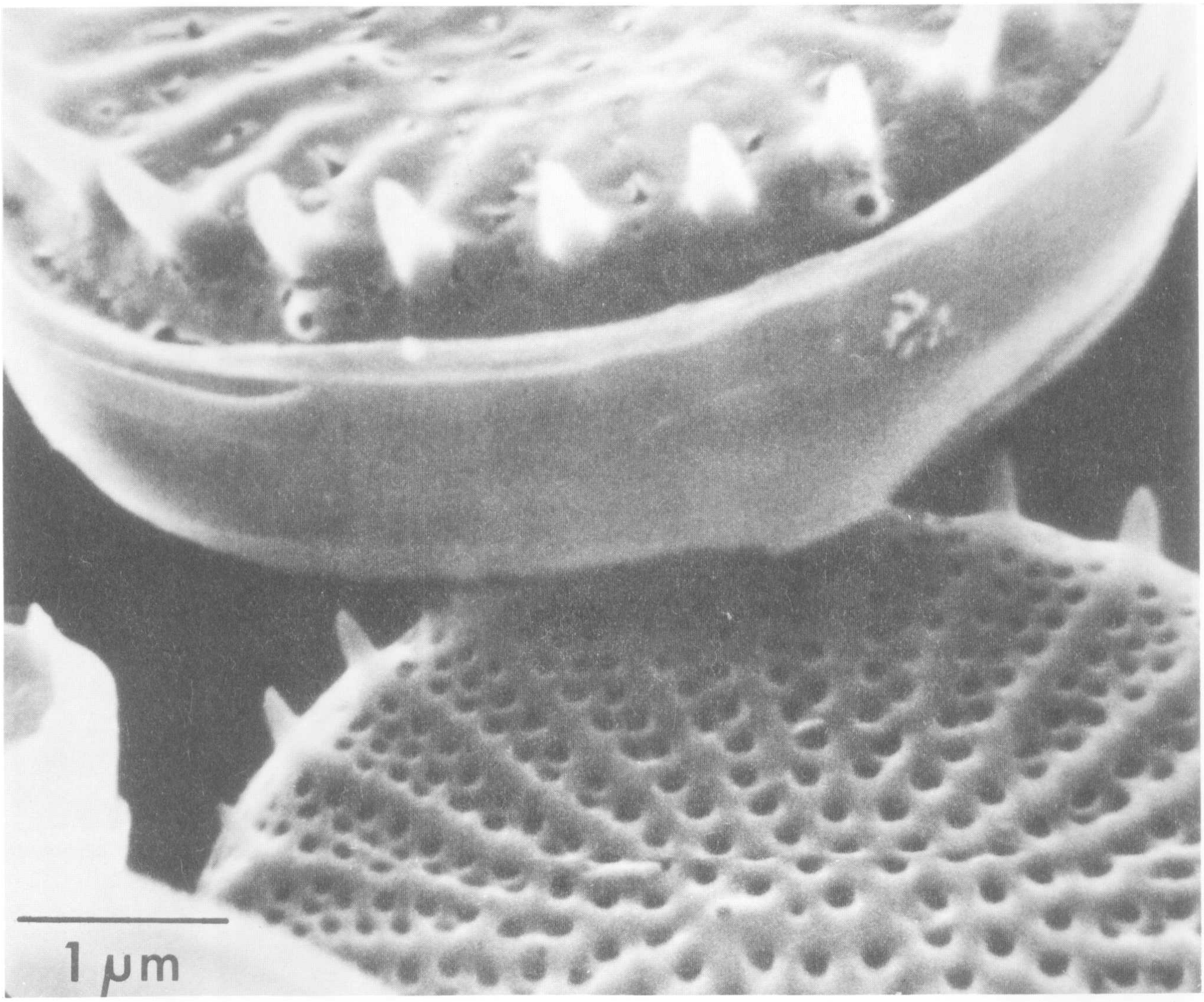


Plate 26—Scanning electron micrograph of a Stephanodiscus*—a centric diatom common in the early spring plankton of Loch Leven. The upper cell shows peripheral spines, sub-spinal tubes and girdle bands. The lower cell shows a cleaned valve surface from the outside, with radically arranged ridges extending to the edge spines, and troughs between them with rows of poroids.*
Photograph A. E. Bailey-Watts.

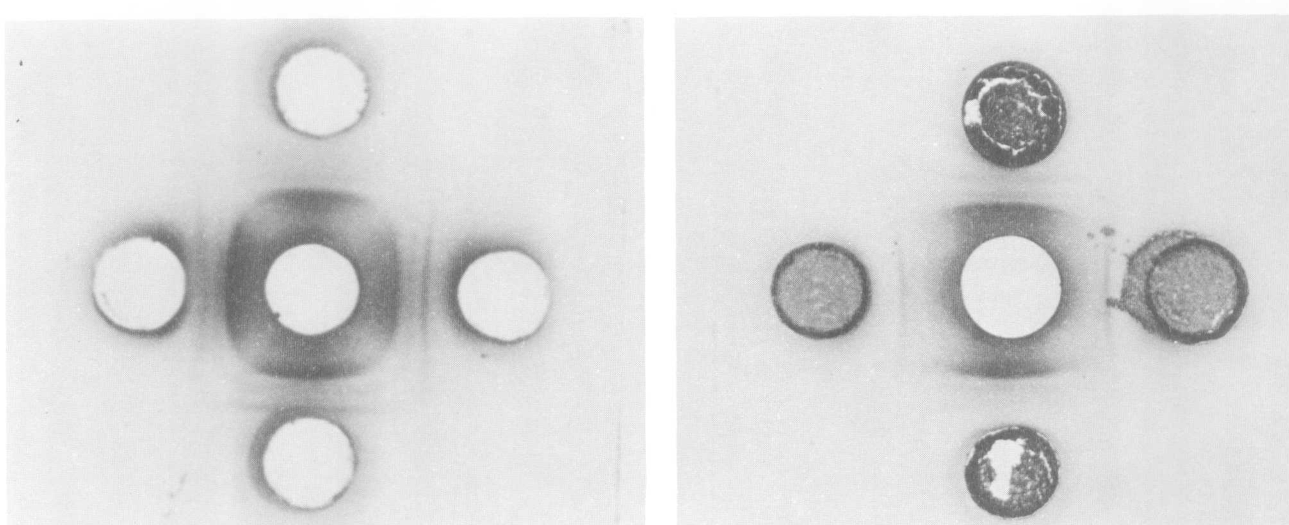


Plate 31—Precipitation bands formed when antiserum produced against mycelium of Mycena galopus *(in central wells) reacted with antigenic preparations of* M. galopus *(in all outer wells of left-hand photograph and north/ south wells of right-hand photograph) and of* M. alcalina *(in east/west wells of right-hand photograph) in a gel-diffusion test for specifity of the antiserum. Diameter of wells approximately 4 mm.*
Photograph Jane Chard.

Two lines of investigation were followed. One established that these seabirds, in common with many other forms of life, probably contain the protein metallothionein which is thought to limit the toxicity of cadmium (Osborn 1978). The other approach was to examine the structure of tissues by electron miscroscopy for signs of damage from cadmium exposure. Attempts were also made to locate the exact position of cadmium in any damaged tissue, since this would give clues to its biochemical activity. Such information is needed if we are to assess properly the effects of cadmium on animal and human health.

The results of this second line of investigation showed quite clearly that, in laboratory experiments, cadmium concentrations at and below those found in St Kilda seabirds caused extensive damage to the kidneys of laboratory mice (Swiss AG strain) and captive starlings (*Sturnus vulgaris*). Strikingly similar damage was also found in the wild St Kilda seabirds examined, puffin (*Fratercula arctica*), fulmar (*Fulmarus glacialis*), and Manx shearwater (*Puffinus puffinus*) (Plates 22–25) (Nicholson in press).

This research raises at least 2 important questions:

1. If metallothionein is present, why is it not protecting the animal from kidney damage?
2. Is the damage to kidney sufficient to impair kidney function, or to reduce survival or breeding success below that of birds at colonies where lower cadmium concentrations are found?

Work on this topic is continuing; on the physiological side, much depends on localising the cadmium without the cell. Already it seems that much more cadmium is present in the darker cells of affected kidneys than in the lighter (younger?) cells (Kendall & Nicholson in press). This result emphasises the importance of the degree to which animals can replace damaged kidney cells—simultaneously perhaps excreting stored cadmium.

This study may provide results relevant to human and domestic animal health, in addition to determining the effects of cadmium on the seabirds of St Kilda, as similar results have been obtained in captive starlings, wild seabirds, and a standard strain of laboratory mice. Severe damage occurs at tissue concentrations of about 100 mg kg^{-1} Cd dry weight—a level below the current WHO 'safe' limit for human kidney cortex—and marked damage also occurs at lower tissue levels, equivalent perhaps to those found in many human kidneys.

J. K. Nicholson and D. Osborn*

*a CASE student

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DEVELOPMENT OF ASSAYS TO MEASURE RABBIT PITUITARY HORMONES

Most changes in the environment that influence breeding in the wild rabbit have their effects through the animal's hormonal system. At the base of the brain lies the pituitary gland which secretes small protein hormones into the blood stream. Several hormones are produced by the pituitary, of which the so-called 'gonadotrophins' are responsible for the control of breeding. These gonadotrophins are of 2 types: luteinizing hormone (LH) and follicle stimulating hormone (FSH).

In order to understand the relative importance of various environmental factors on rabbit breeding, it was essential to be able to measure changes in blood concentrations of LH and FSH during the course of the year and at different stages of breeding. In view of the low concentrations of hormones involved, this measurement could only be done by developing highly sensitive radioimmunoassays. For radioimmunoassays, hormone molecules are attached to radioactive iodine atoms, and the amount of radioactively labelled hormone is determined using a radiation counter. Using this technique, as little as one or 2 molecules of the hormone can be detected.

When any foreign hormone is injected into an animal, antibodies are produced that bind the hormone and inactivate it. The amount of antibody in the animal's blood is assessed according to the amount of radioactively labelled hormone it will bind. This amount is usually expressed as the dilution of the blood containing the antibodies that is required to bind a set proportion of labelled hormone added. As illustrated in Figure 40, the amount of antibody produced increases with repeated injection of the hormone.

In this study, antibodies were raised against sheep LH and FSH because the relatively large amounts of purified rabbit hormones needed for immunization were not available. Fortunately, sheep and rabbit LH and FSH are sufficiently similar that the antibodies will bind both corresponding hormones (Figure 40).

In radioimmunoassays, a constant amount of both antibody and radioactive purified hormone is added to all tubes. To a series of these tubes is added *different* known dilutions of an unlabelled preparation of the same hormone. The unlabelled and radioactively labelled hormones compete for binding to the antibody and the amount of each that becomes bound is proportional to the concentration of each hormone present. In the absence of unlabelled hormone, all the radioactive hormone will be bound to the antibody (ie = 100% bound, Figure 41). Increasing concentration of unlabelled hormone in the assay series reduces the amount of labelled hormone bound to the antibody. When expressed as a percentage of maximum labelled hormone binding (ie 100% bound), a dose response curve is produced (Figure 41).

For a good radioimmunoassay, the antibody should have a marked preference for its corresponding hormone over any other similar hormone that might be present. For the FSH assay, as little as 0·1 ng/tube can be detected, whereas the concentration of TSH must be 150 times greater and that of LH 400 times greater in order to be detectable in the assay. The FSH antibody does not bind to the other pituitary hormones, prolactin or growth hormone. For rabbit LH, as little as 0·02 ng/tube is detectable. Thus, specific assays for LH and FSH can be produced by use of appropriate antibody preparations. We are now in a position to begin to measure gonadotrophin concentrations in rabbit blood through the year, and thus to gain greater understanding of the factors controlling breeding.

D. T. Davies

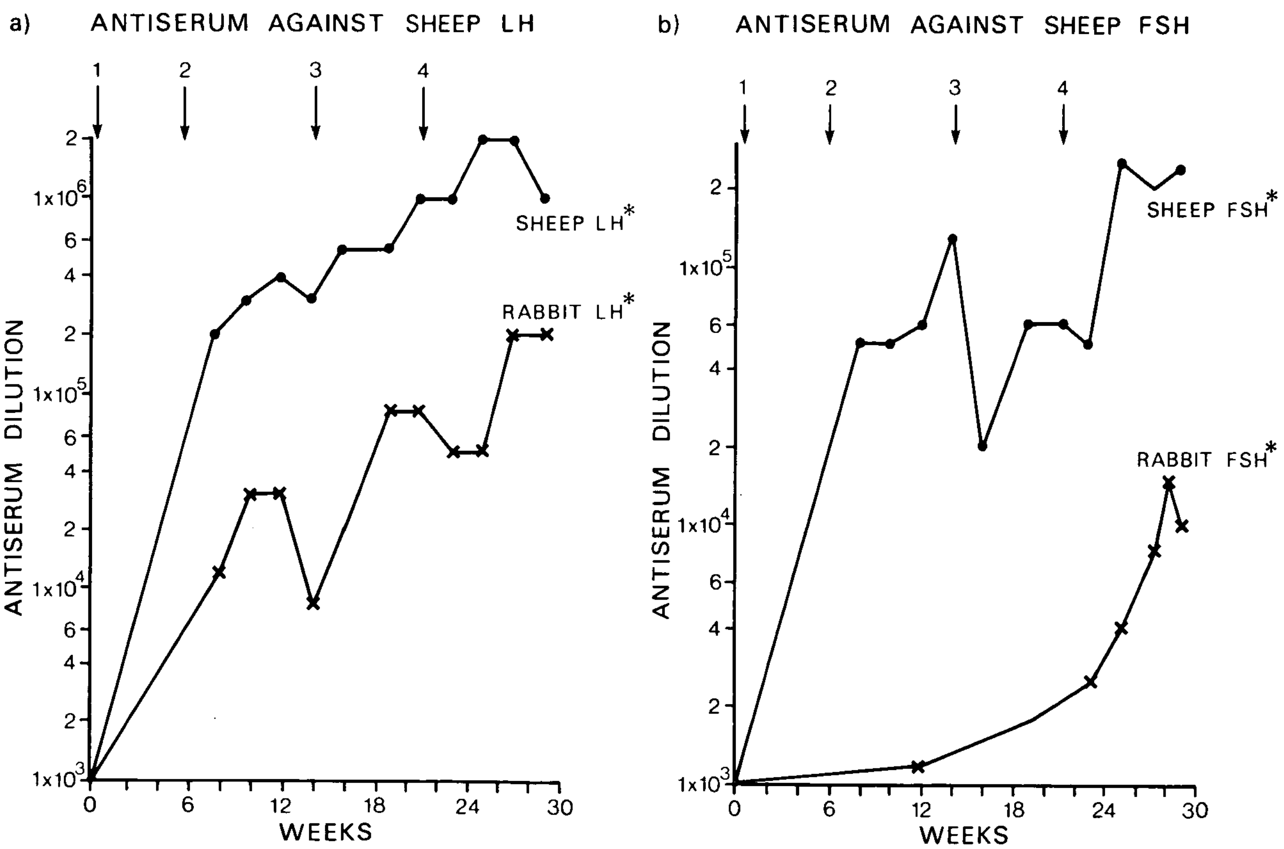

Figure 40 Change in antibody concentration from 2 rabbits immunized with (a) sheep LH and (b) ovine FSH. At times indicated by arrows 1, 2 and 4, 700 µg of hormone were injected into the skin. Injection 3 consisted of the same amount of hormone given beneath the skin. Antibody concentration is expressed as the reciprocal of the antibody dilution required to bind 40% of the radioactively labelled sheep or rabbit purified hormones added [LH-radioactively labelled LH; FSH*—radioactively labelled FSH].*

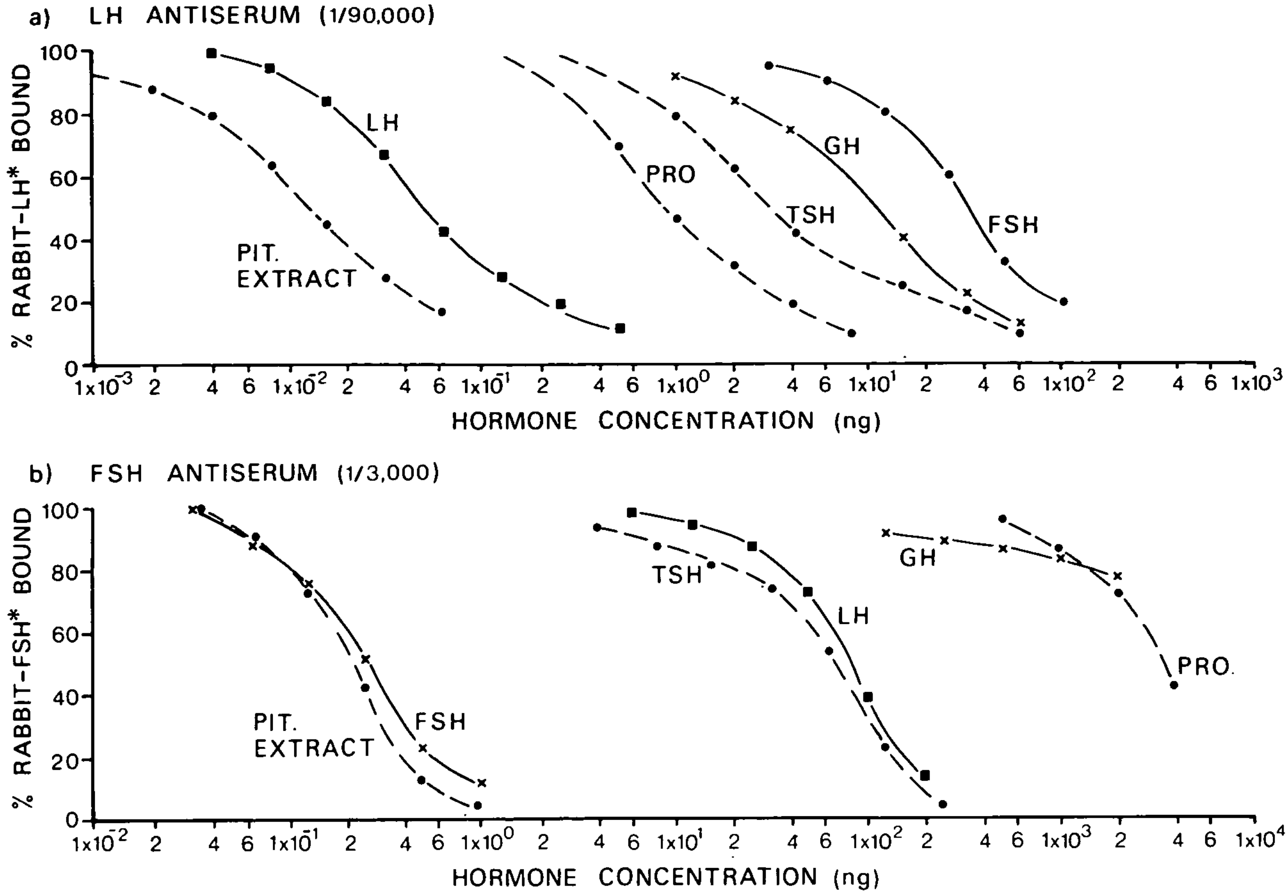

Figure 41 Illustrations of specific radioimmunoassays for (a) rabbit luteinizing hormone (LH) using a final antibody dilution of 1/90,000 and (b) rabbit follicle stimulating hormone (FSH) at a final dilution of 1/3,000. Radioactively labelled purified rabbit LH and FSH* are used as 'tracers' and the amount of detectable hormone is expressed in nanograms/tube. [ng ≡ 1/1,000,000,000 g]. With the corresponding hormone (ie LH in (a); FSH in (b)) and a rabbit pituitary gland extract, a reduction to 50% binding of the labelled hormone is achieved at very low concentrations, while much higher levels of the other pituitary hormones are required to produce the same response. Note that the LH assay is 10 times more sensitive than the FSH assay. [TSH, thyroid stimulating hormone; PRO, prolactin; GH, growth hormone].*

Plant Biology

GENECOLOGY OF *SPHAGNUM*

Because ranges of morphological forms often exist within species of *Spagnum*—within species variation, some early systematists created classifications in which each species had several sub-species or varieties. However, observations in the field, or on plants grown in culture, suggest that morphology may change in response to environmental conditions. An example is a more plumose form, eg of *S. cuspidatum,* growing in pools. In this instance, the distinction between pendent and spreading branches becomes less obvious than in terrestrial forms, while branch leaves become more elongated and more divergent from branch axes. These observations have given rise to conflicting concepts about the origins of morphological variation. One theory implies that morphological differences are genetically determined, whereas the other suggests that the environment is of over-riding importance, with genetic variation playing only a minor role. Genetics and environmental conditions together determine the final form of plants in the field, but what is the relative importance of each?

Four closely related species of the sub-generic group Cuspidata are being investigated, namely (using the nomenclature of Isoviita 1966) *S. pulchrum, S. flexuosum, S. angustifolium* and *S. fallax.* These species have been confused, but careful observations have identified a number of morphological characters which, taken in combination, are sufficient to separate them.

To show patterns of variation, assessments are being made of quantifiable characters, including stem leaf lengths, length/width ratios of stem and branch leaves, and numbers of pores on the adaxial surface of hyaline cells of branch leaves, a measure of porosity. Samples have been collected throughout Britain and for initial presentation have been divided into groups from main geographical areas. When they have all been characterised in detail, trends will be fully investigated using multivariate analysis.

However, the types of variation can be illustrated from observations made on *S. pulchrum* and *S. fallax* (Figures 42 and 43).

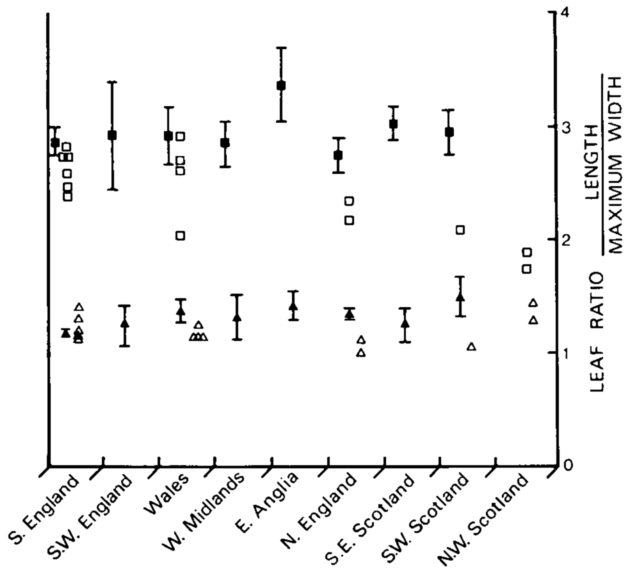

Figure 42 Variation in length/width ratios of stem leaves (▲, △) and branch leaves (■, □) of samples of Sphagnum fallax *(▲, ■) and* S. pulchrum *(△, □) collected from many locations in Britain.*

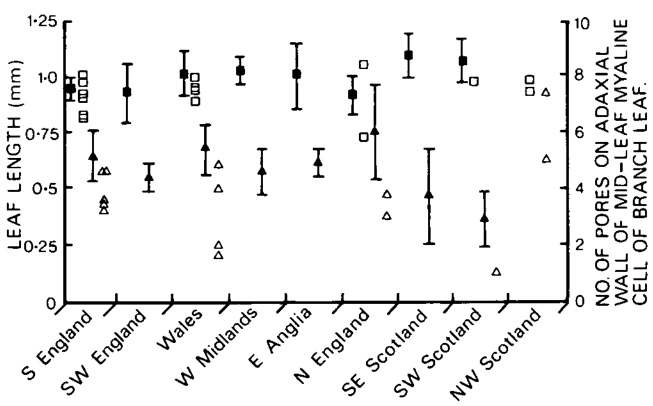

Figure 43 Variation in stem leaf lengths (■, □) and numbers of pores in the walls of mid-leaf hyaline cells (▲, △) of samples of Sphagnum fallax *(▲, ■) and* S. pulchrum *(△, □) collected from many locations in Britain.*

NB In both figures, mean values and 95% confidence limits are shown for measurements of S. fallax *characters. As the number of* S. pulchrum *samples examined to date is small, individual results are shown.*

Stem leaves tend to be less variable morphologically than branch leaves and this is reflected in the similarity of (i) lengths and (ii) length/width ratios of stem leaves on all specimens of *S. fallax* so far sampled. For the most part, branch leaf ratios are also similar, except that those of samples from East Anglia are larger. However, the extent to which local variation occurs may differ considerably. Extreme values among the highly variable group from south-west England are from plants growing on the same site, whereas samples spread across southern England, from Dorset, through the New Forest to Surrey and Ashdown Forest, show a low level of overall variation. There is a suggestion that the porosity of branch leaf hyaline cells decreases further northwards. *S. pulchrum* appears to be less variable, but the few data available so far suggest that branch leaves are relatively shorter in relation to their width in northern England and Scotland than in southern England.

As *S. fallax* has a very widespread distribution throughout Britain, it might be anticipated that clinal change in characters might be found in response to overall changes in conditions. In contrast, *S. pulchrum* has a disjunct distribution, and the populations found in the different locations are widely separated from each other. They also grow in different climatic and physico-chemical environments (valley mires in Dorset, raised bog in central Wales and north-west England, and high oceanic raised/blanket bog in western Scotland), and so some divergence might be expected. In most features, this divergence does not seem to occur.

Although several biochemically different clones have been identified by using electrophoresis, this technique has shown that they are not restricted to particular sites; more than one clone is usually present, even within a continuous carpet of *Sphagnum.* Two clone types are easily distinguished in both *S. pulchrum* and *S. fallax:* a red variant and a yellow variant. Both red and yellow forms of *S. pulchrum,* which are distinct in terms of their isozymes, are found in Dorset, in Wales and in Argyll. Remembering that *S. pulchrum* seems to enter the sexual phase very rarely in Britain – only one spore capsule has been reported – how does this within-site variation arise, and how extensive is it?

A similar range of variation has been found in 'biochemical clones' of *S. fallax, S. flexuosum* and *S. angustifolium* (species in which capsules are not uncommon): it does not appear to follow a geographical pattern.

Despite the isoenzyme variations within the different species, there appear to be common and characteristic bands or combinations of bands which enable the species to be separated. Distinct banding combinations also appear to exist for at least some of the sub-generic groups, eg section *Sphagnum* (Cymbifolia) show sets of bands common to all the British species.

These studies indicate that individual populations may contain a variety of genetically different clones whose responses to changed environmental conditions may differ. The responses of samples taken from variable populations of this sort suggest that the effects of water table and chemical environment, when tested in controlled conditions, are minimal, except in extreme circumstances. However, the effects may have been obscured by the use of genetically variable samples. To overcome this problem, clones are being cultured from selected parent plants.

R. E. Daniels

Reference

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POPULATION DYNAMICS OF BURIED SEEDS ON MOUNTAINS

At many locations, ground which has been disturbed by the activities of man, by rapid snow melt, severe frost heave and intense exposure, is recolonised by plants growing from wind-blown propagules (forming 'seed rain') and seeds which have remained viable while buried in soil (the elements of a 'seed bank'). The importance of 'seed rain' and 'seed banks' will differ greatly from habitat to habitat, the size of both reflecting the climatic and edaphic restrictions to seed production.

When studying *Calluna vulgaris* along altitudinal gradients, Miller and Cummins (1976) found that seeds were not formed in some seasons at locations in the Cairngorm Mountains above 600 m. More recently, parallel studies of seed rain and seed banks have been made at sites at different altitudes where either *C. vulgaris* or *Nardus stricta* is the dominant plant species. These species are common components of plant associations in the Cairngorms and range widely in altitude from <200 m up to 900 m (*C. vulgaris*) and 1200 m (*N. stricta*).

Seed rain

C. vulgaris and *N. stricta* produced many thousands of seeds m^{-2} in 1978 at sites below 650 m: they were shed continuously for 14 months by *C. vulgaris* (Figure 44) and for 11–13 months by *N. stricta* (Figure 45). Above 850 m, seed shedding by both species was sparse and intermittent.

The rate at which seeds of *C. vulgaris* were shed at 370 m and 580 m was maximal in November 1978, when about 90% of seeds could germinate (Figure 44): fewer of the seeds dispersed earlier and later could germinate. Thus, in September, when there was a mixture of seeds formed both in the current and previous seasons, germination was especially poor. At 860 m, only seeds shed from March – May had the ability to germinate.

As with *C. vulgaris*, the shedding and ability to germinate of seeds (caryopses) of *N. stricta* varied seasonally (Figure 45). In this instance, rates of shedding and ability to germinate at 300 m and 610 m were maximal from August to October 1978; most of the seeds shed in May-August 1979 had lost their viability.

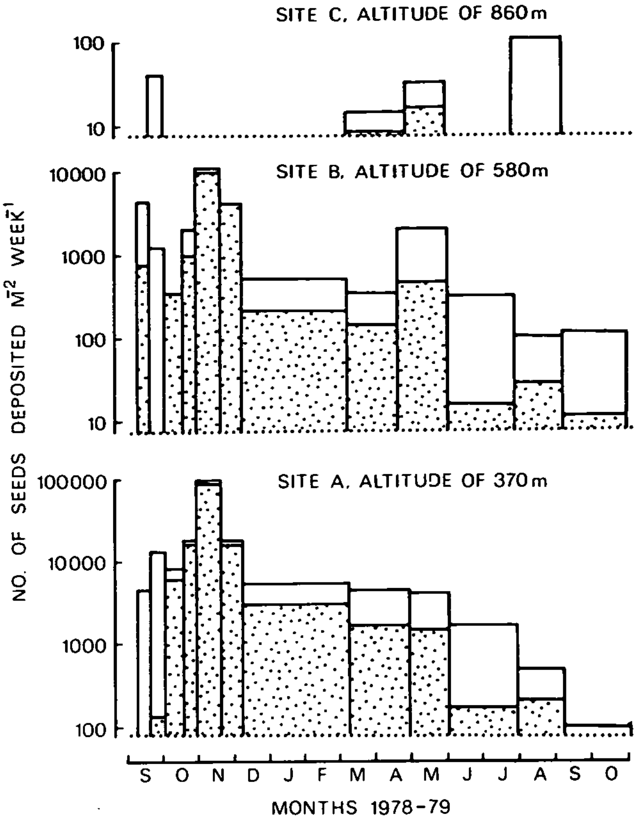

Figure 44 Rates at which seeds of Calluna vulgaris *were deposited on heathland at different altitudes (□, total numbers of seeds; ▨, numbers of viables seeds).*

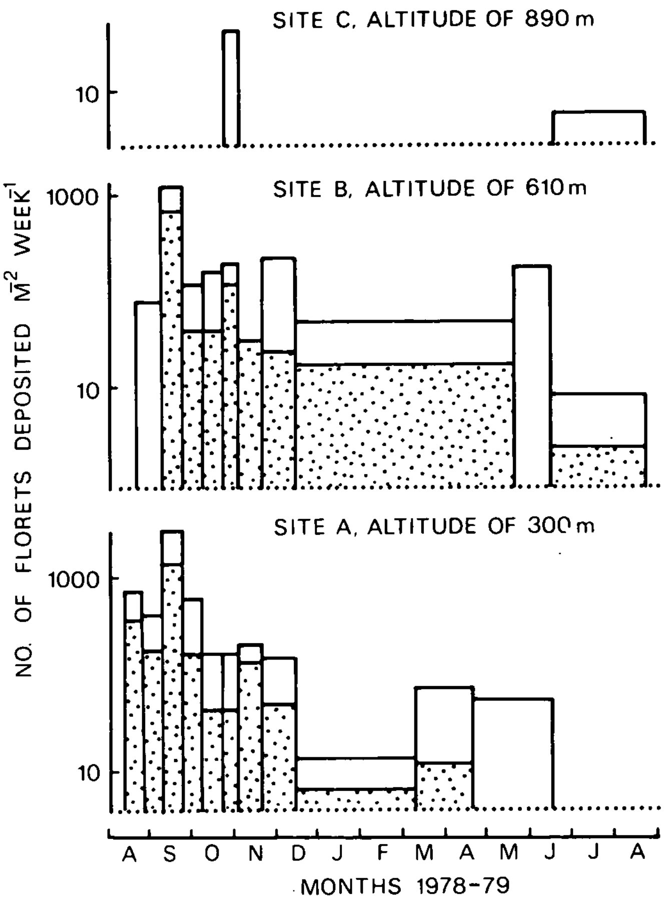

Figure 45 Rates at which florets of Nardus stricta *were deposited on grassland at different altitudes (□, total numbers of florets; ▨ numbers of florets with viable caryopses).*

Table 25. Seed rain and seed bank at sites dominated by:
(a) *Calluna vulgaris* and (b) *Nardus stricta* at low, intermediate and high altitudes

Vegetation type	Altitude (m)	Species (10^3 m^{-2})	No. of germinable seeds shed in 1978–79 (10^3 m^{-2})	No. of naturally occurring buried seeds that germinated when soil was sampled in July 1978 (10^3 m^{-2})
(a) *Calluna vulgaris* heathland	370	*C. vulgaris*	418	69
		Others	3·3	41
		Total	421	110
	580	*C. vulgaris*	53	68
		Others	0·19	17
		Total	53	85
	860	*C. vulgaris*	0·24	14
		Others	0·0	4·1
		Total	0·24	18
(b) *Nardus stricta* grassland	300	*N. stricta*	5·0	3·2
		Others	17	44
		Total	22	47
	610	*N. stricta*	2·3	2·7
		Others	0·96	32
		Total	3·3	35
	890	*N. stricta*	0·0	0·46
		Others	0·0	4·7
		Total	0·0	5·2

The production of germinable seeds decreased rapidly with increasing altitude (Table 25). At heathland sites, numbers of *C. vulgaris* seeds decreased from 400 000 seeds per m^2 at 370 m to a mere 240 seeds per m^2 at 860 m. At the grassland sites, numbers of seeds of the dominant *N. stricta,* which contributed less than 70% to the total seed rain, decreased from 22 000 per m^2 at 300 m to zero at 890 m.

Seed bank

Numbers of germinable seeds buried in the top 50 mm of soil decreased at increasing altitudes, but the changes were less severe than those of the seed rain (Table 25). As a result, the seed banks of *C. vulgaris* and *N. stricta* were smaller (17% and 64% respectively) than the current year's seed rain at low altitude, slightly larger (128% and 117%) at intermediate altitudes, and greatly in excess at high altitudes. These percentages imply a faster loss of buried seeds at low than at high altitudes. At high elevation, temperatures are colder and presumably there are fewer losses attributable to germination, predation and fungal decay. Because the bank of viable seeds of *C. vulgaris* at 860 m was 58 times larger than one year's seed rain, it seems that seeds of this species may retain viability for many years. Additionally, it highlights the importance of montane seed banks, despite their small size, to the natural re-establishment of vegetation where the annual production of seeds is uncertain. Further studies are being made of factors controlling gains to, and losses from, seed banks.

G. R. Miller and R. P. Cummins

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DAMAGE TO LICHENS BY TRAMPLING IN THE CAIRNGORM MOUNTAINS

Slight damage to vascular plants caused by trampling is difficult to detect: the debilitating effects on many montane species of the Ericaceae may result in slow die-back for a year or more after disturbance (Bayfield 1979). In contrast, damage to lichens (broken or crushed thalli) is immediately recognisable: as yet there is no evidence of delayed die-back or bruising. For these reasons, the potential of lichens as indicators of trampling damage has been investigated. In the Cairngorms, the widespread and frequent species *Cladonia uncialis, C. impexa, C. arbuscula* and *C. rangiferina* were studied, with assessments of damage being made in quadrats at different distances from footpaths with a known visitor usage (range 0–<18·8 people/day).

Damage to *C. uncialis* was maximal, 22% by area, near to paths that were frequently used (Figure 46). Amounts of damage were appreciably less on infrequently used footpaths and declined as the distances from footpaths increased. However, at the most heavily used sites, damage was significantly greater than at less frequented sites even 50 m from paths. The other species of *Cladonia* were not as severely damaged as *C. uncialis*, but the patterns of their responses to the different intensities of use were nonetheless similar. The maximum 22% damage to *C. uncialis* was matched by 16%, 10% and 6% on *C. arbuscula, C. rangiferina* and *C. impexa* respectively.

Lichen evidence has confirmed that damage is likely to be more extensive adjacent to paths crossing open terrain, where there are few constraints on walkers, than alongside confined paths where the terrain and/or other

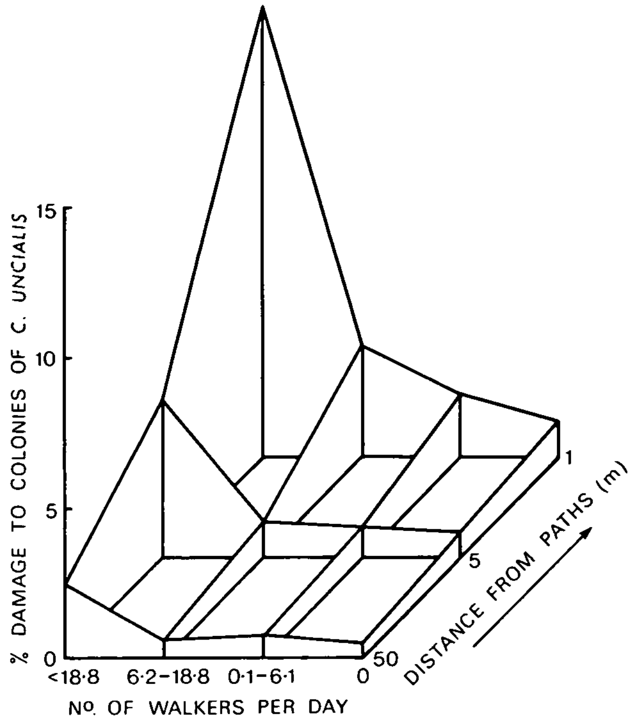

Figure 46 Effects of different numbers of walkers on the damage done to the terrestrial lichen, Cladonia uncialis, *at different distances from footpaths in the Cairngorm Mountains.*

features restrict the freedom of walkers to wander (Table 26). Damage to lichens was substantially greater both 1 m and 50 m from open than confined paths, for all 4 species.

The extent of damage to lichens by trampling was influenced by their water content. Figure 47 shows the relationship between water content and damage for *C. uncialis,* and similar relationships were found for the other 3 species. At a water content below about 25% of oven dry weight, breakage increased dramatically. There appeared to be a fairly abrupt change from a condition where podetia were elastic and pliable to one of inelasticity and brittleness. There was also a greater fragmentation of dry lichen thalli than moist thalli.

This study has shown that naturally occurring lichens are, and can be used as, sensitive indicators of

Table 26. Damage (%) done by trampling to naturally occurring colonies of 4 species of *Cladonia* spaced 1 and 50 m from 'open' and 'confined' paths in the Cairngorm Mountains. (Data taken from paths with at least 6·2 visitors per day)

	Distances from paths			
	1 m		50 m	
Type of path	Open	Confined	Open	Confined
C. uncialis	21	3·8	2·4	1·0
C. arbuscula	13	3·7	1·2	0·6
C. rangiferina	10	0·7	1·6	0·5
C. impexa	11	1·1	1·8	0·3

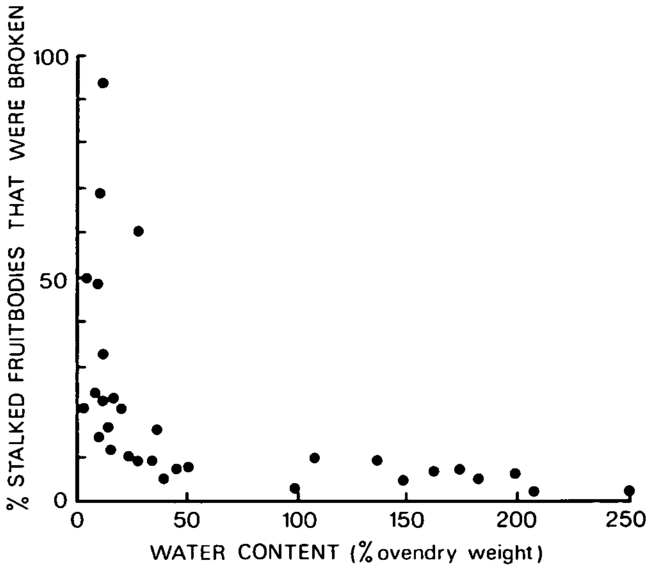

Figure 47 Effects of tissue moisture on the % breakage of thalli of Cladonia uncialis *resulting from a single footfall of a person weighing 55 kg.*

trampling distance. Because some damage can be detected at distances of 50 m from paths, it seems that low levels of trampling may be widespread on high altitude plateau areas of the Cairngorms where the ground is 'open' and where there are many footpaths.

N. G. Bayfield

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ENVIRONMENTAL INFLUENCE ON SHOOT GROWTH IN SITKA SPRUCE

In temperate regions, weather can change with a range of frequencies: (i) from day to day, a *high* frequency of change, (ii) over periods of a few days to one or 2 weeks *intermediate* frequency, as a result of changes in atmospheric pressure systems, or (iii) gradually from season to season, *low* frequency. The amplitude of these changes is usually least for those occurring at a high frequency and greatest for those occurring at a low frequency. They affect tree growth in distinctive ways.

1. Immediate response. Daily changes of the weather can have direct and measurable effects on growth rates.
2. Acclimatization. When conifers are subjected to changes of weather sustained for 20 or more days, the physiological mechanisms concerned with growth are known to be modified, ie they acclimatize to different sets of conditions.
3. Adaptation. Although photosynthesis may continue throughout the year whenever conditions are favourable, tree growth occurs during restricted, defined periods. In Britain, the main period of

shoot growth in conifers is restricted to 30–40 days in late spring and early summer, a period reflecting the growing seasons these conifers experience in their native habitats mostly in north-west America, ie the trees are adapted to the length of the growing season.

The study of tree growth in natural environments is complicated by (i) the sometimes simultaneous occurrence of low, intermediate and high frequency weather changes, and (ii) the range of mechanisms involved in the responses of trees to environmental changes which are not always distinct. For example, termination of shoot extension has been correlated with decreasing daylengths after mid-summer, but shoot extension is also affected by temperature. To study the effects of environmental changes, experiments are being done in 2 controlled environment rooms installed at ITE's laboratories on the Bush Estate, near Edinburgh, and each able to house 25 trees up to 1·5 m tall. Air temperatures can range from −8°C to +30°C, so encompassing most of the temperatures experienced in upland Britain. At air temperatures greater than 5°C, relative humidity can be controlled between 50% and 90%. In addition, weather conditions and amounts of light can be varied (because they are controlled by a micro-processor based system) to give different and continuous patterns of change over different periods of time. The effects of low and high frequency changes can be tested concurrently.

Observations in forests indicate that shoot extension is positively related to increasing temperatures and amounts of light, the effects of increasing temperature as suggested by Ford (1980) being to increase the rates of plant reserve mobilization, whereas increasing amounts of light are likely to create supplies of photosynthates for immediate growth. To examine these 2 factors, vegetatively propagated Sitka spruce were placed in the 2 controlled environment rooms just prior to bud break. In one room ('constant'), trees were grown at a constant temperature of 13°C, in 19 h days

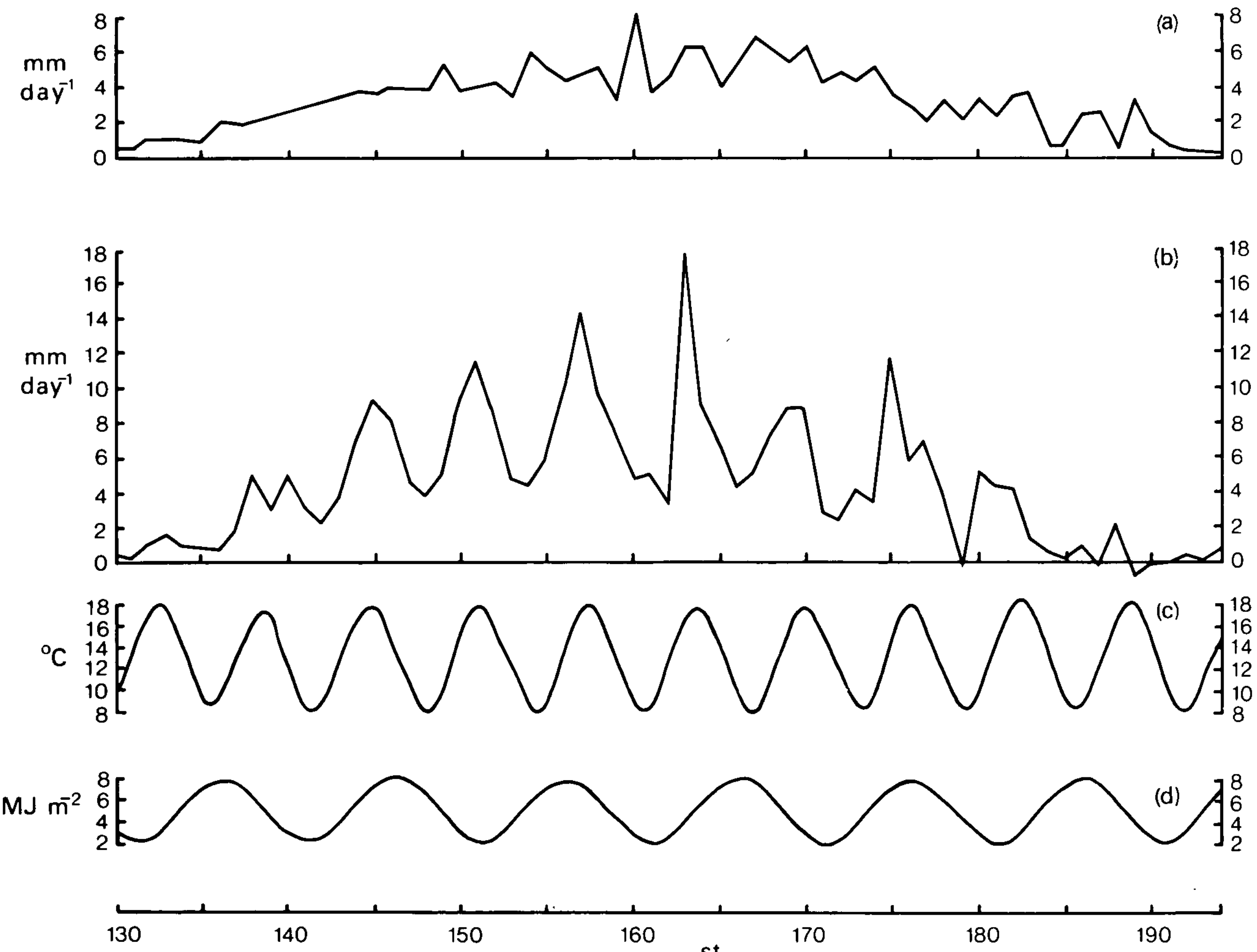

Figure 48 Cyclical patterns, after bud break, of leading shoot extension in vegetatively propagated Sitka spruce. (a) Trend of increasing and decreasing increments when growing in an unchanging environment of 13°C and 5 MJ m^{-2}. (b), (c), (d). Data related to shoot extension in a varying environment with changes of temperature and light intensity shown in (c) and (d) respectively. Inspection of (b) shows, despite the existence of the trend noted in (a), that the extent of shoot elongation is also related to temperature fluctuations, but not to those of light.

with daily amounts of radiation equalling 5 megajoules per square metre (MJ m^{-2}). In the other 'fluctuating' room, daylengths followed the seasonal pattern of change after bud break: radiation, in periods of 10 days, changed, following a sine wave, from 3 to 7 MJ m^{-2} with a mean of 5; temperature changes, like those of radiation, followed a sine wave pattern, but in this instance of 6·25 days' duration—they ranged from 10·5°C to 15·5°C with a mean of 13°C (Figure 48). In the 'constant' room, the daily increments of shoot growth, measured with an automatic shoot extension sensor (ITE Annual Report 1979, p93), followed a progressive pattern of increase and decrease. In the 'fluctuating' room, the increments closely followed the sine wave of temperature, the sizes of the responses changing as growth proceeded.

Remembering that numbers of needle primordia are, after the seedling phase, mostly predetermined in buds of Sitka spruce, these results suggest:

1. Shoots grow with a cycle of enlarging and diminishing increments—the evidence from the 'constant' environment room indicates that this cycle is not related to changing daylengths: observations from the 'fluctuating' room show that the cycle persists, despite fluctuating temperatures and amounts of radiation.
2. Shoot increments, which vary from day to day, are strongly influenced by changes in temperature, the magnitude of the responses changing as growth proceeds.
3. Shoot increments were not altered by the amounts of light tested.

Together, conclusions 2 and 3 suggest that shoot extension is not dependent upon current photosynthates, but instead upon rates of plant reserve mobilization. This conclusion supports the suggestion made by Ford and Deans in this Report (see page 80) to explain the large production of coniferous forests, namely that their growth relies, to a considerable extent, upon the mobilization of reserves produced at times of the year when conditions favour photosynthesis, but when growth does not occur. However, this conclusion would not apply to the 'free' growth of seedlings. In this instance, growth would be dependent upon current photosynthates, amounts of which would, in turn, depend upon the production of needles, a process that is strongly temperature dependent.

E. D. Ford, E. J. White and R. Milne

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THE HIGH RATE OF PRODUCTION ACHIEVED BY A PLANTATION OF SITKA SPRUCE

There is an increasing world demand for wood and timber products, and it seems likely that shortages will develop and that costs will increase during the next 20 years. As the United Kingdom is dependent upon other countries to a very large extent—it imports 92% of its timber requirements—it is particularly vulnerable. To lessen the risks, it has been suggested that the area of coniferous forest in the UK should be doubled (Forestry Commission 1977; Centre for Agricultural Strategy 1980), but the effect of this increase depends upon production per unit area.

Many studies have shown that rates of volume increase are maximal at a relatively early stage in the development of coniferous plantations; they decrease thereafter. To quantify these changes and to relate them to photosynthetic area and to apportionment of dry matter between bole, branches, needles and roots, observations were made of a typical plantation in Dumfriesshire of Sitka spruce (*Picea sitchensis*)—the principal plantation species.

Above-ground biomass was estimated 16 and 18 years after planting when rates of production would be nearly maximal. Having measured the basal areas of 7 and 9 trees in the different years, the trees in question were felled and separated into bole, branches, and needles of different ages before being weighed dry. From (i) regression equations relating dry weights to basal area, and (ii) measurements of basal area of a large number of trees, it has been possible to estimate the forest production of biomass. Root growth is particularly important in the UK, where forests are frequently subject to strong winds and consequent risks of windblow. The biomass of thick, structural roots was estimated after excavating the intact root systems of 8 trees 16 years after being planted. Roots were sectioned to identify annual rings and to relate biomass increments to their year of formation. The biomass of fine roots (<0·2 cm diameter) was estimated from fragments in soil cores taken at regular intervals (Ford & Deans 1977).

Net above-ground dry matter (tops) production was estimated to be 25·5 tonnes ha^{-1} yr^{-1} (Table 27), considerably greater than the mean production of coniferous forests in temperate zones, namely 14·5 tonnes ha^{-1} yr^{-1} (Kira 1975). When the weights of roots were added to those of tops, the annual production of Sitka spruce in Dumfriesshire reached 34·0 tonnes ha^{-1} yr^{-1}, a production estimate many times greater than those for annual crops which, in the UK, are generally 5 tonnes ha^{-1} yr^{-1}, excepting sugar beet and fodder maize which reach 7—9 tonnes ha^{-1} yr^{-1}.

The high production of coniferous forests has been attributed to their maintenance of large amounts of foliage throughout the year, but is Sitka spruce a typical

Table 27. Mean biomass and net annual production of a young stand of Sitka spruce (*Picea sitchensis*) growing in Dumfriesshire, south Scotland. (Data are means of assessments made 16 and 18 years after planting)

	Biomass Tonnes ha^{-1}		Production Tonnes ha^{-1} yr^{-1}	
Above ground ('tops')				
Bole	54		16·2	
Branch	23		3·6	
Foliage	25	102	5·7	25·5
Below ground				
Fine roots	5		5·3	
Thick roots	20	25	3·2	8·5
Totals of tops and roots		127		34·0

conifer? In seeking an answer to this question, it is instructive to compare the production of tops by Sitka spruce with comparable data for 2 other productive temperate forests: *Tsuga heterophylla* in Oregon, USA, producing 30·7 tonnes ha^{-1} yr^{-1} (Fujimori 1971), and plantations of *Pinus radiata* in New South Wales, Australia, producing 22·4 tonnes ha^{-1} yr^{-1} (Forrest & Ovington 1970). Of these, the Sitka spruce plantation (i) had the largest foliage biomass (*P. sitchensis* 25 tonnes, *T. heterophylla* 21 tonnes, *P. radiata* 7 tonnes), (ii) invested more in new foliage, as a proportion of total above-ground production (*P. sitchensis* 0·29, *P. radiata* 0·27, *T. heterophylla* 0·24), but (iii) produced less above-ground biomass per unit weight of foliage (*P. sitchensis* 1·0 g g^{-1} yr^{-1}, *T. heterophylla* 1·5 g g^{-1} yr^{-1}, *P. radiata* 3·4 g g^{-1} yr^{-1}). It seems, therefore, that the productivity of the Sitka spruce plantation is more dependent upon the maintenance of large amounts of foliage than that of *T. heterophylla* and *P. radiata*.

Interestingly, the maximum annual basal area increment was observed to be coincident, in the Sitka spruce plantation, with the period when annual increment of new needles was also maximal—the areas of first year needles per unit ground area changed from 2·63 in the fourteenth year after planting to 2·80, 2·90, 2·42 and 2·00 in successive years. It was also the time when the effects of competition on basal area relative growth rates were first observed, competition possibly also being the cause of decreased needle production, particularly of shaded small trees. Because the annual increments of new needles (per unit ground area) decreased, it seems that their production by large trees did not compensate for losses attributable to the demise of small trees.

New roots and current season increments to thick roots account for 34% of root biomass, more than 60% of which is allocated to short-lived fine roots; successive within-season observations showed that the annual production of fine roots exceeded mean fine root biomass by 46%. Like those of basal area, annual thick root increments decreased in parallel with the decreased rates of needle production.

The rate of dry matter production reported here for Sitka spruce is likely to be close to the maximum achieved by the plantation during its lifetime. As a consequence, the average rate, during a complete forest rotation, will be less: the UK national average has been estimated to be 3–4 tonnes ha^{-1} yr^{-1}, a rate of production comparable to that achieved by arable crops which in the UK, unlike forests, are mostly grown in lowland environments with annual applications of fertilizers.

E. D. Ford and J. D. Deans

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FUELS FROM NATURAL VEGETATION AND PLANTS INTRODUCED TO GREAT BRITAIN

(This work was largely supported by EEC and Department of Energy funds)

Introduction

Two recent desk studies (Callaghan *et al.* 1978; Lawson *et al.* 1980) have shown that natural, and semi-natural, assemblages of plants have considerable potential as renewable sources of energy. They extend over 8·6 × 10^{6} ha, equivalent to 40% of the rural area of the United Kingdom (UK), and contain some species which produce more biomass in their poor habitats than traditionally cultivated crops.

Extensive heather (*Calluna vulgaris*) moors or bracken (*Pteridium aquilinum*) fells could be harvested as '*opportunity* energy crops' without significantly disturbing traditional land uses; alternatively, species which are more productive than traditional crops could be planted as '*dedicated* energy crops' on areas of land designated for the purpose.

To manage an energy crop, it is necessary to understand its seasonal development, including changes in chemical composition which strongly influence the type of technology required to produce fuel. Because it would be essential to sustain biomass yields of perennial energy crops, it is also necessary to know the amounts of inorganic nutrients removed when harvesting biomass. With this knowledge, replacement of nutrients could be arranged. If, after these investigations, species still show potential, it is then appropriate to investigate the technological and economic feasibility of managing them as energy crops.

To learn about the seasonal development, yield and chemical composition of potential energy crops, experimental studies were initiated in 1979. The initial one-year field-based programme working with many species was followed by a 3-year intensive study of the management of 3 plant species which showed the greatest potential as energy crops.

Yields

Peak yields of shoots in natural stands varied from 4·0 tonnes ha^{-1} in meadowsweet (*Filipendula ulmaria*) to 37·5 tonnes ha^{-1} in *Reynoutria sachalinensis* (Cover photograph), an alien invasive weed of Great Britain (Callaghan *et al.* in press). Most peak yields were, however, within range 6–13 tonnes ha^{-1}; they were obtained without cultivation or the application of fertilisers.

Yields of bracken (*P. aquilinum*) are particularly noteworthy (Figure 49). This species yielded up to 15 tonnes ha^{-1} compared with 6 tonnes ha^{-1} from upland pastures, formerly under bracken, which had been seeded and supplied with fertilisers (Hill Farming Research Organisation 1979). As bracken occupies over 3 200 km^2 of Great Britain, it is a potential opportunity crop of considerable significance.

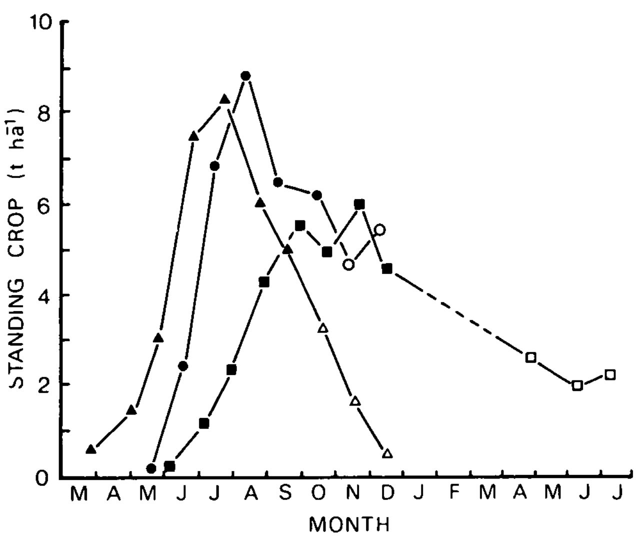

*Figure 49 Changes during 1979 in the 'standing crops' of 3 potential energy crops: ▲, △ butterbar (*Petasites hybridus*); ●, ○ bracken (*Pteridium aquilinum*) both growing in a woodland clearing in Derbyshire; □, ■, cord-grass (*Spartina anglica*) growing in salt marsh, Cumbria. ▲, ●, ■, plants living; (△, ○, □, foliage and stems moribund).*

Cord-grass (*Spartina anglica*) yielded 6 tonnes ha^{-1} at a 'poor' salt marsh site, but recent intensive studies at a more typical and extensive site gave yields up to 16·8 tonnes ha^{-1}. Although this species currently occupies only 120 km^2 of British salt marshes, it is at an invasive stage and its potential distribution on land currently of no economic use could be extensive; its potential is therefore worth considering.

Plants growing on verges, on amenity land and waste sites often produce a large biomass, eg great willowherb (*Epilobium hirsutum*) with yields of 12·9 tonnes ha^{-1}. For this reason, they should be considered as possible opportunity crops, more especially as energy is at present expended on their control.

Indian balsam (*Impatiens glandulifera*), an annual species, produced a biomass peak of 11·4 tonnes ha^{-1} within 3 months of germination. Because it tolerates pollution, it could be an important dedicated energy crop in association with sewage treatment. Japanese knotweed (*Reynoutria japonica, R. sachalinensis*) and Indian balsam might be planted as dedicated energy crops. Both species of knotweed yielded in excess of 20 tonnes ha^{-1} in small stands, though only 11·8 tonnes ha^{-1} was produced by an extensive stand of *R. japonica*. In transplant trials, the survival of plants growing from rhizome fragments exceeded 98%, suggesting that energy crops of *R. japonica* might be easy to establish. The replacement of some areas of grassland with Japanese knotweed and other species from which protein could be extracted (Plaskett in press) before residues are used for fuel is a long-term possibility.

The conversion of plant biomass to fuel

The type of technique used for converting biomass to a usable fuel will depend upon the quality of the biomass. Water content is important when deciding the suitability of biomass for anaerobic digestion or thermal methods of conversion, whereas amounts of soluble carbohydrates and protein, lignin and ash influence the efficiency of anaerobic digestion. If native species were harvested in summer at peak standing crop, amounts of energy rich compounds and water would be large (over 75% of fresh weight). Anaerobic digestion would probably be the most suitable conversion method, and species like butterbur (*Petasites hybridus*) and Indian balsam, like most herbaceous plants, should be digested very efficiently. Cord-grass, however, produces much ash (31% of dry weight). The actual efficiency with which these various species can be digested is now being assessed experimentally.

If native species were harvested when senescent, water contents and amounts of easily digestable compounds would be relatively small. In these conditions, thermal conversion would be preferable to anaerobic digestion. Whereas the senescent shoots of bracken, Japanese knotweed, cord-grass, great willowherb, rosebay willowherb and meadowsweet are readily harvestable during autumn and winter, those of butterbur and Indian balsam would be difficult to harvest because they collapse in the autumn.

Fertiliser requirements

Removing harvested biomass from site could affect the subsequent regrowth of perennial species by removing inorganic and organic nutrients which would normally be recycled. In general, plant tissues have maximal concentrations of inorganic nutrients (N, P and K) in spring and these decrease during summer and autumn as tissues age (Figure 50). In some species, such as bracken and cord-grass, nutrients appear to be translocated from shoots to rhizomes during senescence, with amounts of foliar N, P and K decreasing faster than dry weight.

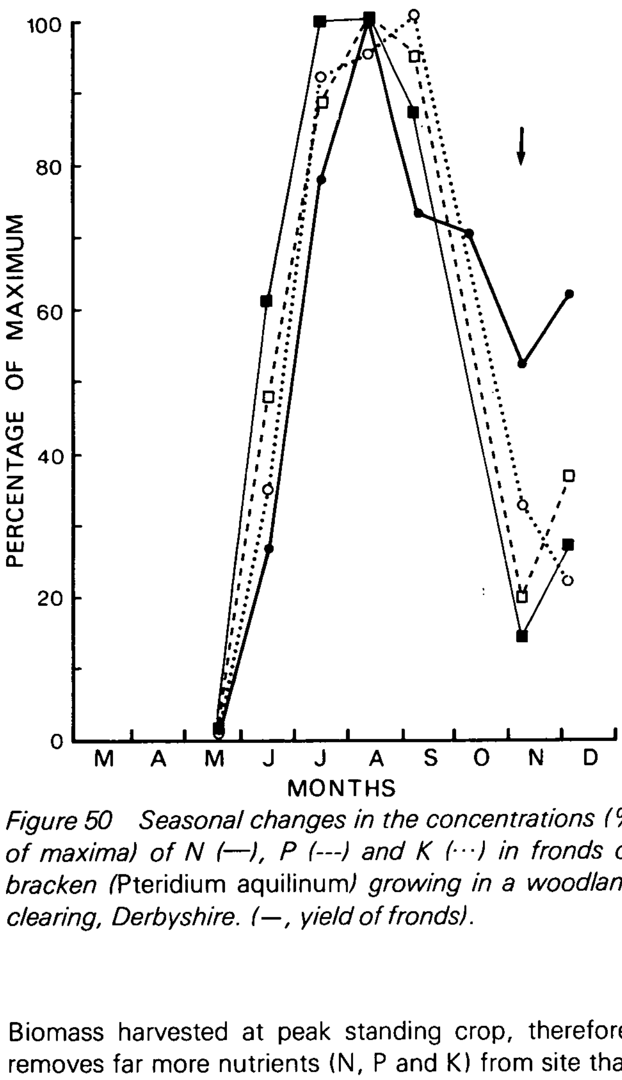

*Figure 50 Seasonal changes in the concentrations (% of maxima) of N (—), P (---) and K (···) in fronds of bracken (*Pteridium aquilinum*) growing in a woodland clearing, Derbyshire. (—, yield of fronds).*

Biomass harvested at peak standing crop, therefore, removes far more nutrients (N, P and K) from site than biomass harvested when senescent. The amounts of N, P and K required to replace those lost when harvesting bracken at peak standing crop would be larger than most fertiliser applications in lowland agriculture. However, if biomass were harvested when energy crops were senescent, the replacement applications of N, P and K would be small (Figure 50). For cord-grass, the annual nutrient inputs brought in by flooding may be greater than the amounts removed when it is harvested after senescing. Thus, in terms of nutrient replacement, harvesting strategies aimed at removing senescent material would be preferable to those aimed at removing maximum yields.

Economic feasibility of energy crops

Excluding the costs of conversion, it has been estimated that the harvesting costs of opportunity crops of bracken, heather (*Calluna vulgaris*) and common reed (*Phragmites communis*) could be £1.12, £0.31 and £7.45 respectively, per barrel of oil equivalent. Even assuming that the production of biomass has been overestimated, these costs suggest that the exploitation of 'dedicated' and 'opportunity' crops is worth taking to the next stage, particularly when it is remembered that muirburn (controlled burning of heather) costs £2.47 ha^{-1} and the herbicidal control of bracken £120 ha^{-1}.

Crop management

Much has been learnt from the one-year field study, but, to understand the responses of perennial energy crops to repeated annual harvests, it is essential to establish long-term experiments. Where natural vegetation is to be maintained as an energy crop, it may be worthwhile, when considering costs and the yield of energy, to apply fertilisers.

Experiments have been established in extensive areas of bracken and cord-grass, while Japanese knotweed has been transplanted and established in monocultures on agricultural land.

T. V. Callaghan, R. Scott, G. J. Lawson and Heather A. Whittaker

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CULTIVATION OF MOSSES

It is often desirable to maintain stocks of living mosses as source material for controlled environment, or cytological, studies. While some species will grow on mist benches for several years, many others will not. Traditionally, mosses have been cultured from (i) stem fragment with leaves attached, or (ii) isolated leaves, but it is difficult to exclude microbes from these cultures. The use of 10% sodium hypochlorite solution minimizes the incidence of contamination, but the rate of contamination is still too high. However, the problem can be avoided by taking spores from unopened moss capsules whose contaminating microbes, which are external, can be killed with bactericides without fear of impairing spore (moss) germination.

While interest in spore germination has been focused on the process *per se* and the examination of developing protonemata, few attempts have been made to produce mature populations for further study. To this end, a method, based initially on standard micro-culture techniques using nutrient agar and involving the transfer of colonies to a secondary substrate, has been developed. Half strength Knop's nutrient solution containing KNO_3, K_2HPO_4, $MgSO_4$, $Ca(NO_3)_2$ plus Fe, solidified with 1% agar, is autoclaved, cooled to 40°C and poured into deep sterile plastic petri dishes which hold sufficient agar to maintain growth for 6 months. At the same time, 10 ripe capsules with intact opercula are shaken in 10% sodium hypochlorite for 10 minutes before being immersed in 20 ml of sterile distilled water, when opercula are removed and spores released. Two drops of the resulting spore suspension are then inoculated (spread) on to Knop's nutrient agar using a sterile hypodermic syringe with a 19 gauge needle. Because they are subsequently kept in environmental cabinets which cannot be kept sterile, dishes are sealed with 'cling film'—another precaution to avoid contamination.

In the environmental cabinets, maintained at 15°C with a 12 hour day, using a 2:1 mixture of 'warm white' and 'growlux' fluorescent tubes emitting 200 mE $m^{-2}sec^{-1}$ of photosynthetically active radiation, germination takes place within 2 to 13 days, depending on species. Subsequently, there is an equally variable period of protonematal development before leafy shoots appear (Cover photograph). As soon as feasible, colonies with leafy shoots are transferred, one to each 7·5 cm pot, after first removing excess agar but without disturbing the mats of protonemata. To minimize unnecessary stress while being 'weaned', pots are, in the first instance, only half filled, with peat or fine gravel, so that the upper part of the pot provides shelter. They are then placed on mist benches until adult plants become established. By this method, it has been possible to produce, and maintain for periods of up to 2 years, pure cultures of a range of European mosses, eg *Atrichum undulatum, Bryum capillare, Ceratodon purpureus, Funaria hygrometrica, Grimmia pulvinata, Hypnum cupressiforme, Mnium hornum, Pohlia nutans, Polytrichum juniperinum* and *Tortula ruralis*, var. *alpina* (*Tortula norvegica*). Some sub-Antarctic mosses including species of *Dicranella* and *Mielichhoferia* have also been successfully established. Several species have produced sporophytes in these conditions.

This technique developed from a study of spore germination, fragment regeneration and subsequent protonematal development in a range of species. Its significance, however; extends beyond these interests to the long-term maintenance of plants and an increasing interest in the genecology, ecophysiology and reproduction of mosses. Additionally, because mature colonies can be grown from spores, is it not possible to envisage the conservation of mosses by the preservation of viable spores, as is being done with the seeds of higher plants?

B. G. Bell and T. D. Murray

Plant Community Ecology

TOWARDS THE END OF THE LINE

A biological survey of British Rail land was begun in response to a Parliamentary question (House of Commons Parliamentary Debates 1961) about the effects of altered verge management practices on railway wildlife. Information has been collected from 820 sites distributed along active railway lines throughout Britain. The sites are of 2 kinds: most were selected by stratified random sampling related to geographic and environmental factors (Sargent and Mountford 1980), while the remainder were chosen subjectively on the basis of suspected biological interest. (A third subset of sites, specifically concerned with cuttings and embankments, was discontinued because the information obtained was not susceptible to valid analysis.) Vegetational and environmental data have been collected at all sites and records made of all identified animals.

The Parliamentary question particularly identified the introduction of chemical scrub control following the discontinuance of systematic scything and clearing. Chemical sprays are usually applied in early summer and are more or less restricted to bands 3 m wide on either side of the permanent way. Preliminary analyses of data for the Southern and Western Regions of British Railways (Sargent & Mountford in press) indicate that sprayed areas support vegetation characteristic of disturbed sites (Grime 1979), whose distribution is independent of local factors. These areas may have a useful role in providing habitats for species that grow on waste ground: for example, the frequently recorded winter annuals *Arabidopsis thaliana* or *Erophila verna*, which complete their life cycles before verges are sprayed, or species such as *Senecio viscosus* or *Epilobium montanum*, which may benefit from both the absence of competition when other plants are removed and the accelerated and more extensive dispersal of seed in air currents by railway traffic.

It is not known to what extent the policy change has favoured the spread of woody species. In 1978, 43%

of vegetation in the Southern and Western Regions was classified as scrub or secondary woodland (Sargent & Mountford 1979). Whereas the occurrence of base-poor oak woodlands, and associations dominated by alder, was correlated with geographical factors, the distributions of ash, sycamore and hawthorn scrub suggested that they had frequently spread radially from established sources. Bramble was often recorded colonising unstable slopes of recently exposed ballast where the ability of this species to produce runners is clearly advantageous.

Most railway grasslands are dominated by combinations of oat-grass (*Arrhenatherum elatius*), cock's-foot (*Dactylis glomerata*) and red fescue (*Festuca rubra*), but, where nutrients are limiting, fine-leaved and often species-rich grasslands remain widespread. In Eastern Region, for example, Messenger (1968) documented certain areas of *Deschampsia flexuosa* grassland which are still extant, whilst considerable tracts of characteristic (although uncut) chalk, limestone and bent/fescue grasslands remain respectively in Southern, London Midland and Scottish Regions. This result contrasts with Gulliver's (1980) claim that, with the discontinuance of scything, "very soon one or two aggressive grasses, such as false oat-grass and cock's foot came to dominate these (uncut) swards".

Field work in all the regions of British Railways is nearing completion. The attention of the Nature Conservancy Council has been drawn to areas of particular interest. Distribution maps and analyses relating vegetation to (i) environmental factors and (ii) management practices remain to be completed. The final results should indicate what needs to be done to ensure a rational approach to this extensive asset.

Caroline M. Sargent and J. O. Mountford

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AREA AND ISOLATION

For the last ten years, the theory of island biogeography, propounded by MacArthur and Wilson (1967), has caught the attention of theoreticians and conservationists in the United States of America. More recently, its popularity has spread to the UK and, as a result, it is influencing attitudes to conservation in Britain at a time when American colleagues are beginning to be disenchanted with some of its tenets. The time seemed opportune, therefore, to bring together British ecologists to assess current views of the theory by holding a symposium at Monks Wood Experimental Station during October 1980.

Thirteen papers were presented by 15 authors; 6 of the authors came from the Institute of Terrestrial Ecology, 3 each from the Nature Conservancy Council and York University, and one each from the Universities of Aberdeen, Bangor and Oxford. The other members of the symposium showed a similar range of academic research and conservation interests with, however, the conservation interest usually predominating during discussions.

The most urgent question for many participants concerned *area*: is one large nature reserve better than several small reserves? The general consensus seemed to favour several small reserves rather than one large reserve. Peterken and Game, for example, using data on woodland species, found that several small woods could hold more species than a larger one of equivalent area and suggested, as there appeared to be no increase in diversity with age and because relaxation effects did not occur, that the selection of woodlands for reserves should be made on a basis of floristic composition. Usher, together with Higgs and Margules, dealt with theoretical aspects, and, like Peterken and Game, he favoured multiple reserves because of the greater probability of small, but significant, ecological differences between several reserves: he gave decision rules for determining the magnitude of the differences necessary for several small reserves to be better than one large reserve, of equivalent area.

While not dissenting from the consensus about areas, other speakers, such as Reed (Oxford) and Hockin (Aberdeen), nevertheless thought that greater emphasis should be put on ecological and behavioural characteristics of the component species. They suggested that a reliance upon area as the major determinant of species assemblages could lead to errors in the selection of reserve sites.

As distinct from area, isolation seemed to be a less important consideration, possibly because 'isolation' is difficult to define and measure. Magurran (Bangor), dealing with larch stands surrounded by spruce plantations, was forced to conclude that their isolation was more apparent than real. Similarly, but at the other extreme, Gray, dealing with genetic isolation in *Agrostis setacea*, found patches of genetically distinct plants even within continuous carpets of the species. Hooper suggested that isolation could occur within contiguous

Plate 27 – The surface of the coastal cliff at Highcliffe, Dorset, prior to engineering works. The plateau sands and gravels overlie an impervious layer of Barton clays, and the surface mosaic of clay and gravel results from continual slippage, especially in winter months.
Photograph A. J. Gray.

Plate 28 – One of the plots in the preliminary trial of soil treatment methods and seed mixtures on the Highcliffe cliffs, photographed one year after sowing. The 2m × 2m blocks are arranged in 5 × 5 latin square design. Only the treatments in which top soil was added gave successful establishment (treatments A & B, Table 33). 'A' blocks occur on the diagonal of the plot. The bottom row from left to right is E, lime only; D, fertiliser only; C, lime and fertiliser; B, topsoil, lime and fertiliser; A, topsoil and fertiliser.
Photograph A. J. Gray.

Plate 29 – Part of Highcliffe cliffs in 1979 following the main seeding. Seeded areas occur on the top part of the slope to the right of the picture and in the background. In the centre and middle foreground is part of the trial of salt- and drought-tolerant varieties. The stoney areas running across the picture are drains.
Photograph A. J. Gray.

Plate 30 – The toe of the cliffs at Highcliffe showing successful establishment of vegetation on the lower slopes in an area where waves break over the revetment and on to the cliff. The pool of water is seawater.
Photograph A. J. Gray.

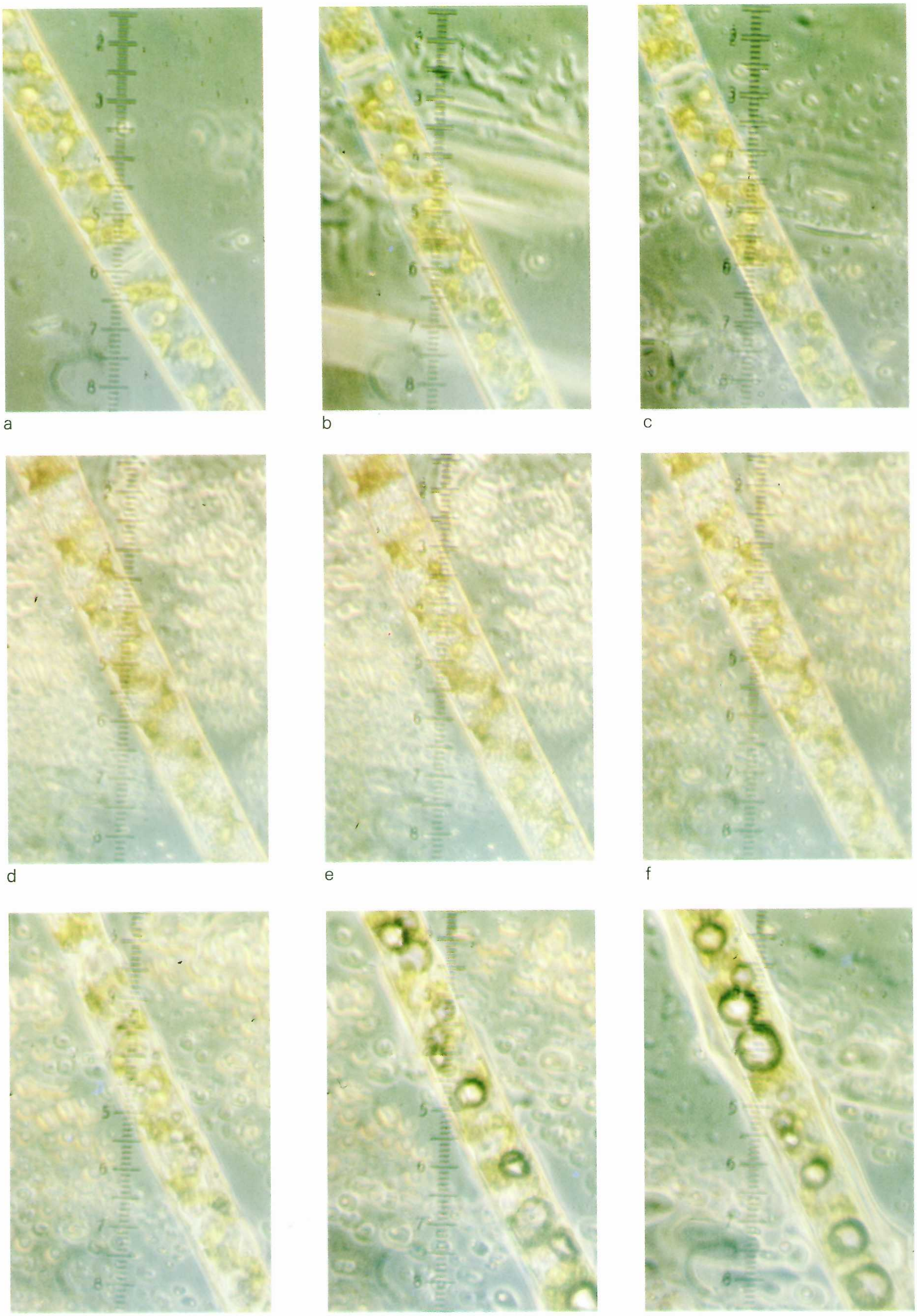

Plate 32 — Response of 2 filaments of Spirogyra *to freezing and thawing; rates of cooling and warming were 10°C min[-1] (Magnification × 625). (a) Control. (b-d) during cooling; (b)-2·5°C, (c)-5°C, (d)-7·5°C, (e)-10°C. f)-i) during warming; (f)-7·5°C, (h)-2·5°C, (i) + 5°C.*
Photograph G. J. Morris.

areas but, on this occasion, at the species level: whether or not species should be regarded as isolated would seem to depend upon the strategies used by different species for dispersal.

During discussion, the idea that the species/area relationship is central to island biogeographic theories was criticised: instead, the theory should be centred on the equilibrium between immigration and extinction. To an extent, the situation has arisen because field assessments of species/area relationships, for species of conservation interest, can be determined relatively easily, whereas immigration and extinction are, at the moment, only amenable to treatment in artificial experiments very often using small organisms of little conservation value.

For the future, it seems desirable to widen the definition of 'conservation value' to include small organisms, and also to develop a critical experimental approach to the biology of larger species at the community level.

M. D. Hooper

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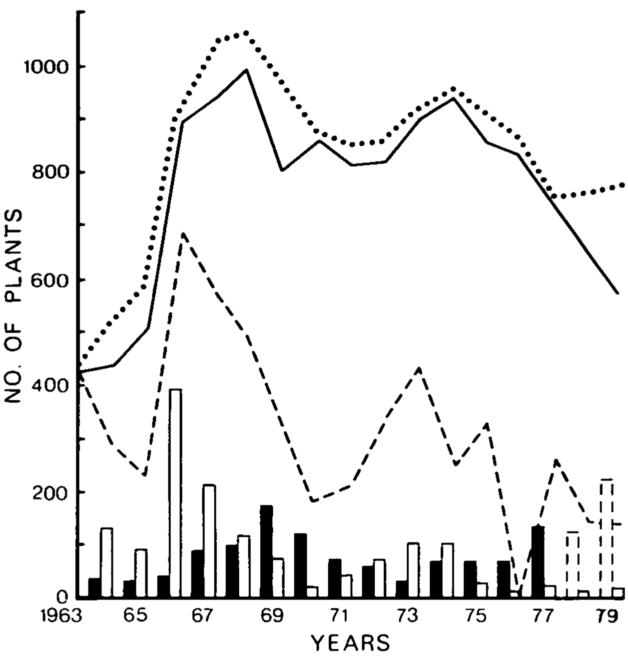

*Figure 51 Performance of a population of autumn lady's-tresses (*Spiranthes spiralis*) at a chalk grassland site (1963-79). (---, numbers of emergent plants that flowered; —, total numbers of emergent plants whether flowering or remaining vegetative, • • •, numbers of vegetative and reproductive plants plus viable tubers that did not produce shoots; □, new recruits; ■, dead plants); [ ] estimated mortalities).*

POPULATION STUDIES OF TERRESTRIAL ORCHIDS

Although terrestrial orchids are among the most beautiful and biologically interesting of native wild flowers, few studies have been made of their changing populations, despite the pioneer studies of Tamm (1948, 1972). It has often been asserted that populations of orchids fluctuate greatly from year to year. To test this hypothesis, populations of autumn lady's-tresses (*Spiranthes spiralis*), man orchids (*Aceras anthropophorum*) and musk orchids (*Herminium monorchis*) have been studied at chalk grassland sites in Bedfordshire. Having recorded their positions, using a co-ordinate system, the progress of individuals within a population has been followed in successive years (Wells 1967).

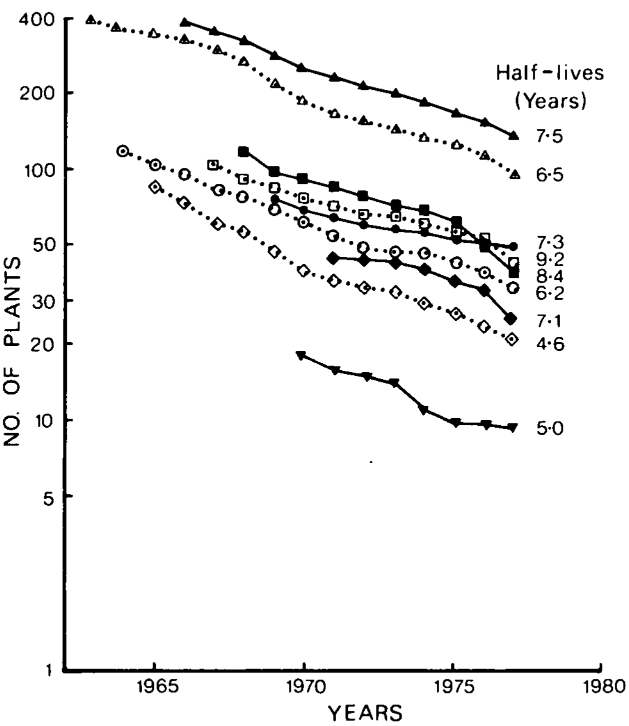

*Figure 52 Survivorship curves for 9 cohorts of autumn lady's-tresses (*Spiranthes spiralis*) that emerged at a chalk grassland site between 1963 and 1971.*

During the period of study, the population of autumn lady's-tresses has grown from 420 plants in 1963 to a maximum of 1 050 in 1969, remaining at between 870 and 950 plants until 1976, thereafter decreasing to about 800 plants in 1979 (Figure 51) (Wells in press). Recruitment to the population has been uneven, with 383 new plants in 1966, but only 3 in 1978. Overall, there has been a tendency for fewer plants to be recruited since 1974, a feature which may be related to the growth of coarse grasses at the site since about 1968. Mortalities, calculated as percentages of the total population, have fluctuated from 15·3% in 1969 to 3·9% in 1973. Mostly, losses are attributed to (i) physical damage, done by cattle hooves to the shallowly placed tubers, (ii) consumption of tubers by beetle larvae specific to orchids, and (iii) competition from dense tussocks formed by upright brome (*Bromus erectus*). Although the slopes of survivorship curves for 9 cohorts (groups of plants in the same age class) of autumn lady's-tresses differ, suggesting that their chances of survival, and hence longevity, may depend upon the year in which the cohort was formed, the outstanding feature is the linear nature of the survivorship curves (Figure 52). This characteristic suggests that the risk of death, despite the inclusion of the exceptional drought of 1976, is constant throughout the life of a population, despite the vagaries of climate. As far as survival is concerned, it is not possible to identify good and bad years. The calculated half-lives for the 9 cohorts ranged from 4·6 to 9·2 years, but, perhaps of more significance, the calculated time for each cohort to decline to a single plant varied from 23 years for the small 1970 cohort of 18 plants to 67 years for the 1969 population of 75 plants. The mean expected life of all cohorts (ie longevity) was 53 years.

During the first 6 years of study, the population of 110 plants of man orchids remained remarkably stable (Figure 53), but there has subsequently been a period of sustained enhancement which appears to be continuing, the population in 1980 exceeding 400 plants. New plants were recruited every year, but numbers fluctuated widely from 116 in 1974 to less than 10 in 1969 and 1971. Mortalities varied from 3·6—18·0%, but causes of death were not ascertained. Survivorship curves for cohorts recruited in 1966, 1968, 1972, 1973 and 1974 suggest that the man orchid has a half-life of 4·0 to 7·8 years (Figure 54). The linearity of the survivorship curves, especially of the 1966 cohort,

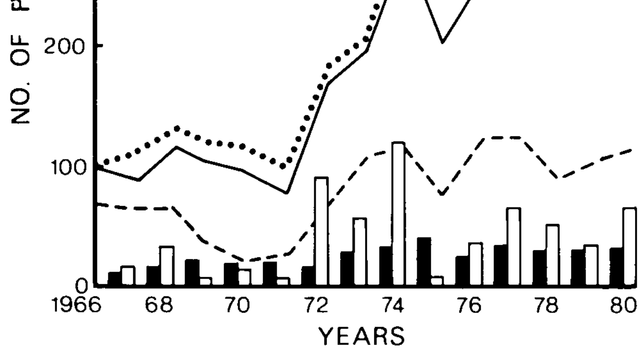

*Figure 53 Performance of a population of man orchids (*Aceras anthropophorum*) at a chalk grassland site (1966-80). (---, numbers of emergent plants that flowered; —, total numbers of emergent plants whether flowering or remaining vegetative; • • • , numbers of vegetative and reproductive plants plus viable tubers that did not produce shoots; □ new recruits; ■ dead plants).*

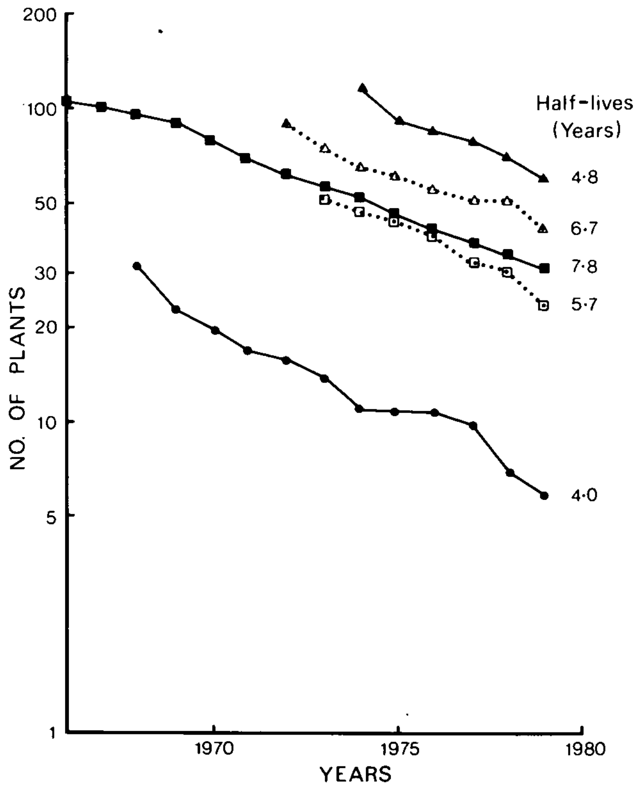

Figure 54 Survivorship curves for cohorts of man orchids (Aceras anthropophorum) *that emerged at a chalk grassland site in 1968, 1972, 1973 and 1974; also a depletion curve for a population of 104 plants present in 1966.*

of 106 plants suggests, as with *S. spiralis*, that the risk of death is constant throughout the life of the population. If the present trend continues, the 1966 population will be reduced to a single plant in the year 2014.

The proportions of autumn lady's-tresses, man and musk orchids that flowered varied considerably from year to year (Table 28). Man orchids flowered more

Table 28. Percentage of emergent plants that flowered in successive years from 1966 to 1979 in populations of man orchids, musk orchids and autumn lady's-tresses in chalk grasslands in Bedfordshire.

Year	Man orchid *Aceras anthropophorum*	Musk orchid *Herminium monorchis*	Autumn lady's-tresses *Spiranthes spiralis*
1966	67·0	38·0	73·6
1967	72·7	12·8	57·0
1968	51·2	15·7	44·7
1969	31·2	16·2	33·0
1970	17·5	8·2	19·2
1971	30·9	7·1	22·9
1972	31·1	36·6	37·3
1973	52·9	19·4	42·3
1974	36·6	27·9	23·4
1975	33·0	10·6	34·8
1976	44·9	0·4	1·3
1977	38·1	0·0	30·8
1978	32·3	11·2	19·8
1979	35·6	32·1	20·7
Mean	41·1	16·9	32·8

consistently (41%) than the others, with 17% in musk orchids and 33% for autumn lady's-tresses over the same 14 years. A closer look at the behaviour of 38 man orchids, present in the population for 14 years, showed that 25 plants (65%) have flowered in less than 6 years; one has flowered in 13. Because these differences between individuals could not be related to micro-environmental factors, it seems likely that the propensity to flower may be governed by biological factors, such as the activity of the fungal symbiont. The ability to flower does not decrease significantly with increasing age, an observation which agrees broadly with the results obtained by Russian demographers, such as Uranov and Rabotnov (See Harper 1977).

T. C. E. Wells

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AMENITY TREE SURVEYS-IMPLICATIONS FOR CONSERVATION

The designation 'Amenity trees' includes trees growing in fragments of woodland less than 0·4 ha (1 acre) in extent, in hedgerows, shelter-belts, parks, gardens, city streets, roadside verges, watercourses and in many other niches. In 1965, the Forestry Commission estimated that hedgerow and park timber in England amounted to 15 million m^3, equivalent to one fifth of all the timber in the forests and woodlands of England, Scotland and Wales (Locke 1970). It was found that the proportion of saplings was considerably decreased between 1947 and 1965, to an extent suggesting that the ratio of saplings to mature trees was "incapable of supporting an adequate and continuing promotion to timber sizes". As 88% of the trees concerned were broadleaved and only 2% of productive forest is broadleaved, it would seem that our hardwood timber resource, a fundamental component of British landscapes (Crowe 1963; Fairbrother 1974), is in jeopardy. This situation is being exacerbated by recent and continuing hedgerow removal (Westmacott & Worthington 1974), and by the damage done to elm by the devastating attacks of the aggressive strain of the fungus of Dutch elm disease (Brasier & Gibbs 1973), both of which have heightened awareness and concern for the future of amenity trees. The forester's concept of 'management to sustain', which, while not new to arboriculture, has received little attention in the immediate past, is now gaining wide acceptance. But, to be evolved rationally, it is essential to have a detailed understanding of the nature of the resource. Detailed surveys have been made of amenity trees in Edinburgh (Last *et al.* 1976) and the Lothian region (Good *et al.* 1978) of Scotland, and, latterly, in the Arfon district (Good & Steele 1981) and Bangor in north Wales.

Contrary to what was found in England by the Forestry Commission and in more detailed studies of East Anglia (Baird & Tarrant 1972; Penistan 1973; Norfolk County Council 1977), the size distribution of trees in north Wales suggested that most species were likely to be sustained, with adequate numbers of saplings. For example, the populations of the 4 commonest species of 'forest' trees, which, interestingly, are the same in each region, have satisfactory proportions of saplings (<20 cm diameter at breast height), namely oak (*Quercus robur* and *Q. petraea*), sycamore (*Acer pseudoplatanus*), ash (*Fraxinus excelsior*) and wych elm (*Ulmus glabra*). In the Lothian region, however, there were too few oak and wych elm saplings, so indicating a need for their selection, protection and planting (Table 29).

Table 29. Proportion (%) of oak, sycamore, ash and wych elm in different size classes when the amenity trees in the Lothian region of Scotland and the Arfon district of north Wales were surveyed in 1975 and 1978 respectively.

		Location	
	Size class (diameter (cm) at breast height)	Lothian region, Scotland. Proportion (%) of trees in the different size categories	Arfon district, Wales. Proportion (%) of trees in the different size categories
Oak	<20	24	59
	21–40	34	21
	>40	42	20
Sycamore	<20	67	80
	21–40	14	12
	>40	19	8
Ash	<20	68	84
	21–40	19	11
	>40	13	5
Wych elm	<20	36	67
	21–40	35	17
	>40	29	15

Comparisons and contrasts of the lists of trees in Edinburgh, other burghs in the Lothian region, and Bangor indicate that social attitudes in major conurbations and in small towns in rural settings greatly affect the choice of trees (Table 30). In Edinburgh, 'ornamental' trees such as apple (domestic and crab: *Malus* spp), lilac (*Syringa vulgaris*), flowering cherry (*Prunus* spp), rowan (*Sorbus aucuparia*), cypresses (*Chamaecyparis* spp, *Cupressus* spp, × Cupressocyparis *leylandii*, *Thuja* spp) and laburnum (*Laburnum* spp) are numerically important, being replaced in small towns by sycamore, oak, wych elm, hazel (*Corylus avellana*), hawthorn (*Crataegus* spp), holly (*Ilex aquifolium*), birch (*Betula pendula* and *B. pubescens*) and ash. Interestingly, Bangor and the Lothian burghs

Table 30. Estimated numbers (in hundreds) of the 10 commonest trees growing in Edinburgh (1972), other residential areas, burghs, of the Lothian region (1972–75) and Bangor, north Wales, (1980).

Edinburgh		Lothian burghs (excluding Edinburgh)		Bangor	
Apple, domestic	1400	Sycamore	410	Oak	265
Lilac	810	Wych elm	190	Sycamore	210
Flowering cherry	660	Hawthorn	160	Hazel	168
Sycamore	650	Elder	140	Holly	66
Rowan	560	Birch	110	Hawthorn	58
Cypresses	450	Rowan	100	Ash	54
Apple, crab	440	Oak	100	Cypresses	35
Beech	410	Flowering cherry	90	Flowering cherry	35
Laburnum	400	Ash	90	Wych elm	33
Birch	370	Apple, domestic	80	Rowan	28

NB The 10 commonest trees account for 64% of the total in Edinburgh, 66% of the total in Lothian burghs (excluding Edinburgh), and 86% of those in Bangor.

(excluding Edinburgh), although widely separated geographically, share 7 of their 10 commonest species, while the Lothian region, as a whole, and the Arfon district share only 4: being a small town in the countryside appears to have a greater bearing on the choice of trees than does its location.

Surveys may highlight problems requiring attention, such as the threat posed to hedgerow trees, not only by hedgerow removal, but also by present-day management procedures involving repeated machine maintenance. Contrary to what might be expected, species are not equally affected, regeneration of oak and elm being more severely hampered than that of beech, ash and sycamore. The strong control of apical growth in beech and sycamore, and particularly ash, enables the rapid development of a few strong shoots which may develop substantially between cuts to an extent that encourages hedgerow trimmers to leave them untouched on subsequent occasions. In contrast, oaks and elms usually produce small competing shoots which are continually at risk. For this and other reasons, there could be fundamental change in the species composition of mature hedgerow trees, unless positive measures are taken to protect oak saplings. Interestingly, where walls and hedges are about equally common, as in north Wales, populations of trees associated with walls, and hence not subject to machine trimming, contained a satisfactory distribution of size classes.

In addition to compiling inventories of amenity trees, it is important to understand their growth characteristics, which, in comparison to those of the limited range of plantation trees, are virtually unknown. Tables of life expectancies are being prepared while seeking the relations between size and age, so enabling culturists to ensure that the resource will be sustained. A start has been made with sycamore, ash and hawthorn, but preliminary results indicate that the twin influences of site diversity and intraspecific variation are responsible for a great deal of variation. Nonetheless, it is hoped, by excluding data from trees growing in extreme conditions (waterlogged soil, severe exposure, tarmacadam pavements, etc), that it will be possible to make useful generalisations, possibly with the development of 'regional' tables to accommodate major soil and climate differences.

J. E. G. Good

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LOCH LEVEN PHYTOPLANKTON SUCCESSION

To obtain a better understanding of the relationships between the biota and chemical constituents of the shallow mixed Loch Leven, it has been necessary to (i) assess factors controlling seasonal, annual and long-term changes in the composition and abundance of phytoplankton assemblages, and (ii) assess and predict how these assemblages would be altered by 'natural' and man-induced factors.

The phytoplankton study was started in 1967 in collaboration with colleagues in universities and other research institutions who have been concerned with physical, geological, chemical and complementary aspects of the biology of Loch Leven. Much of the early work was summarised in the Proceedings of the Royal Society of Edinburgh (1974). More recently, algal investigations being made within ITE have been integrated within a project group including physical limnologists and others working with crustacean and rotifer zooplankton, and fish, with studies on juvenile perch development and feeding being the latest additions (Jones, see page 45 of this Report).

Phytoplankton samples have been taken at more or less weekly intervals in the period 1968–80 to assess (a) crop density (volumes and weights, also amounts of chlorophyll *a*) and (b) species diversity, abundance and chemical (N, P, C. and SiO_2) content (Bailey-Watts 1974, 1978). Additionally, the interactions between population fluctuations and water chemistry have been considered (Bailey-Watts 1976*a*, *b*), as have the effects of grazing zooplankton on the abundance of phytoplankton (Bailey-Watts & Lund 1973; Bailey-Watts 1974), the latter recently becoming the focus of experimental studies.

The seasonal patterns of phytoplankton growth have, in recent years, differed markedly from those in earlier years (Bailey-Watts in press). In particular, large algae, eg *Anabaena* (Cyanophyceae), produced the largest biomass in 1979, whereas in 1968 *Synechococcus* n sp (Cyanophyceae)–a very small species–predominated. As a consequence, and because annual mean concentrations of chlorophyll *a* have decreased, total numbers of individuals are now much smaller (Table 31).

Many factors control the structure of freshwater phytoplankton communities (Lund 1965; Hutchinson 1967), but it is thought that long-term changes in Loch Leven are mainly attributable to changes in water chemistry and zooplankton.

Table 31. Features of the phytoplankton that developed in Loch Leven in 1968 and 1979.

	1968	1979	
I *Chlorophyll a concentrations* (mg m^{-3}			
Annual mean	94	41	
Means Jan–June	120	35	
Means July– Dec	63	46	
Annual maximum and date of occurrence	188 (June)	160 (Mar) 350 (Oct)	
Annual minimum and date of occurrence	35 (Aug)	2 (Jan & Dec)	
Index of variation–number of times the temporal graph plot crosses (in either direction) the annual mean value	4	12	
II *Species composition*			
Major classes (by volume)	Bacillariophyceae (B) and Cyanophyceae (C)	Bacillariophyceae (B) and Cyanophyceae (C)	
Temporal distribution of important genera			
Jan–Mar	Unicellular Centrales (B) *Asterionella* (B)	Unicellular Centrales (B)	
Apr–June	As for Jan–Mar plus *Diatoma* (B) and *Synechococcus* (C)	As for Jan–Mar plus *Asterionella* (B)	
July–Sept	**Dictyosphaerium* Unicellular Centrales (B) *Synechococcus* (C)	*Anabaena* (C) *Microcystis* (C)	
Oct–Dec	Unicellular Centrales (B) *Synechococcus* (C)	*Anabaena* (C)	
Species producing largest population (by volume)	*Synechococcus* n sp	Unicellular Centrales	*Anabaena*
Mean volume of individuals of species producing largest volume (μm^3)	10·6	120	200
Peak numbers of individuals of species producing largest volume (ml^{-1})	$4{\cdot}4 \times 10^6$	$1{\cdot}7 \times 10^5$	$9{\cdot}8 \times 10^3$
Peak numbers of phytoplankton individuals (ml^{-1})	$5{\cdot}0 \times 10^6$	$1{\cdot}91 \times 10^5$	

**Dictoyosphaerium* is a genus within the Chlorophyceae.

i. *Water chemistry*
The annual loadings of phosphorus to Loch Leven from 1968 to 1972 were 1·5 g m^{-2}, but, with industrial (woollen mill) effluents being subsequently lessened, these loadings had decreased to <0·5 g m^{-2} by 1975 (Holden & Caines 1974; Holden 1976). In contrast, amounts of nitrogen have tended to increase, with winter maximum concentrations of nitrate in 1980 being nearly double those detected 12 or more years ago. As a result of these changes, the N:P ratio is likely to have increased.

ii. *Crustacean zooplankton*
When comparing zooplankton development in Loch Leven in 1969 and 1972, Johnston & Walker (1974) found that the copepod *Cyclops* occurred in almost pure stands in the earlier year, whereas the cladoceran *Daphnia*, which was initially absent, occurred in appreciable numbers in 1972. Subsequently, many observers have recorded annual maxima of 80 *Daphnia* per litre, while recent populations of *Cyclops* are about one sixth the size of those recorded in 1969. Field and laboratory investigations (Fryer 1957; Miss E. W. Rutkowski pers. comm.) indicate that *Cyclops* feeds on algae, rotifers and Crustacea, including its own young; contrastingly, *Daphnia* is herbivorous with a preference for small algae. Nonetheless, the removal of small algae by *Cyclops* should not be discounted, as its early life stages may take food of this sort.

The long-term as well as seasonally varying importance of grazing pressures, relative to the effects of changed chemistry, remains to be resolved. However, changes in species, and their population densities, seem to be of cardinal importance. But how should these changes be represented? By plotting numbers of species and 2 indices of diversity (the Shannon-Wiener, and equitability), it was found that species diversity decreased when amounts of chlorophyll greatly increased as in February/March and October (Figure 55). Seasonal differences were also found when the size frequency distributions of different algal crops were examined (Bailey-Watts & Kirika in press) (Figure 56). The sharply defined peaks for February, March and June 1979 contrast with the distribution in September, when cells ranging widely in length were more equally abundant.

How are populations of phytoplankton and rotifer and crustacean zooplankton interrelated? Changes in phytoplankton density in laboratory systems containing collections of natural phytoplankton/zooplankton assemblages were compared with concurrent changes in similar systems from which the larger (crustacean) zooplankton elements were removed by net (Figure 57). From series of week-long experiments done at fortnightly intervals throughout most of 1978, it seems that the removal of zooplankton, especially in the middle of the year when the filter-feeding *Daphnia* is most abundant, results in smaller decreases in algal abundance when the crop is declining and greater

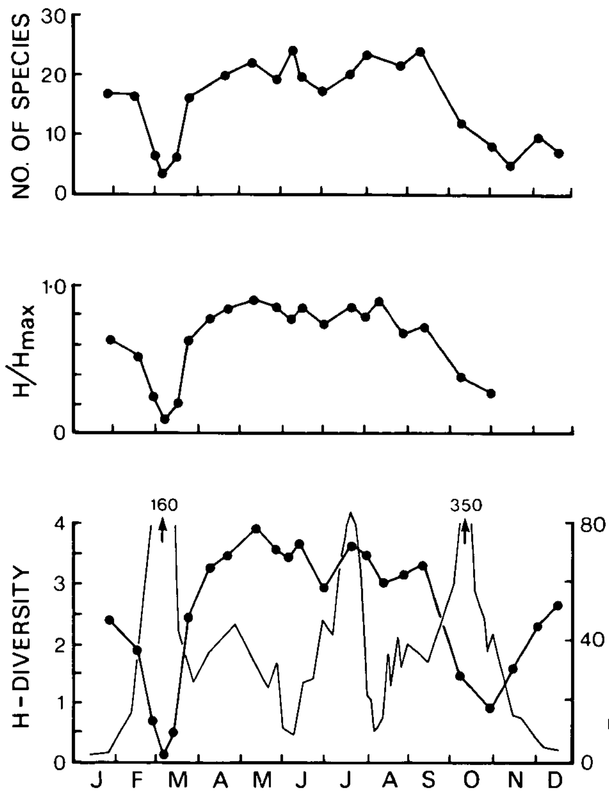

Figure 55 Changes of concentrations of chlorophyll a (lower graph, thin line) in Loch Leven during 1979 related to changes in the diversity of species of algae plotted as (i) numbers of species (upper graph), (ii) Shannon-Wiener diversity index (H—lower graph •——•), and (iii) equitability index (H/H_{max}—middle graph).

increases when the crop is increasing. These experiments will be continued to further our understanding of zooplankton grazing on the populations of different algae.

Despite decreased supplies of phosphorus to Loch Leven, the incidence of bloom-forming blue-green algae, of the *Anabaena* type, has increased: this change is associated with an increase in the relative frequency of larger species of algae, possibly because the smaller species are grazed by *Daphnia*. Reynolds and Walsby (1975) associate large populations of *Anabaena*—because it can fix molecular nitrogen—with waters having relatively small amounts of nitrogen compared with those of phosphorus. Because of the changes in nutrient loading, the average N:P ratio in Loch Leven would be expected to be higher than heretofore. However, examination of the data indicates that the N:P ratios are very low in late summer. (Figure 58).

More attention than hitherto will be given to the possibly major and long-lasting effects of relatively short-term changes of physical (weather) conditions on the chemistry and biology of Loch Leven.

Ideally, ecological investigations should be supported by critical taxonomic studies. Scanning electron

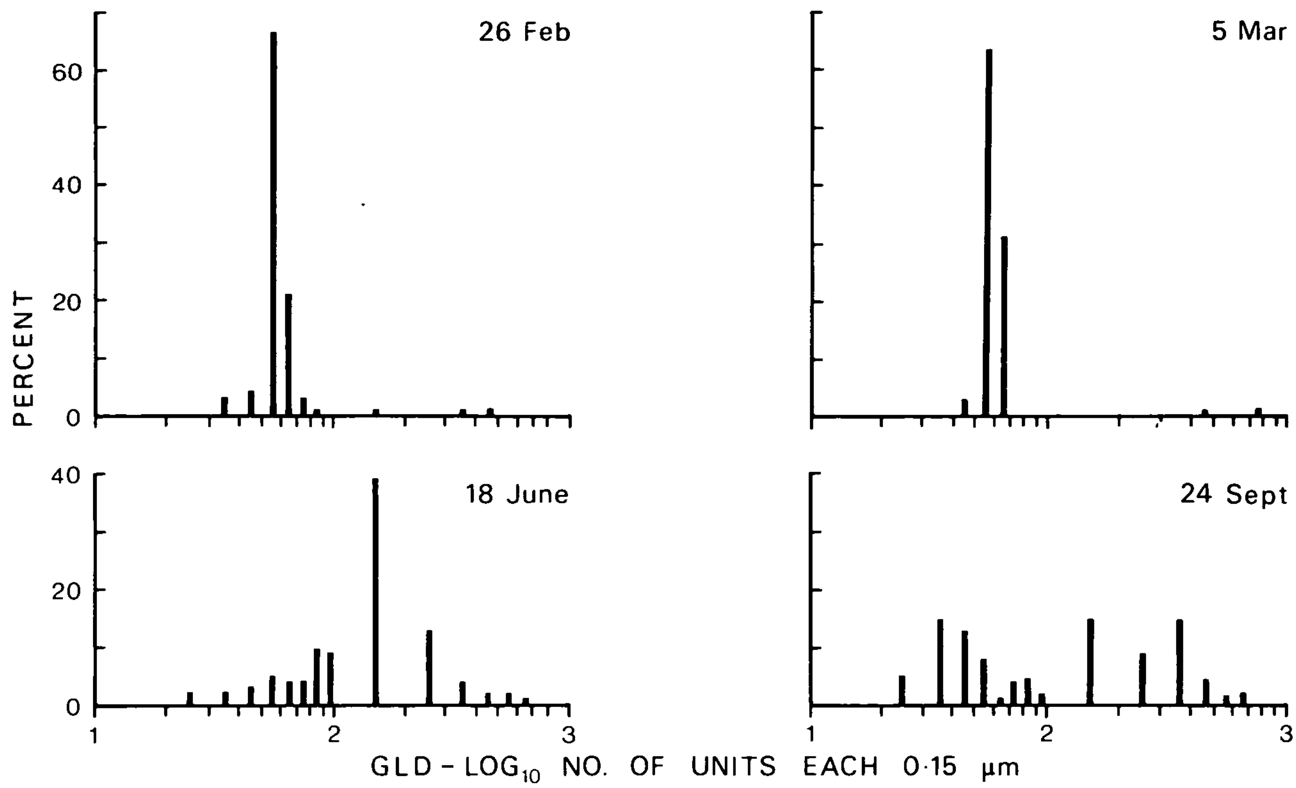

Figure 56 Size class distributions of phytoplankton algae in Loch Leven on selected dates during 1979. GLD is the greatest linear dimension.

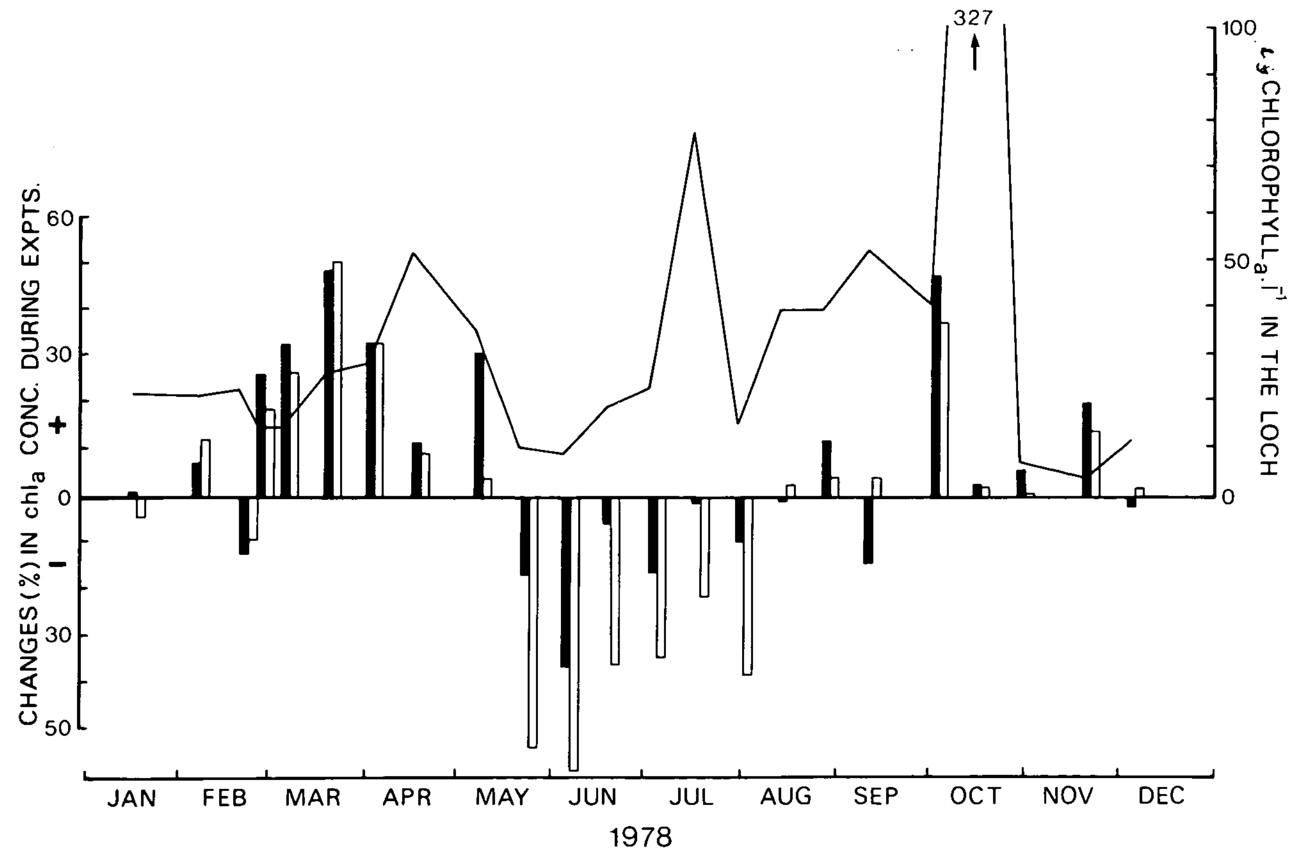

Figure 57 Increases (+) and decreases (−) in Loch Leven phytoplankton density (as chlorophyll a) expressed as percentages of the initial densities in experimental containers with control (natural—open columns) and treated (Crustacean zooplankton removed—solid columns) collections of plankton. Right-hand axis refers to algal abundance in the bay sample used for the experiments (solid line).

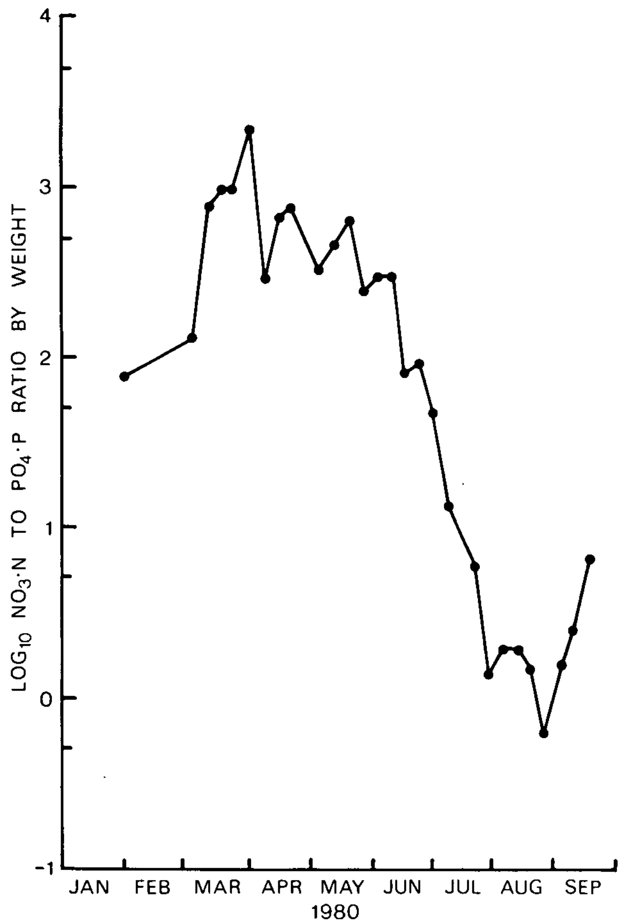

Figure 58 Seasonal changes during 1980 in the ratios, by weight, of dissolved nitrate-N: dissolved inorganic phosphate-P, found in Loch Leven.

microscopy is being used to show the detailed architecture of species of small unicellular diatoms, eg *Staphanodiscus* spp (Plate 26), which still occur in Loch Leven in large numbers (1 to 2 × 10^5 cells ml^{-1}, equivalent to between 5 and 10 mg silicate silica (SiO_2) l^{-1}) in early spring, before numbers of zooplankton increase.

A. E. Bailey-Watts

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SULPHUR AIR POLLUTION

Research in ITE on air pollution has been in progress for 5 years. Initially, there were few details of the atmospheric pollutants in rural environments either in the gaseous form, or in precipitation causing the phenomena known as 'acid rain'. Interest, therefore, has been centred, though not exclusively, upon the distribution of gaseous and particulate substances derived from emissions of sulphur compounds, and their impacts on tree growth and forest ecosystems.

Effects of air pollutants on crops and other plants are usually grouped for convenience into *direct* effects, eg those attributable to the impact of gaseous compounds or polluted rain on leaves and their functions, and *indirect* effects, eg those arising from influences on soil properties. Taking into account the diverse character of pollutant impacts, it was considered essential to adopt, initially, a broad approach (i) describing the chemical characteristics of precipitation and the nature of gaseous pollutants and their changing concentrations, (ii) quantifying the 'sulphur' inputs in *dry deposition* and *wet deposition* to forests, and (iii) characterising the 'pathways' of sulphur derivatives through vegetation to soil.

The environment — gaseous pollutants and acid rain

Analyses of monthly samples of precipitation, collected during 1978 and 1979 in 18 rain collectors distributed between the English Lake District and the north coast of Scotland, have shown that precipitation is usually more acid in the east than in the west (Figure 59).

Using the Mg/SO_4 ratio method, it was found that amounts of 'excess' sulphate (ie sulphate attributable to the activities of man) were largest in south-east Scotland and the central highlands (80%) and least in the north-west (20%). Although concentrations of hydrogen ions and excess sulphate were positively correlated, nitric and hydrochloric acids contributed to acidity at some sites. If precipitation were unpolluted,

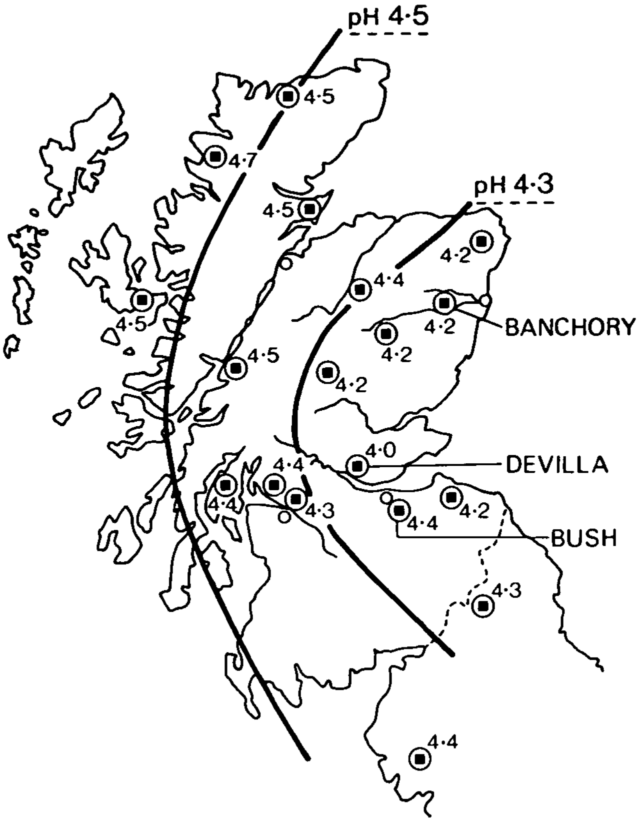

Figure 59 Mean pH of rain falling at different locations in northern Britain during 1978 and 1979.

theoretically it would have a pH of 5·7, but at Banchory, where collections were made daily, rain was more acid than pH 4·4 during 50% of precipitation events. Indeed, taking the data overall, it is clear that the main timber-growing area in northern Britain is exposed to precipitation that has been markedly acidified. This situation is similar to that recorded in parts of Norway where acid precipitation has been the focus of considerable concern (Figure 60).

This regional analysis of the occurrence of acidified precipitation over northern Britain, an area with relatively few major industrial sources of SO_2 or other gaseous emissions, has shown that amounts of pollutants can vary spatially. Continuous measurements of gas concentrations at a rural site in central Scotland have shown that amounts also vary in time.

Measurements of SO_2, NO_x and O_3 made during the last 3 years in the turbulent boundary layer above the canopy of Scots pine in the Forestry Commission's Devilla forest show that concentrations of SO_2 and NO_x at this relatively polluted commercial forest were usually larger in winter than in summer, whereas those of O_3 were maximal during periods of photochemical activity in spring/early summer (Figure 61). Concentrations of SO_2 and NO_x, and SO_2 and NO were positively associated ($r = 0{\cdot}58$ and $0{\cdot}51$, respectively), presumably indicating that they originated from the same sources. By contrast, concentrations of NO_x and O_3 were negatively correlated ($r = 0{\cdot}50$).

During the first 18 months of the monitoring period, when the annual mean SO_2 concentration was 10·5 ppb by volume (30 $\mu g\ m^{-3}$), concentrations exceeded 100 ppb (280 $\mu g\ m^{-3}$) for a total of 4 hours; amounts were greater than 50 ppb (140 $\mu g\ m^{-3}$) for 300 hours.

During 1978, the frequency distributions of 10-minute concentrations of SO_2 closely followed a log-normal distribution: there was a reasonable fit for NO_x, but not for O_3. From calculations involving theoretical means and standard deviations for each of the fitted log-normal distributions, it has been predicted that the maximal 10-minute concentrations of SO_2, NO_x and O_3 at Devilla forest are likely to be 370, 290, 450 (ppb) during a one-year span and 520, 370, 600 (ppb) for a period of 5 years. These results indicate that Devilla

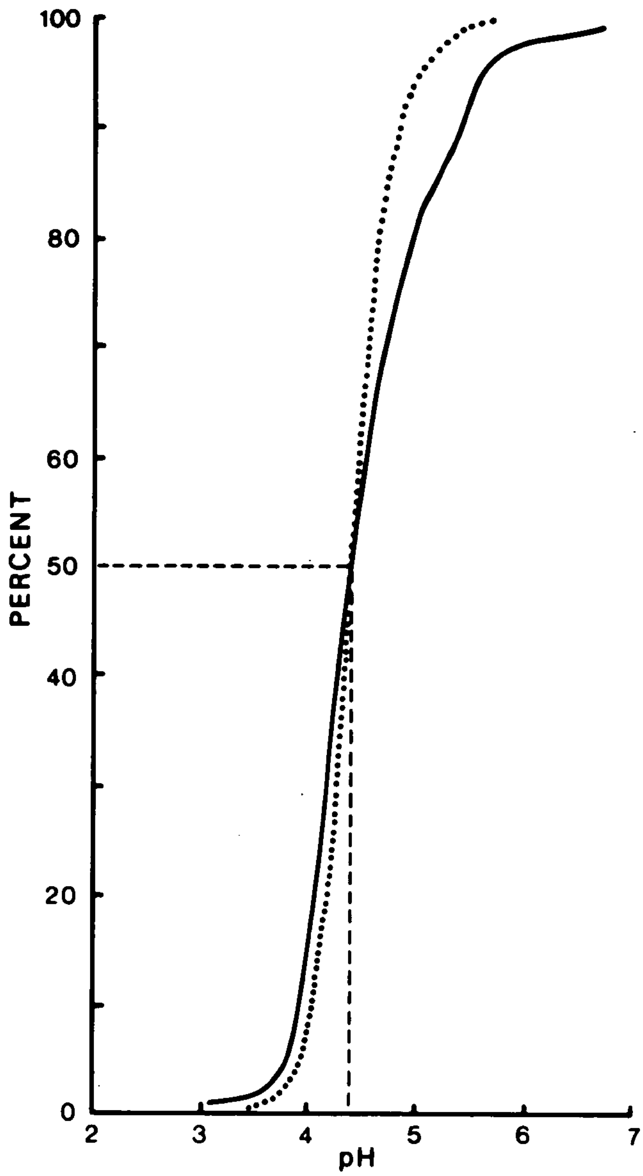

Figure 60 Cumulative distributions showing percentage of total rain with pH lower than given values for Banchory (—) in north-east Scotland (mean annual rainfall 780 mm) and Birkenes (Dovland, Joranger & Semb 1976) in southern Norway (mean annual rainfall 3900 mm).

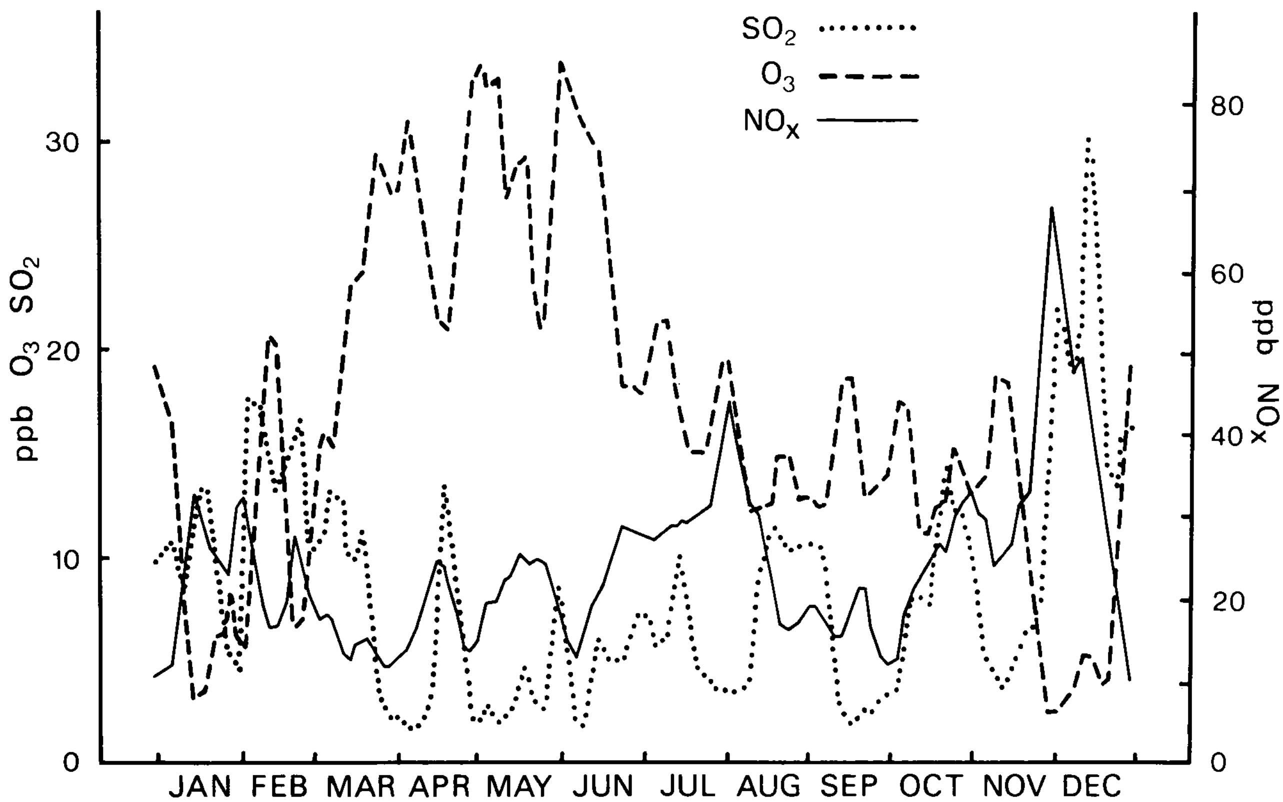

Figure 61 Changes during 1978 (11 day running means) in the concentrations of gaseous pollutants above the canopy of a Scots pine plantation at Devilla, near Kincardine-on-Forth, Scotland.

forest is liable to be fumigated repeatedly for periods with appreciable concentrations of atmospheric pollutants, SO_2 concentrations sometimes being more than 10 times larger than the mean annual concentration. The strong correlation between amounts of SO_2 and NO_x suggests the need to be aware of the occurrence of mixtures when attempting to identify the causes of damage. How often has damage been ascribed to SO_2, not knowing that similar concentrations of NO_x may also have been present?

Sulphur deposition

Based on work in Australia and at Imperial College, London, a fluxatron, with a rapid SO_2 sensor, has been constructed. In due course, this device will be used to make direct assessments of SO_2 fluxes from atmosphere to forest. Calculations made with SO_2 concentrations recorded 2 m above ground at the Bush Estate, near Edinburgh, suggest, assuming a deposition velocity (Vg) of $8{\cdot}0 \times 10^{-3}$ m s^{-1}, that dry deposition of SO_2 accounts for 21 kg S ha^{-1} yr^{-1}, and, calculating from rainfall measurements, wet deposition accounts for 11 kg S ha^{-1} yr^{-1}.

Effects of forest canopy on sulphur input to soil

Stemflow and throughfall studies at Devilla forest have shown that stands of Scots pine (*Pinus sylvestris*) can greatly change (i) the chemical composition of precipitation descending through it, and (ii) the spatial distribution of water deposited on the forest floor. In 1979, 57% of precipitation (794 mm) reached the forest floor as throughfall and 9% as stemflow; the rest, 34%, was lost by interception.

The acidity of precipitation increased as it passed through the forest canopy, from a pH of 4·2 to 3·7 (throughfall) and 3·3 (stemflow). Concentrations of sulphate-S, Ca and Mg were greater in throughfall and stemflow than in gross precipitation, particularly large concentrations of S being found in stemflow (Table 32). On average, twice as much S was deposited per unit ground area by throughfall as by gross precipitation. Assuming that stemflow influences soil in a band 5 cm wide around the bases of individual trees, then amounts of S deposited by stemflow are 100 times greater per unit area than those of gross precipitation. Calculations of lime potential, pH − ½p (Ca, Mg)*, show that the capacity of stemflow water to acidify soil was considerably greater than that of gross precipitation and throughfall.

Taking into account the role of the canopy in (i) accumulating dry deposited sulphur (and other acid-

Table 32. Chemical composition of gross precipitation, throughfall and stemflow.

	Gross precipitation	Throughfall	Stemflow
pH	4·2	3·7	3·3
Total Ca (mg $litre^{-1}$)	0·7	2·2	4·7
Total Mg (mg $litre^{-1}$)	0·5	1·2	2·0
Sulphate-S (mg $litre^{-1}$)	1·7	6·4	16·0

*Solution measurement for indicating the acidity level or acid-base status forming substances) which are subsequently washed off by precipitation, (ii) the large inputs per unit area around stems, and (iii) the low lime potential of stemflow, it is evident that Scots pine has a strong potential for locally acidifying soil. This potential is likely to be considerably strengthened by increasing atmospheric concentrations of SO_2 and other acid-forming gases.

Effects of polluted atmospheres on the surfaces of pine needles

Research in controlled conditions in many countries has shown that effects of pollutants on plant growth and development can be ascribed to perturbations of several different physiological and biochemical processes. Our study of needles of Scots pine suggests that alterations of leaf surface waxes may have significance.

Needle samples were taken from individuals of the 'Altyre' provenance of Scots pine growing in (i) an unpolluted region of south Scotland (winter mean conc<3 ppb SO_2m^{-3}), and (ii) a polluted area of northern England (winter mean conc>30 ppb SO_2 m^{-3}). When studied with a scanning electron microscope, it was found that the structure of epicuticular waxes was degraded more rapidly at the polluted site than at the other; this effect, which was conspicuous during the first 8 months of needle expansion, was later associated with premature senescence. These changes, attributable to ambient mixtures of pollutants, were associated with concomitantly decreased cuticular resistances to water vapour loss and therefore increased water losses. The latter may, during periods of water shortage, limit stomatal opening, thus decreasing photosynthesis. Calculations suggest that dry matter production might be decreased by 5%.

In characterising the complex changing mixtures of gases and particulates that occur in polluted atmospheres, several important 'effects' studies, direct and indirect, have been identified. What effect does acid precipitation have on soil processes and how does this affect the growth of terrestrial plants, also the chemical and physical nature of run-off and the performance of aquatic plants and animals? However, for the immediate future, priority is being given to the direct effects of mixtures of atmospheric pollutants on plant performance.

I. A. Nicholson

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REEDSWAMP CHANGES IN THE NORFOLK BROADS

The Norfolk Broads consist of a series of rivers and man-made lakes, mostly less than 2 m deep, which are usually fringed with reedswamp vegetation growing where the normal summer depth of water is up to 1 m. In recent years, however, concern has been expressed because much of the original reed appears to have died. For this reason, a study was made of areas of reedswamp in 18 Broads, representing 82% of the total area, with changes in their distribution being deduced from the '1880', '1905' and '1926' Ordnance Survey maps and aerial photographs taken in the period 1945 to 1978 (Boorman & Fuller 1981). Between 1880 and 1905, the area of reedswamp increased because the colonisation of open water exceeded losses by succession to fen. After 1905, the trend was reversed, with losses of reedswamp increasing dramatically from 1946 onwards. Reedswamp in the study area decreased from 121·5 ha in 1946 to 49·2 ha in 1977, the lost areas, which occurred in closed Broads and those open to pleasure boat traffic alike, reverting to open water.

On analysis, the pattern of reedswamp losses from 1945 to the present day was found to be related to changes in numbers of the introduced South American rodent, the coypu, whose numbers in East Anglia, since the 1930s, varied between a few hundred and about 70 000 (Figure 62). As numbers of coypus increased rapidly after 1947, the area of reedswamp decreased, the rate of loss slowing dramatically after the severe winter of 1962/63 when more than 90% of the coypu population died. Other calculations indicate that the damage could be attributed to coypus even if reedswamp, a preferred food, formed no more than 66% of their diets. However, as reeds are very sensitive to grazing damage, their loss may solely reflect the consumption of the palatable buds and young shoots, which, if taken *in toto*, would probably form no more than 10% of the coypus' diet. Grazing by wildfowl, especially feral geese, may also be involved, exacerbating earlier coypu damage, particularly in some of the Bure and Ant Broads.

Although grazing now seems to be the major factor concerned with reed dieback, eutrophication may play some part. Eutrophication tends to increase rates of sedimentation, and, in doing so, may increase the risks of grazing damage because buds in soft muds are more accessible; plants in anaerobic conditions, which develop with eutrophication, may be more sensitive to grazing damage because the removal of shoots may disrupt the supply of oxygen to roots. Although it was not possible to substantiate a deleterious direct effect of eutrophication on the growth of common reed (*Phragmites australis*), eutrophication virtually eliminated other aquatic macrophytes in some areas. As a result, wildfowl and coypus graze on reedswamp as an alternative food.

L. A. Boorman and R. M. Fuller

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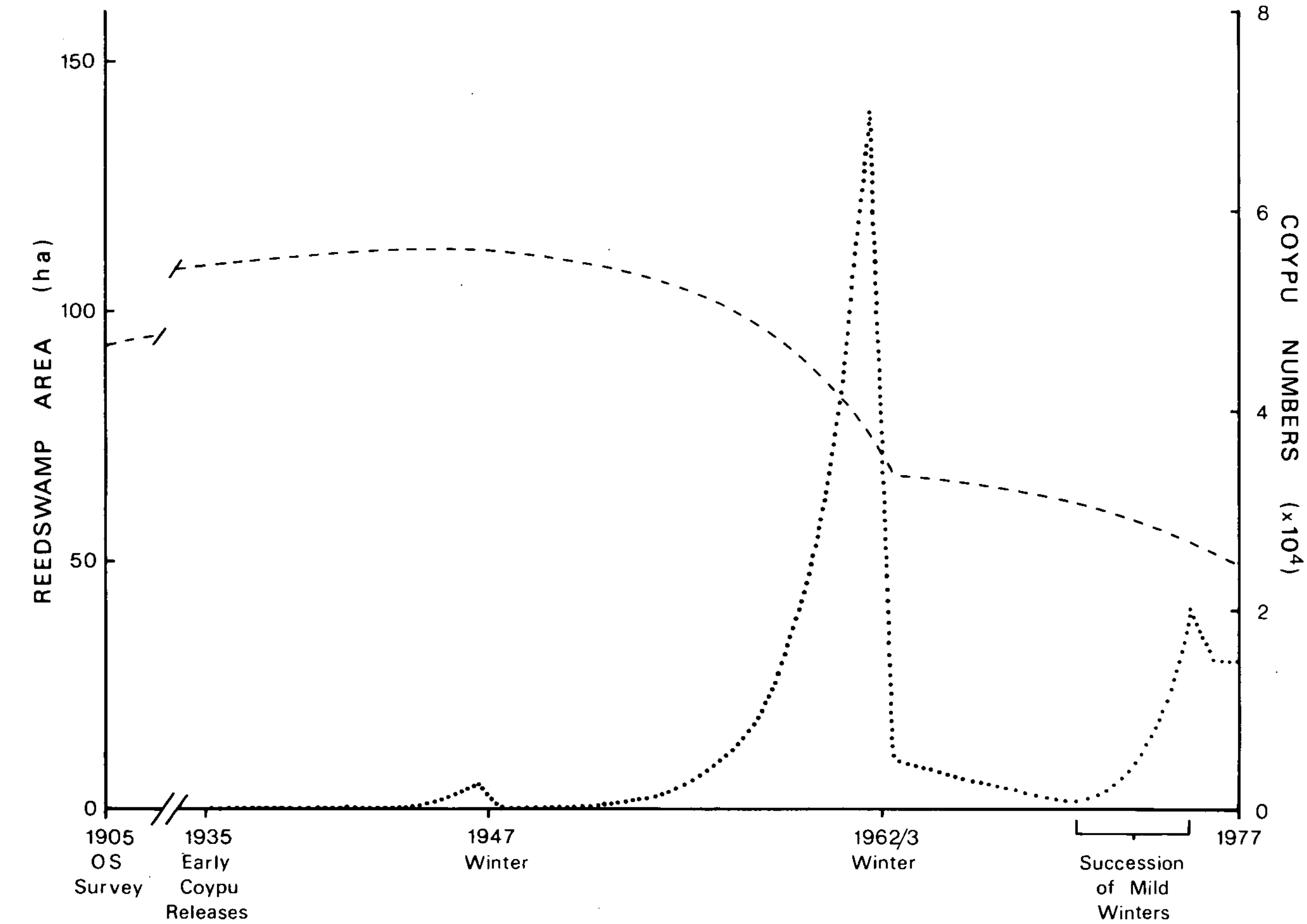

Figure 62 Relation between numbers of coypus (···) and areas of reedswamp (---) in the Norfolk Broads (1905/77). Details of reedswamp succession to fen have been omitted.

HISTORICAL PERSPECTIVES ON LAND MANAGEMENT

Not all lessons learnt from history can be put to use. Circumstances change so much that it is seldom possible to draw exact parallels between one situation and another. However, historical studies can provide a context, or a perspective, with which to appraise, and at times predict, trends in the natural environment of today, or in the future.

In general, sources of historical information are of 3 types: printed and manuscript material; the evidence preserved in the landscape, or ground, itself; and the information to be gleaned from people's memories (Sheail 1980). In a case study of a remarkable nineteenth century botanist, the Marchioness of Huntly, Sheail and Wells (1980) have illustrated the value of correlating the different types of available historical information. The specimens preserved in her herbarium make it possible to check the identification of plants mentioned in her day journals, and the journals frequently describe the conditions in which the specimens grew. The information that emerges from the herbarium and written records is invaluable in reconstructing the changes that followed, for example the drainage and reclamation of the meres and sphagnum bog in the Huntingdonshire fenland in the nineteenth century.

A range of ITE projects have explicitly included an historical component. On page 34 of this Report, there is reference to the way in which movements in the moorland edge, and other trends in land use and management, were traced in the study areas which were the subject of the Upland Landscape Study (Project 522). The Nature Conservancy Council has commissioned a study of the impact of land drainage on wildlife, with the aim of constructing base lines for as many points in time as possible, indicating the pattern of drainage, land use and management, and the biological status of those areas. In the initial phase of the study, particular attention is being given to the effects of changes in drainage regime on the wildlife of the Romney and Walland Marshes in Kent (Project 718).

As well as studying the effects of changes brought about by land use and management, historical research in ITE attempts to trace the more important shifts in attitude toward the natural environment. Following the publication of a history of the nature conservation movement (Sheail 1976), papers have been written on the early perception of national parks, coastal preservation, rural amenity, and the environmental problems arising from demands for facilities for outdoor recreation. Many of the features of rural planning and conservation, taken so much for granted in Britain today, can be traced back to the inter-war period (Sheail 1981).

There are many reasons for the strong sense of frustration that is felt over our present inability to settle land use questions expeditiously and effectively. One of these reasons may be related to the way in which we tend to exaggerate the novelty of many of these problems, causing us to look for equally dramatic ways of resolving them. A better appreciation of how conflicts in land use have developed over a longer time period might help to emphasise the fundamental, and therefore intractable, nature of many of the issues raised. Although the term had not been coined then, 'environmental crisis' could certainly have been used to describe some of the situations developing in Britain during the first half of the century. By 1900, there was increasing evidence of springs and watercourses in Hertfordshire being affected by the abstraction of underground water for the supply of London. It was feared that the deleterious effects on local water supplies, land use and vegetation would be irreversible, and considerable controversy ensued as to what was the most appropriate form of response to these changes. The term 'environmental crisis' might also have been applied to the despoliation of the Northamptonshire countryside by opencast iron-mining in the late 1930s. Ameliorative measures were sought, not only in the political and economic fields, but through surveys and experiments designed to see how far, and how quickly, the waste land of hill-and-dale could be rehabilitated for a variety of uses (Project 377).

When reviewing the publications of successive generations of naturalists and, more recently, of ecologists, it has been possible to discern a growing awareness of the effects of land use on individual species and communities. By the turn of the century, this concern had given rise to a nature preservation movement among several Naturalists' Unions. As ecologists began to look in more detail at individual communities and their components, and particularly at the dynamic relationships between each, so they came to take a more explicit interest in the relationships between man and the natural environment. Since the 1940s, ecologists have played a significant role in the nature conservation movement and more general land use issues. One of the more outstanding examples of this form of participation has been their perception of, and response to, the threats posed to wildlife by the use of chemical pesticides in agriculture. ITE has initiated an historical study of the research done on pesticides and other pollutants by the former Nature Conservancy, during the period 1949–73, hoping that it will contribute significantly to an understanding of how research on pesticides and pollution developed more generally in Britain (Project 697).

J. Sheail

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ESTABLISHING VEGETATION ON UNSTABLE COASTAL CLIFFS AT HIGHCLIFFE, DORSET

(This work was largely supported by Christchurch Borough Council funds)

Following consultations with the Borough Engineer's department of Christchurch Borough Council, ITE was invited to investigate and advise on the best methods of establishing a vegetation cover on the earth cliffs at Highcliffe following engineering works. These works, involving protection of the toe, and drainage of the face, had stabilised a section of the Christchurch Bay coastline which had for many centuries been steadily eroded by the sea (Plate 27). Although the forces involved in cliff slippage were too great to be resisted by plants alone, it was believed that, after a satisfactory engineering solution had been found, vegetation would help to bind the soil surface, prevent soil wash- and run-off, minimize the accumulation of excess soil moisture, and initiate soil development. It would also be of value in providing a visual and recreational amenity in a tourist and residential area.

The cliff 'soil' consisted mainly of immature Barton clays and patches of sand and gravel which, over many years, had dropped from the layer of plateau gravel on the top of the cliff. The lack of organic matter, the low nutrient status and the extreme physical properties of the clay together ensured that very few plants were able to survive. Coupled with this feature was the instability and steepness of many slopes and their constant disturbance by engineering works and trampling, preventing the establishment of all but a few ephemeral weed species.

In 1978, a series of pilot trials were arranged to test (i) the effects of different soil treatments on vegetation establishment and (ii) the performance of a range of grass species and varieties (Table 33). A standard seed mixture was used in the soil treatment trials, the mixture having proved to be the best in an earlier series of trials on a coastal bank subject to salt and drought in the Wash (Gray 1978). All plots were levelled with a small drainage trench dug at the top of each plot.

Assessments made in late summer of the year of planting highlight the superiority of soil treatments A and B which included the application of topsoil (Table 34, Plate 28). Germination was good, although patchy, in all treatments, but seedlings died in the absence of topsoil during a period of drought. The growth of white clover, perennial rye-grass and creeping bent was enhanced by additions of lime (compare treatments C and D). Red fescue was not a successful component of the mixture in the first year (although it performed well

Table 33. Soil treatments and seed mixture used to investigate vegetation establishment on unstable clay cliffs.

Soil treatments	A: Topsoil applied 20.4.78. Fertiliser (Enmag) applied after germination at rate of 80 g m^{-2} (2.6.78)
	B: Topsoil + fertiliser as in Treatment A. Lime raked into the surface with seed
	C: Lime + fertiliser only
	D: Fertiliser only
	E: Lime only
Seed mixture (sown at rate of 10 g m^{-2}) (% by wt):	20% *Lolium perenne* cv 'Melle'; 25% *Festuca rubra* cv 'Theodor Roemer'; 25% *Agrostis stolonifera* cv 'Emerald'; 20% *Festuca longifolia* vc 'Biljart'; 10% *Trifolium repens* S184.
Experimental details:	5 × 5 latin square sown on 24 April 1978 with each plot measuring 2 m × 2 m.

without competition in single species strips and in later years) and hard fescue, included in the mixture because of its proven drought tolerance, failed completely. In the single species strips in which peat had been added to the clay and gravel, creeping bent (cv 'Emerald'), red fescue (S59), perennial rye-grass (cv 'Melle' and S23) and Yorkshire-fog (variety unspecified) all germinated and established reasonably well when lime and fertiliser were also added, but their performance again demonstrated the need for topsoil.

On the basis of the results from these pilot trials and of seed availability, large-scale attempts to plant the cliffs were started in 1979. Because of variations in slope, substrate and accessibility, different parts of the cliff were treated separately:

A. The *'terraces'*, the reasonably level areas, were scraped to produce an uneven clay surface, with ridges running parallel to the coastline, which enabled low cost topsoil from a nearby council development to knit into the surface.
The seed mixture, consisting of 20% perennial rye-grass (S23), 50% red fescue ('Nova rubra'), 20% creeping bent ('prominent'), and 10% white clover ('Huia'), was hand sown at 150 kg ha^{-1} and then raked into the surface: slow-release fertiliser (Enmag) was added after germination.

B. *Slopes* greater than 20° were hydro-seeded directly. Because of the risk of being washed away during winter, topsoil was not applied. A mulch of milled sphagnum peat was applied at a rate of 2·5 tonnes ha^{-1}, and lime, ground limestone, applied at 500 kg ha^{-1} – procedures based on work in the Wash (Roberts unpublished) and on China clay waste tips (Sheldon & Bradshaw 1977). The seed mixture included rye-grass (25%), creeping bent (30%) and white clover (15%) as on the terraces, and to these were added Yorkshire-fog (30%).

C. Other areas including part of a lower terrace slope were sown with a range of grass varieties and species including some selections from a plant breeding programme, maintained by Dr. M. O. Humphreys, Welsh Plant Breeding Station, Aberystwyth, with the aim of producing grass varieties tolerant of salt and drought and suitable for amenity use (Humphreys 1980).

The development of the main seedings has been extremely encouraging (Plate 29). A dense cover of vegetation has been established over a large area of the cliffs, including some of the steepest slopes. The established stands have already acted as seed banks from which other areas have been colonised. This success in 1979 stimulated the planting in 1980 of previously unsown areas.

There has been considerable local interest in the project which is now entering its second phase, during which some small shrubs, mainly leguminous, will be planted, and the optimal maintenance regimes (including mowing and the application of fertilisers), and the effects of use on the swards will be assessed. Where waves break directly on to the sward (Plate 30), it is hoped to resow small barren patches with a new variety of red fescue selected from Dr. Humphreys' trials and

Table 34. The effect of soil treatment on vegetation establishment at Highcliffe after one year.

Treatment (see Table 33)	Cover/abundance index* of species and bare ground: S184 clover	Melle rye-grass	Emerald bentgrass	Th Roem red fescue	Biljart hard fescue	Yorkshire-fog	Other‡ weed species	Bare ground
A: Topsoil + Fertilizer	97	58	12	1	0	0	45	10
B: Topsoil + Fertilizer + Lime	97	69	13	0	0	0	35	10
C: Lime + Fertilizer	67	44	36	3	0	6	26	43
D: Fertilizer only	35	25	18	3	0	6	32	70
E: Lime only	31	3	3	3	0	0	22	89

*cover/abundance index = the number of times present in 100 10 cm × 10 cm squares in a central 1 m^2 quadrat (mean of 5 plots – see Table 33)
‡a total of 25 weed species were found in the plots, the most common being *Equisetum telmateja, Tussilago farfara, Juncus articulatus, Holcus lanatas* and *Polygonum aviculare*

currently being tested for distinctiveness, uniformity and stability before multiplication to commercially-available quantities. The death of the original sward in these small patches, after inundation by high winter tides, has shown that even dead remains of swards prevent surface channels developing and therefore minimize the risk of soil being washed downslope.

A. J. Gray, Sarah E Le V. dit Durell and Helen E. Bates

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Soil Science

METAL TOLERANCE IN BIRCH CLONES

In the field, glasshouse and laboratory, the variation among seedlings from open pollinated birch trees is considerable. Different responses to phosphorus and variations in leaf shape, hairiness and form, in dates of leaf emergence and fall, in degrees of rust infection and in assemblages of associated autumn-produced fruitbodies of mycorrhizal fungi have been observed. Could different degrees of tolerance to minerals such as zinc, copper and lead exist? These minerals are often found in toxic amounts on derelict land and spoil tips which are currently being reclaimed. Though strains of grasses and other herbaceous plants with tolerance to these substances have been exploited for the amelioration of despoiled sites, there are no records of a similar exploitation of tolerance in trees.

Aseptic methods for cultivating birch, described in ITE Annual Reports 1974 and 1977, were used for identifying tolerant seedlings, the agar nutrient medium being modified by the addition of zinc sulphate. Seeds from an open pollinated *Betula pubescens*, taken from an area of Scotland where there are no known accumulations of zinc, were surface sterilised and spread aseptically on the media with different concentrations of zinc sulphate. Although their germination was not affected, subsequent growth was affected deleteriously by the larger concentrations (Table 35).

One seedling (tolerant) growing on the medium supplemented with 64 ppm zinc and another (sensitive) which germinated but did not grow on the medium with 32 ppm were transferred to media without zinc,

Table 35. Effects of increasing concentrations of zinc, as zinc sulphate, on the germination of seeds, and survival of seedlings from *B. pubescens* taken from Inverpolly, Ross and Cromarty, Scotland.

Concentration of Zn (ppm)	Percentage germination	Percentage seedlings still growing 35 days after sowing seed
2	41	100
4	38	90
8	44	92
16	44	58
32	41	35
64	35	5

incubated, and, in due course, cloned and compared on media supplemented with different concentrations of zinc (0-80 ppm). Whereas the growth of the sensitive clone was significantly decreased by 48 ppm Zn, and prevented by 64 ppm, the tolerant clone continued to grow at concentrations exceeding 48 ppm and was only significantly decreased by 80 ppm (Figure 63).

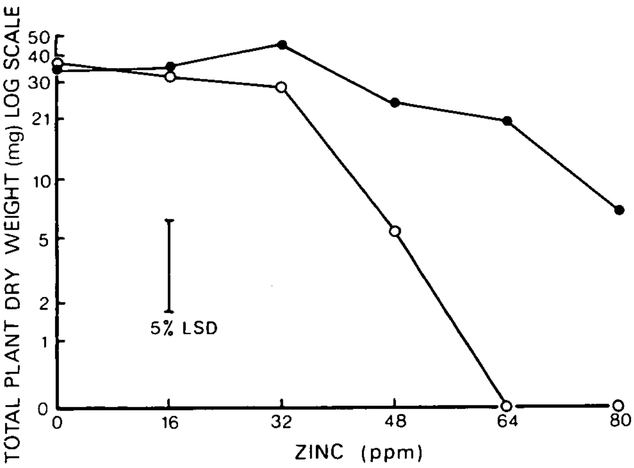

Figure 63 Effects of zinc, added as $ZnSO_4$ $7H_2O$ to nutrient agar, on the aseptic growth of zinc tolerant (●) and sensitive (o) clones of Betula pubescens.

Chemical analyses of stems and leaves showed that large amounts of zinc accumulated in plants of the sensitive clone, but not in those of the tolerant clone. As amounts of zinc increased in the foliage of the sensitive clone, amounts of calcium decreased, suggesting a form of competition between zinc and calcium. Although (i) the tolerance mechanism and (ii) the efficacy of tolerant clones on zinc-contaminated soils are unknown, the results indicate that a useful degree of tolerance to zinc, and possibly other toxic minerals, could be discovered by simple screening procedures.

J. Pelham

MYCORRHIZAL SUCCESSION AND GROWTH OF BIRCH

Mycorrhizal fungi develop symbiotic associations with the roots of trees, enhancing their nutrient uptake. Judged by the production of fruitbodies, it seems that the types of ectomycorrhizal fungi change as trees get older (Chu-Chou 1979; Mason *et al.* in press). The reasons for these fungal successions are unknown, but 3 hypotheses are currently being investigated:

i. Early members of the fungal succession require trees to supply relatively small amounts of energy (sugar), whereas later members demand larger supplies.

ii. Early members of the succession are only able to supply their hosts with soil nutrients that are freely available, whereas later members of the succession are more efficient at mobilising diminished reserves of inorganic nutrients and/or are able to break down organic materials.

iii. Early members are more competitive and grow more strongly than late members which characteristically form mycelial strands. The latter group may benefit from the activities of decomposer microbes.

Evidence supporting the energy demand hypothesis (i) has been obtained from ITE experiments which showed that late members of the fungal succession needed large concentrations of glucose before appreciable growth was made on agar media, whereas early members were less demanding.

To investigate hypotheses (ii) and (iii), experiments are being done with seedlings of birch and lodgepole pine inoculated with different mycorrhizal associates and grown in perlite with different concentrations of phosphorus. Using a ^{32}P-uptake bioassay technique (Harrison & Helliwell 1974), it seems that the early colonising fungus *Hebeloma saccharoliens,* when inoculated to birch, increased P-uptake compared with that of non-mycorrhizal control seedlings and seedlings with the late coloniser *Amanita muscaria.* However, the effects on shoot weight were relatively small compared with those of different phosphorus concentrations. With pine, the opposite set of effects was observed, ie a big influence of mycorrhizas, and a relatively small response to phosphorus concentration. These experiments are being extended to include effects of nutrients derived from inorganic and organic sources.

J. Dighton

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EPIDEMIOLOGY OF SHEATHING (ECTO–) MYCORRHIZAS

The sequential production of fruitbodies of mycorrhizal fungi, appearing in the first 7 years after planting birch, (*Hebeloma* sp.→*Laccaria laccata*→*Inocybe lanuginella* →*Lactarius pubescens*→species of *Leccinum* and *Cortinarius*) suggests that the colonisation of roots may be programmed systematically (Cover photograph). Because of increasing interest in the strategy to be adopted when making pure culture mycorrhizal inoculations during sapling propagation, experiments are being done to investigate the fate of, and benefits derived from, different fungi. Is a later member of the fruitbody succession, eg *Leccinum* spp and *Amanita muscaria*, able to keep pace with, and colonise comprehensively, roots of saplings when grown, after inoculation, in field and forest soils?

Birch seedlings inoculated at the start of an 8-week period of propagation with *Hebeloma sacchariolens, Paxillus involutus* (2 'early' fungi) or *Amanita muscaria* (a late stage fungus) were planted into 2 peaty and 2 mineral-type soils. Growth was thereafter assessed at intervals of 10 days when plants were sampled destructively, measurements being made of shoot and root development. Although analyses of data are incomplete, it is already obvious that *A. muscaria,* unlike *H. sacchariolens* and *P. involutus*, was unable to spread and infect the roots forming in the 4 different soils. Thus, by the tenth week after planting, fewer than 1% of roots of seedlings inoculated with *A. muscaria* were mycorrhizal, compared with 10% and 30% where *H. sacchariolens* and *P. involutus* were used.

Root systems of seedlings successfully infected with *H. sacchariolens* or *P. involutus* seemed to resist colonisation by other fungi, although many individual roots remained non-mycorrhizal. In contrast, roots of seedlings inoculated with *A. muscaria* or in the series of uninoculated controls, were beginning, after 12 weeks' growth, to form mycorrhizas with *Thelephora terrestris* and a range of other fungi including *Laccaria proxima, Inocybe lanuginella* and *Hebeloma mesophaeum*. In the autumn, many of these fungi produced toadstools (earth fans in the case of *T. terrestris*), but they were restricted to birch seedlings growing in mineral soils. Likewise, fruitbodies of *H. sacchariolens*, which only appeared in association with seedlings inoculated with *H. sacchariolens,* were restricted to mineral soils (Table 36).

Although both formed many mycorrhizas, *H. sacchariolens,* unlike *P. involutus,* fruited in the first season after inoculation. It would seem, therefore, that periods between root colonisation and toadstool formation differ among mycorrhizal fungi, but generalisations should not be made until numbers of isolates of different fungi have been tested. Reassuringly, the within-season occurrence of fungal fruitbodies was similar to that occurring in the field, with *H. sacchariolens* occurring in early September,

Table 36. Effects of inoculating birch seedlings with *Hebeloma sacchariolens*, *Paxillus involutus* or *Amanita muscaria* on the production of fruitbodies during the first autumn after being transplanted to either mineral or peat soils.

Seedlings inoculated with, and grown in:	Nos of seedlings (one per pot) of a possible 30 with associated fruitbodies of: *Hebeloma sacchariolens*	*Paxillus involutus*	*Amanita muscaria*	*Thelephora terrestris*	*Laccaria proxima*	Others
Hebeloma sacchariolens						
(a) Mineral soils	18	0	0	0	0	0
(b) Peaty soils	0	0	0	0	0	0
Paxillus involutus						
(a) Mineral soils	0	0	0	1	0	1
(b) Peaty soils	0	0	0	0	0	0
Amanita muscaria						
(a) Mineral soils	0	0	0	8	4	0
(b) Peaty soils	0	0	0	0	0	0
Uninoculated controls						
(a) Mineral soils	0	0	0	6	7	2
(b) Peaty soils	0	0	0	1	0	0

being followed in turn by *T. terrestris*, *Inocybe lanuginella* and eventually, at the end of October, by *Laccaria proxima*.

P. A. Mason, Julia Wilson and F. T. Last

EFFECTS OF *LUMBRICUS RUBELLUS* ON MOORLAND SOILS COLONIZED BY BIRCH

The reputation of birch as a soil improver dates back at least to the eighteenth century. Although studies on experimental birch plots set up in the late 1940s on the Yorkshire moors have failed so far to reveal improvements, observations on a series of less base-deficient birch stands (Miles 1978) suggest that birch growth may indeed result in a trend from podzol towards brown podzolic or brown forest soil with the formation of mull humus. The transition from a surface layer of peaty raw humus under heather to an intimate mixture of soil mineral and organic material under birch has been attributed, at least partially, to earthworm activity, but few species of worms can tolerate the extreme acidity of heather peat. Of the few that can, the most likely initiator of soil change under birch is *Lumbricus rubellus*, which ingests both organic and mineral matter and is commonly a surface feeder on dung in moorland habitats.

Current field studies on the ecology of this species include assessments of (i) the rates at which populations would build up during birch colonisation, (ii) the amounts of carbon these populations could be expected to remove from soil organic matter as respired carbon dioxide, (iii) the extent to which *L. rubellus* stimulates microbial decomposition of raw humus and (iv) its ability to mix surface organic material into the soil profile.

Preliminary work on the basic ecology of *L. rubellus* has shown that the optimal temperature for reproduction is about 18°C and that, in laboratory cultures, it grows well on a diet of dung if it is able to ingest soil or sand, but grows more slowly in the absence of ingestable mineral matter or if the environment becomes anaerobic (Table 37).

Although respiration rates and weights of worms were not related at 2°C and 5°C, studies with a Gilson respirometer have shown, as expected, an inverse linear relationship at temperatures from 10°C to 20°C. The respiration rate per gram can now be estimated, and work is in hand to estimate the weight of worms present in birch stands of different ages.

This work is being done in collaboration with Dr. Colin Millar of Aberdeen University.

J. E. Satchell and M. Gillham

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Table 37. Effects of different media on the ratios and weight after 28 days at hatching of *L. rubellus*. *rubellus*.

Culture medium	Dung over soil	Dung, soil mixed	Dung over sand	Dung over glass balls	Dung only	Dung over waterlogged sand
	27·6 ± 2·05	26·5 ± 1·94	27·9 ± 2·26	10·7 ± 2·10	6·4 ± 1·32	2·4 ± 0·82

GEOCHEMICAL CYCLING

In 1979, as a result of recommendations from the Advisory Board of Research Councils, additional funds were made available for basic research on geochemical cycling, and, in collaboration with other institutes and the University College of North Wales, a research programme was initiated to investigate some aspects of mineral weathering. Although there have been many studies on mineral weathering, insufficient is known about (i) the release of major (K, Mg, Ca, P) nutrients and associated (Fe, Al, Mn) elements into soil solutions by the weathering of primary and secondary minerals, (ii) transfers of these elements within soils and into surface and ground waters, and (iii) the effects of land management practices on these releases and transfers.

The first stage of the study to correct these deficiencies in knowledge has been based on 5 small tributary catchments, 4 first order and one second order, at the headwaters of the River Wye and within the Institute of Hydrology experimental catchment. Some of the upland rough grazing catchments have shale bedrock, others have mudstone; within each group, at least one has been ameliorated with the addition of fertilisers. Elemental inputs in precipitation, and outputs in stream water and sediments, are being monitored weekly, with more frequent and detailed sampling during specific rain events. Ultimately, the data will be used to formulate geochemical budgets for the different catchments, including assessments of (i) rates of weathering in shale and mudstone catchments, and (ii) the influences of fertilisers. To date, the results indicate that (i) wind direction influences precipitation chemistry, and (ii) stream water chemistry is affected appreciably by the application of fertilisers and slightly by differences in bedrock. Additionally, the concentrations of some ions in stream water vary seasonally.

Soil water is sampled from the dominant stagnopodzol soils of each catchment by using ceramic cup samplers and tensionless collectors. Chemical analyses have shown that the effects of amelioration, including the application of fertilisers, even if applied 30 years previously, are still detectable. In the next stage of the field study, water movements and parallel within-catchment chemical changes will be observed.

Field observations are being complemented by laboratory studies of the stagnopodzols. To simulate processes in the field, soil profiles reconstructed in plastic cylinders are being leached in a way that may explain and help to predict the likely impacts of different management practices.

M. Hornung

IMMUNOFLUORESCENCE OF *MYCENA GALOPUS*

The inability to discriminate between most species of micro-organisms *in situ* is a major problem in soil biology. However, fluorescent-antibody staining has been found to be a potential means of detecting and quantifying the hyphae of the saprophytic toadstool fungus *Mycena galopus,* an important decomposer of woodland litter (Frankland *et al.* 1981). Development of a more specific antiserum to *M. galopus* has continued in a joint project with Miss J. M. Chard and Prof. T. R. G. Gray (Biology Department, Essex University).

Several fungi, including genera related and unrelated to *Mycena* and species related to *M. galopus*, have been isolated from woodland soils and plant litter. The fungal reactions against sera obtained by injecting rabbits with a 'whole cell' mycelial extract have then been compared with those of *M. galopus*, using the gel double diffusion method. Unrelated species showed weak, if any, reactions, whereas related species showed common reactions, some stronger than others (Plate 31). Cross-reactive antibodies were removed by absorption of sera with mycelium of another common toadstool fungus *Marasmius androsaceus*. Absorption left an antigenic protein component which appears to be specific to *M. galopus* and its varieties. This protein fraction has now been partially purified by ammonium sulphate precipitation and ion exchange chromatography, and, when injected into rabbits, an antiserum was produced which had increased specificity to *M. galopus*. The new serum is being used to improve immunofluorescent staining of laboratory cultures of the fungus before tests are made on woodland litter.

Juliet C. Frankland, A. D. Bailey and Janet Poskitt

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DISTRIBUTION OF A SAPROPHYTIC BASIDIOMYCETE UNDER SITKA SPRUCE

It seems that the distribution of fruitbodies of mycorrhizal fungi in woodland is related to the position of individual trees and, at least in part, reflects the processes controlling the colonisation of their roots by these fungi (Pelham *et al.* 1979; Dighton this Report). Current research suggests that the spatial arrangement of toadstools of woodland decomposer fungi is also influenced, even if less directly, by the arrangement of trees and by the environmental conditions that the trees create. Maps made, in each of 3 years, of fruitbodies of *Mycena galopus* and *Marasmius androsaceus*, both decomposers, show that the complex aggregations of their fruitbodies in a plantation of Sitka spruce vary from year to year. These patterns are being analysed in relation to tree position and soil conditions. In a related study, Newell (1980) found that clumps of *M. galopus* in the same plantation varied in diameter from 1–3 m and that the ratios of *Mycena galopus* to *Marasmius androsaceus* fruitbodies were larger where the litter rested on a gley, than on a ranker, soil.

Juliet C. Frankland, A. D. Bailey and Pamela L. Costeloe

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PRIMARY PRODUCTION, DECOMPOSITION AND NUTRIENT CYCLING IN BRACKEN: A TRAINING PROGRAMME

Ling-zhi Chen, from the Institute of Botany, Academia Sinica, Peking, China, spent a year (1980) at Merlewood under the sponsorship of the Chinese Government. The aim of her visit was to gain experience in research on productivity, decomposition and nutrient cycling and in statistical analysis and mathematical modelling. A research project on bracken was designed to provide both practical and theoretical training.

Seasonal sampling of a bracken stand on brown earth over limestone near Merlewood showed a maximum aerial biomass averaging 794 g m^{-2} in August. Seasonal variation of below-ground biomass was not marked, but rose from 1 564 g m^{-2} in late winter to 2 986 g m^{-2} in autumn. It is not clear if the increase represents net accumulation by the stand or if some of the increment is lost in respiration over winter. Assuming that the stand is accumulating, net primary production averaged 2 667 g $m^{-2}yr^{-1}$ on deep soils and 1 023 g $m^{-2}yr^{-1}$ on shallow soil.

Estimates of rates of decomposition of litter, using 4 different methods, were consistent, the loss rate ranging from 0·21 to 0·32 g g^{-1} yr^{-1}. Weight loss of dead petioles and pinnules in litter bags was 0·317 to 0·321 g g^{-1} yr^{-1}. Measurement of respiration of litters showed a strong influence of moisture. Based on relationship of respiration to moisture and temperature, and on simple estimates of field variation in climate, it was estimated that 73–88% of the observed weight loss could be attributed to microbial respiration. A third estimate of decomposition rate, based on the change in chemical composition with time, indicated a loss of 0·24 g g^{-1} after 40 weeks in the field. Lastly, based on annual input and standing crop of litter, the constant fraction loss rate for all bracken litter is estimated at 0·26, which implies that it takes about 12 years for 95% turnover of the litter.

From the measurement of live and dead standing crop during the year and their chemical composition, the nutrient flow through the stand was calculated. There is an increment of nutrients in the standing crop from winter to autumn. In autumn, senescence of live fronds results in a loss to standing dead, and some below-ground standing crop is lost to dead rhizomes. The increments and losses are balanced by uptake from soil during the year. For nitrogen (Figure 64), the annual

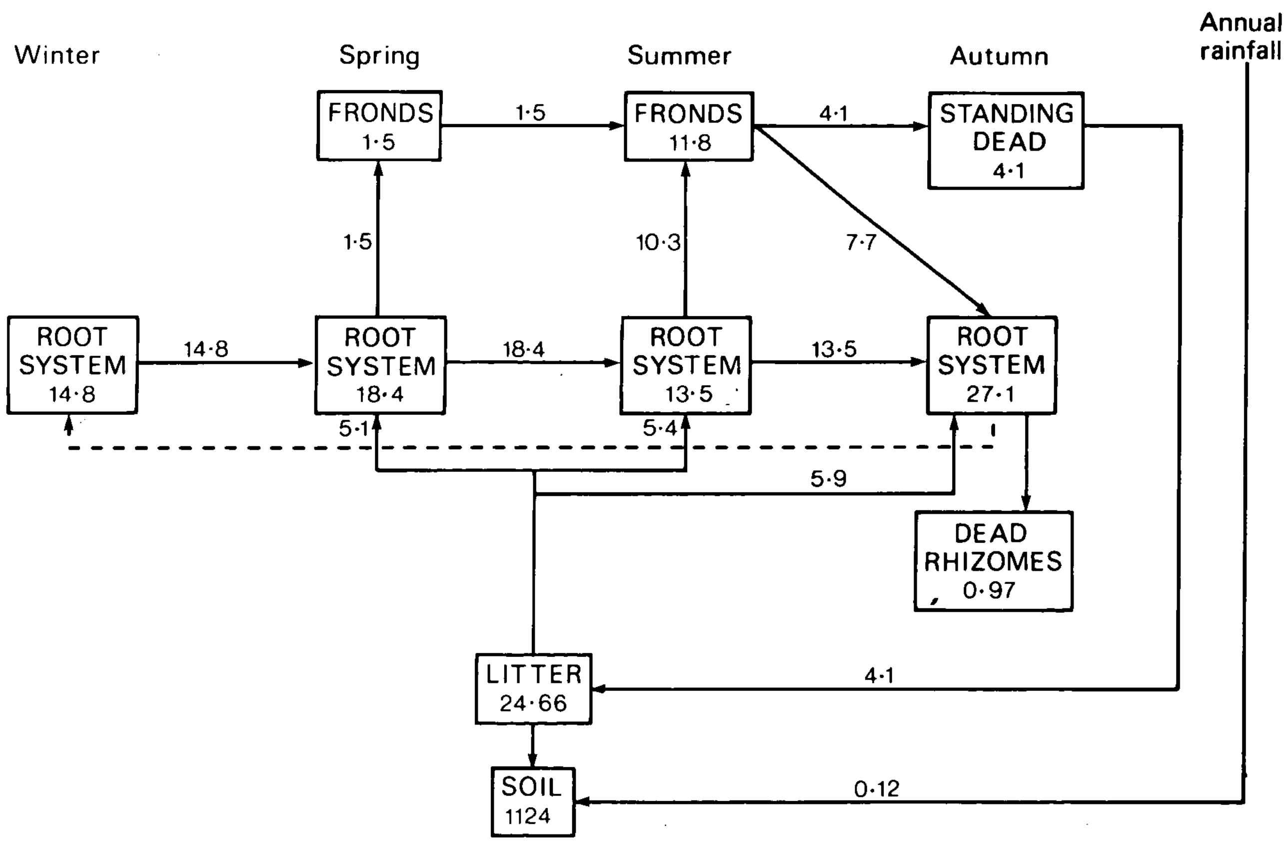

Figure 64 Nitrogen flow in bracken stands (g m⁻²).

uptake is estimated at 16·4 g m^{-2} compared with 2·1 g m^{-2} phosphorus, 14·9 g m^{-2} potassium and 12·8 g m^{-2} calcium. The turnover of elements relative to the standing crop of elements in bracken ranged from 0·59 for potassium to 1·71 for calcium. Compared with the standing crop in soil, the annual uptake by bracken ranged from 0·015 for nitrogen to 0·59 for potassium. Although uptake of phosphorus was only 0·03 of the total soil phosphorus, it was 5·0 of the extractable phosphorus.

The results produced by Mrs Chen are presented in a Merlewood Research and Development Paper, but they must be considered as tentative because of the limited sampling which could be done in the time available. However, they show the type of experience which can be obtained in a one-year study and the results are being used by Mrs Chen's successor, Cui Qiwu, who is now (1981) at Merlewood to develop his expertise in ecological modelling.

O. W. Heal

Data and Information

SERVICES

Computing

The development of computing services within the Institute has inevitably been strongly influenced by the integration of the ITE service (early in 1981) within the NERC Computer Services (NCS). However, there has been progress at all locations, and computing needs are now basically satisfied, although improvements are anticipated when the relationship with NCS is fully functional. The 4 PDP 11s at Monks Wood, Merlewood, Bangor and Brathens continue to be heavily used for the in-house statistical and general station work. Many similar application programs in BASIC are being implemented for all 4 locations, although the operating systems used are not identical. These mini-computers are backed up by Olivetti P6060s at Merlewood (Director's laboratory), Furzebrook and Cambridge. These micro-computers were the basis for a successful training course on systems analysis, given, in China, by the Director and 2 members of the Subdivision, D. K. Lindley and R. T. Clarke, to some 120 Chinese scientists. The visit was sponsored by UNESCO, as part of their Man and the Biosphere project.

Several major projects require main-frame computers, increasingly provided within the framework of NCS, and using the SRC computers at the Rutherford Laboratory or the Honeywell computer at Bidston. A major use of the NERC facilities—using the G-EXEC data management package—has been for the storage of data from TEIS and BRC at Bangor and Monks Wood. ITE Bush and Craighall Road are also major users of main-frame computers at the Edinburgh Regional Computer Centre. The provision of improved in-house input and output facilities for the Edinburgh stations is an urgent requirement. Other university computers are used less regularly at Cambridge and Bangor.

C. Milner

Biometrics and mathematical modelling

The biometricians within the Subdivision have provided statistical, mathematical and modelling advice. The considerable growth of interest in numerical ecology has stretched limited resources, but, nevertheless, advice and analysis have been provided in a wide range of subjects.

The main areas of application have been in modelling population fluctuations, the estimation of animal abundance, analysis of population regulatory factors, data banking and information retrieval, design and analysis of experiments, survey sampling and numerical classification.

A renewed interest in ecosystem modelling has also been evident with work on the freshwater system (through the ITE Loch Leven modelling group) and, at the opposite extreme, the arid and semi-arid ecosystems of East Africa.

Ecobase

Under contract to ITE, the NERC Experimental Cartography Unit (ECU), now a section of NERC Scientific Services, has compiled 'Ecobase'—a digitised map of major physiographic features of the British Isles. The purpose of this project is to make available in computer readable form a base map of important geographic characteristics on which to overlay ecological data in order to display a wide range of ecological and geographical interactions. The main advantage of digitised maps is the flexibility they offer the user in tailoring individual maps for particular applications by selecting, for example, the features to be plotted, the symbols to represent them, and the scale to be used in plotting the map. In addition, the digital map can function as a cartographic data base, enabling computation of line lengths or areas associated with individual features within a designated 'window'.

The initial phase of Ecobase is substantially complete. The planimetry of mainland Britain has been digitised at a scale of 1:250000 from Ordance Survey sheets and the following features recorded:

- Coastline
- Water pattern (rivers, lakes, canals)
- Roads (motorways, class 'A' roads, class 'B' roads)
- Railways (used and disused)
- Urban areas
- Woodlands

Work is in hand to incorporate administrative boundaries and topographic data (metric contours and spot heights and boundaries) from other digital sources. Consideration is being given to the inclusion of other data of ecological significance (eg soil type, drift geology).

Ecobase has been used by ITE in a number of applications, including provision of quantitative physiographic data for the Ecological Survey of Britain and the generation of standard outline maps for publication in BRC atlases. Currently, Ecobase is being used in the preliminary Severn Barrage study, in the analysis and mapping of the vegetation of railway land, and in the preparation of standard base maps for displaying ecological data.

Ecobase is at present held on ECU's PDP 11/40 computer at Wingate House in Swindon. It is planned to make the data directly accessible to users throughout NERC by means of the NERC/SRC computer network. In the meanwhile, anyone with possible applications for Ecobase, or requiring more detailed information, should consult Dr. B. K. Wyatt of the Terrestrial Environment Information System (ITE, Bangor) who is acting as the focal point in ITE for users of Ecobase.

Micro-processors
Cross-assemblers for the RCA 1802 CMOS and Motorola 6800 micro-processors have been written. The programs run under BASIC 11. Each cross-assembler comprises 3 chained programs; the 1802 incorporates some interactive features for coding the interrupt service routine, and the standard call and return subroutine technique.

RESEARCH

Biological losses due to the operation of a pumped-storage scheme

(This work was largely supported by funds from the North of Scotland Hydro-Electric Board)

The operation of a pumped-storage hydro-electric scheme creates a daily cycle of discharging water from the upper reservoir and pumping water (usually at night) to replenish it. Plankton and small fish pass through any screens on intake, and investigations at existing pumped-storage plants have shown that some organisms are destroyed in passing through the turbines, the proportion varying between species.

There was a need, therefore, to develop a model to predict the cumulative effects of continuous operation. Survival of species depends on the losses due to turbine operation, mixing processes in the lower reservoir, and the biological response of organisms.

In the absence of mixing, the same water is discharged and pumped each day. This leads to a zone around the intake where all living matter is destroyed. The fractional loss from the loch as a whole, however, is small, being the ratio of the pumped volume to the lower reservoir volume. The other limiting condition assumes that there is complete mixing each day, ie a single cycle of operations causes an instantaneous, uniform reduction in relative organism density over the entire loch, and that it is this reduced density that is pumped at the start of the following cycle.

Neither limiting condition is realistic, but such calculations emphasise that any rate of loss ultimately leads to extinction in the absence of any compensating biological response, the details determining only the time scale for extinction. The events over a period of one year are, therefore, critical, ie whether the annual reduction in population is sufficiently severe for the number of recruits in the following year to be affected. If this is so, then the effects are cumulative and ultimate destruction of the population will still occur. Investigation of events over a period of a year, involving a very large number of weather changes, means that detailed studies of hydraulic conditions in the lower reservoir are not useful. Much of the investigation concerns the sensitivity of the annual survival of organisms to different assumptions about mixing processes in the loch. Fortunately, survival rate has proved relatively insensitive to the exact nature of these processes so that it has been possible to make reasonably confident predictions.

Losses due to turbine operation have proved to be one of the most important environmental effects of pumped-storage schemes.

I. R. Smith

Chemistry and Instrumentation

SERVICES

Analytical chemistry, Merlewood
This service team caters for the needs of many research projects, which means that analytical requirements can be quite extensive. As far as chemical characteristics are concerned, the emphasis has oscillated between pollutants and mineral nutrients, with organic and physical components sometimes building up to a significant requirement. Up to 4 or 5 years ago, vegetation was the main material type processed in the laboratory, followed, more recently, by large numbers of soil samples. Over the last 2 years, however, the prime need has been for the analysis of water samples.

Two projects (ITE 380 and 594), in particular, have generated a large demand for water analysis. In the geochemical cycling studies (ITE 594), it is necessary to examine the mineral content of rain, lysimeter solutions and stream water. Because of spatial variation, heavy replications are necessary, which, with frequent sample collection, lead to large numbers of samples coming in to the laboratory. The sulphur pollution studies (ITE 380) have been looking at the levels of sulphur and a number of other characteristics in rainwater, stemflow and throughfall from experimental sites around Scotland. These 2 projects together account for about 60% of the water samples which have been tested in 1980. Similar analyses have also been carried out for 10 other projects, for the Nature Conservancy Council and other external agencies. The total through-put of waters during the year has been about 6000 samples, resulting in the analysis of almost 60000 separate characteristics.

The analysis of soil and vegetation samples has continued at a lower level, and about 2000 samples of each category have been examined during the year. Most of these were analysed for major and minor nutrient elements, although a limited number of organic fractionation tests were also carried out. Another bulk source of samples was the programme concerned with fluorine pollution (ITE 160, 524 & 525). A total of 1200 vegetation and animal tissue samples were tested for this element.

Few analytical contracts were taken on for outside customers during the year because of the need to meet ITE commitments. One of the few large contracts which was accepted was from the Atomic Energy Research Establishment, Harwell, which called for particle fractionation and organic carbon tests on soil samples taken in connection with a survey on environmental radioactivity. The section continued to provide an analytical service for biologists of the British Antarctic Survey. Most of the samples coming from this group are skeletal soils and bryophytes which are collected in connection with investigations on soil establishment and nutrient cycling at low temperatures.

One small contract commitment which continued, despite the pressure of other work, was for the Forth Pollution Unit at Napier College in Edinburgh. This Unit has been involved in a monitoring study in relation to schemes for reducing pollution levels in the Forth estuary. Analyses of nitrogen fractions and phosphorus have been carried out in past years and, for the sake of analytical continuity, this support has continued. Analytical work for the Nature Conservancy Council declined markedly during 1980. The amount of work coming from all non-ITE sources accounted for about 10% of the section's total effort.

Although the Merlewood analytical chemistry section, and also the corresponding section at Monks Wood, is primarily a production unit handling large sampling numbers and well tried techniques, there is a continuing need for validation tests and also for occasional technique development. Particular attention was paid towards the end of the year to the need for more validation tests, following publicity that standards have been dropping in some production laboratories. It has always been appreciated that there was a danger of malpractices being introduced when the same routine tests were being carried out over a period of many years, and it was therefore appropriate to introduce a series of independent checks on analytical procedures.

Two methods were investigated. (i) A nitric-perchloric digestion procedure was examined as a possible alternative to the normally accepted dry ashing method for total sulphur in organic materials. Preliminary work indicated that the use of vanadium as a catalyst was efficient and the method compared favourably with the one involving dry-ashing. (ii) The procedure which had been used for determining organic phosphorus in soils and which involved ignition was re-evaluated. It had been found to be unsatisfactory for some non-calcareous soils, and several soil types were therefore extracted with progressively stronger solutions to establish optimum conditions.

There were no new major instrumental developments in this laboratory in 1980. Use of the on-line laboratory computer was extended to utilize all input lines, which enabled one atomic absorption spectrophotometer, one dual flame photometer, 3 auto analysers and 2 analytical balances to feed straight into the processor. By the end of the year, data from the automated and manual instruments were being stored on the computer. Software has been developed for sorting results. This has made it possible to produce a hard copy output of the data together with a limited amount of sample background information.

J. D. Roberts

Analytical chemistry, Monks Wood

The Monks Wood service laboratory has been almost entirely concerned with the analysis of pollutant chemicals, notably heavy metals and organochlorine pesticides. However, in one sense, the position at Monks Wood is similar to that of the Merlewood laboratory, with the emphasis on bulk production using established techniques.

Over the year, almost 12000 individual metal determinations originating from 3500 tissue samples were carried out. Continuing monitoring studies into bird fatalities accounted for some of these samples, but most of the analyses were carried out in support of 2 projects: ITE 455 is concerned with the effects of heavy metal pollution on avian species, whereas ITE 481 deals with effects on aquatic organisms. Principal metals of interest for both projects were lead, mercury and cadmium, although a number of other heavy metals were also examined.

The number of specimens requiring analysis for organochlorine pesticides rose markedly in 1980 compared with the previous year. Altogether, 900 samples were tested using gas chromatography. The principal reason for the upsurge of interest in these pesticides was the transfer to the Monks Wood laboratory of analytical contracts previously carried out for the Nature Conservancy Council by laboratories outside the Institute.

The division of analytical services between Monks Wood and Merlewood laboratories is determined according to the facilities and experience available at each centre. In general, it has been found to be more efficient for each laboratory to specialize in different aspects of analytical chemistry. Occasionally, however, there is a need for a joint analytical support programme by both laboratories, and this was the case for the project concerned with the impact of barytes mining (ITE 705). The tests for chromium and lead were carried out by the Monks Wood laboratory making use of the furnace volatilisation procedure, coupled with the atomic absorption method; the Merlewood laboratory determined the non-pollutant constituents on these samples.

Apart from the introduction of the anodic stripping voltammeter, briefly referred to in a separate report (see p 110), no other major instrumental system was introduced during the year. A number of modifications were introduced to existing instruments, some of which attracted the attention of commercial manufacturers. In one case, a new support for the atomic absorption graphite furnace attachment was developed, whilst, in another modification to the same instrument, furnace extension tubes were designed to prevent deposition of atomised material.

M. C. French

Radiochemistry

The purpose of the radiochemistry laboratory is to service the needs of the project group investigating the distribution of radionuclides in the terrestrial environment.

The prime concern during 1980 was:

1. to establish new laboratories and commission the instruments;
2. to carry out such development work as necessary to establish procedures for the measurement of individual radioactive nuclides in silts, soils and vegetation.

The inevitable delays during the conversion of offices to laboratories meant that occupation was not possible until the late spring. This delay was frustrating from a practical work point of view, but the intervening time was well spent in becoming familiar with the extensive bibliography and in planning and organising the test programme.

Two separate lines of development proceeded concurrently, analysis for gamma-emitters and analysis for alpha-emitters. Gamma-spectra can be obtained using the dry sample with no prior treatment except grinding or sieving to obtain a uniform powder. A number of different types of sample holder are available for use with the Ge(Li) detectors employed in the counting system. Because of the differing geometry, calibration was necessary and was done by spiking the various sample types with nuclides of known gamma-energies and activities. The counting efficiencies were then used to quantify the gamma-spectra of actual samples.

Alpha-spectrometry cannot be carried out directly on the sample, because of interactions between alpha-particles and the sample matrix. Thus, complex chemical separation procedures are required to isolate the elements of interest. Work to date has concentrated on the transuranium isotopes ^{238}Pu, ^{239}Pu, ^{240}Pu and ^{241}Am.

Existing procedures were modified to suit different samples, and separation schemes involving co-precipitation, ion-exchange and electrodeposition on to stainless steel discs were tested. The discs are then subjected to alpha-spectrometry. The efficiencies of the separation procedures are monitored by the addition of known amounts of tracer isotopes of the elements of interest which are not present in the samples. ^{236}Pu and ^{243}Am are currently being used for this purpose.

The track counting method for gross alpha-activity was also adapted as a screening technique. CR-39 polycarbonate sheet is exposed to a pressed pellet of the sample for a suitable time. After development of the sheet with sodium hydroxide solution, the etched alpha-tracks are counted using an image analyser.

All the initial development work was carried out using samples of silt and vegetation obtained from a salt marsh in the Ravenglass area of Cumbria. This source of samples ensured that sufficient activity was present for accurate measurements to be made. Investigations as to the suitability of the procedures for samples of very low activity are proceeding.

J. A. Parkinson

Engineering

The work of this section is generally quite diverse and is entirely determined by the requirements of research projects. The variety of jobs dealt with in 1980 has been as great as ever, but, in comparison with preceding years, tasks have been smaller in scale. The only 2 major undertakings are described later in this Subdivision report (see pages 112, and 113–114).

The structure of the engineering section, although not ideal, lends itself to a degree of flexibility which enables the engineers to make the best use of the expertise and facilities available. The Central Unit based at Bangor supports station engineers at times of pressure and is equipped to handle larger and more complex construction jobs, especially in electronic and microprocessor applications. Most of the stations have their own engineer whose expertise matches the main requirements of his particular station. Although most jobs originate on-station, the engineers' skills are sometimes used for work coming from other centres. Only Furzebrook and the Culture Centre of Algae and Protozoa (CCAP) have no station engineer, and, although the size of Furzebrook in particular warrants such support, present staffing constraints have prevented this appointment being made. Under the Work Experience Programme, a number of trainees are being instructed in workshop practices at 3 of our centres. The Institute's workshops, equipped to deal with a variety of work, are well fitted for this task and the trainees themselves make a useful contribution to the service work.

Apart from housing the Central Engineering Unit, the Bangor workshop serves the routine needs of that station. Perhaps the main station job dealt with during the year has been the updating and overhaul of the controlled environment facilities. Other construction tasks included the adaptation of a dental X-ray machine for radiography of small mammal bones, alterations in the water treatment laboratory, and the construction of monolith display boxes for the soil scientists.

The demand for engineering support at Monks Wood continued to be heavy. Some of the requests needed a great deal of development, for example the electronic control systems for recording bird activity; this work was done by the Central Unit. The station engineer was mainly occupied by mechanical construction tasks which included the construction of experimental irrigation equipment and neutron probe sampling tubes, as well as maintenance and repair jobs.

Much of the engineer's time at Merlewood was also spent on maintenance work, especially for the analytical chemistry and radionuclide teams. It was, however, possible to design and construct a cotton-strip fraying machine (described later, page 112) and to complete the construction and fitting out of a new growth cabinet room.

Electrical work for the station glasshouse and the environmental chambers occupied the engineer at Bush for most of the time in the early part of the year. Another large task, which was carried out for the Edinburgh aquatic team, was the transfer of the aquarium facilities from the former accommodation in the NCC building at Hope Terrace to Craighall Road.

The main requirement at Brathens was different again. The need here was for an engineer with electronic and particularly radio experience to develop and service the radio-tracking equipment needed for so many of the projects of that station. This work occupied the engineer for at least half of the year, leaving the remainder of the time for minor support tasks.

The Nature Conservancy Council's move to new accommodation at Bangor released a number of rooms in the ITE building. Two of these have been assigned to the Central Engineering Unit and will allow more space for the machinery and also provide better storage, technical drawing and office facilities. At Brathens, also, it has been possible to ease accommodation pressure by housing the electronics laboratory away from the mechanical and woodworking workshops.

G. H. Owen

Plant Culture

1. *Glasshouses*

With the increase in glasshouse capacity at Bush, the total plant population has reached 40000. These plants are being grown to meet the requirements of 14 separate projects. Despite the extra glasshouse space, it was necessary to depend on the East of Scotland College of Agriculture and the Hill Farming Research Organisation, both on the Bush Estate, to provide glasshouse space for overwinter protection.

Following earlier successes in the transfer of young (<1 cm) seedlings and propagules from aseptic culture to the glasshouse environment, a further refinement has been introduced, which has involved the transfer of these very small plants individually to 5 cm pots containing a 1 cm layer of 3 mm grit in the bottom, and a further thin layer of grit on the compost surface. This process helped to inhibit algal growth which normally tends to develop in the necessarily high humidity regime which had earlier restricted plant growth. Reduction of fertilizer levels was also effective in this respect.

During the year, priority has been given to improving electrical safety in the Bush glasshouses by extensive rewiring and the use of 24 volt equipment where possible. Essential equipment (mist benches, water pumps, boiler controls and growth cabinets) has been connected to a service supply with the facility for bringing in stand-by generators when necessary. Environment control in the glasshouses has been improved following a review of the siting and screening of temperature sensors.

The installation of a low pressure hot water heating system to replace the electric fan heaters as an energy conservation measure in selected glasshouses was completed during the year. The system has a slower response to temperature changes, and records are being studied carefully to assess its performance through the year.

The present phase of glasshouse development within the Institute was completed by the construction of a 3-compartment glasshouse at Monks Wood.

2. *Field plots*
The programme of artificial wear on the amenity grass mixture was completed in the spring, and was followed by the normal summer management of the turf. Post-wear and recovery of the turf are now being assessed.

Planting of *Betula* hybrids into the new experimental area at Glencorse Mains was carried out in the spring, along with the first of the 'Seed Orchard' trees: *Metasequoia, Betula, Thuja* and *Nothofagus.* Owing to the stony nature of the soil, this field is being sown down to the 'low maintenance' rye-grass cultivar 'SI' mixture of 40% 'Manhattan', 30% 'Pelo' and 30% 'Sprinter' to avoid the need for frequent cultivation and consequent wear on machinery.

Planting of the national birch collection, as originally conceived, is now complete and contains 10 different species, as well as a wide selection of provenances of *Betula pendula* and *B. pubescens,* with representatives from latitudes 28°N to 69°N and longitudes 158°W to 141°E. Plant spacing is 4 m each way to allow individuals to develop unhindered, thus providing a study area for shape and form for amenity use, as well as a scientific collection. This spacing allows easy maintenance of the grass by tractor machinery.

Landscaping advice was provided in 1980 for a number of the organisations on the Bush Estate. These include the Scottish Institute of Agricultural Engineering, the Animal Breeding Research Organisation and Bush House itself. Staff in the unit have gained considerable experience in landscape gardening over the years. This experience, together with access to the extensive plant culture facilities at Bush, put the unit in a strong position to provide a specialist landscape design service.

There were no changes in the permanent staff of the unit during the year, but assistance was provided by temporary staff under the Manpower Services Commission temporary employment schemes. The unit benefited from this injection of labour at a time of pressure and the people concerned received good basic training in horticultural techniques.

R. F. Ottley

Photography
There was some unavoidable disruption to the services provided by the photographic unit, brought about by the transfer of the unit from Norwich to Monks Wood Experimental Station when Colney Research Station was closed. A new photographic suite had to be prepared by converting part of what had been a small residential dwelling in the station grounds. As a result of some novel adaptations, it was possible to convert the former kitchen-dining area to a darkroom and studio. Storage and office facilities were also provided.

The principal demands upon the photographic service in the past year have been for the provision of colour and monochrome transparencies for use in lectures, and for high quality black and white prints for inclusion in reports and publications. There has been some reduction in the number of requests for colour prints from colour slides which is due, in some part, to the relatively high cost of this process. Another factor has been the reduction in exhibition work.

A series of colour prints was produced to illustrate the work of the Institute on red grouse studies at the Game Fair, and over 700 prints were produced for the Bush open day display.

No new major items of equipment were purchased during the year, but several techniques for producing lecture slides using different film/chemistry combinations were devised to meet particular requirements, and proved to be successful.

P. G. Ainsworth

RESEARCH

Monitoring of aquatic pollutants
For some years, marine bivalves have been used to monitor the levels of heavy metals in the marine environment. Freshwater mussels have received much less attention, although it has been shown that one British species, *Anodonta anatina*, is a potentially useful monitoring organism (Manley & George 1977).

Over the last 2 years, the heavy metal content of bivalves from the River Ouse, Cambridgeshire, has been studied at Monks Wood (ITE 481). Three main species are found in the River Ouse: *Anodonta anatina, Unio pictorum* and *Unio tumidus.* More than 1 500 individual mussels have been collected and are being analysed for mercury, cadmium, copper, zinc and iron. It has been found that metal concentrations in the soft tissue vary considerably within a mussel population. Some of the variation can be related to the size and age of individual animals; it is hoped that a better understanding of these relationships, and how they vary with location, season and exposure, will give us more information on the use of these species for monitoring metal concentrations.

K. R. Bull and D. V. Leach

Reference
Manley, R. & George, W. O. 1977. The occurrence of some heavy metals in populations of the freshwater mussel *Anodonta anatina* (L.) from the River Thames. *Environ. Pollut.*, **14**, 139 – 153.

Anodic stripping voltammeter

The investigations concerned with the River Mersey bird mortality (ITE 181) incident have been described elsewhere in this Report (see page 68). There was reason to believe that di- and tri-alkyl lead compounds were a cause of bird mortality. In order to confirm this was the case, there was a need to analyse avian tissue for this group of compounds. The most suitable method for this purpose proved to be one based on an electro analytical technique: anodic stripping voltammetry (ASV).

The analysis involves an extraction of avian tissues, first with toluene, and a subsequent re-extraction with nitric acid (Hodges & Noden pers. comm.). Analysis is then carried out in a buffered (pH 5) sodium chloride medium which is found to enhance the stability of methyl lead compounds (Hodges & Noden 1979). The method depends on the dissociation of di- and tri-alkyl lead compounds at a mercury-plated glassy-carbon electrode. The resulting lead can then be determined by the standard ASV procedure using the differential pulse mode. Interferences are prevented by using ethylene diamine tetra-acetic acid (EDTA). Inorganic metal ions, including lead, are effectively complexed by this reagent, which permits the selective determination of the alkyl compounds.

A hanging mercury drop electrode and a clean air cabinet have also been obtained for the ASV system which will provide additional trace metal analytical facilities for the studies at Monks Wood. These include examining the ionic state of some of the heavy metal pollutants.

K. R. Bull and P. Freestone

Reference

Hodges, D. J. & Noden, F. G. 1979. The determination of alkyl lead species in natural waters by polarographic techniques. In: *Proc. int. Conf. on Management and control of heavy metals in the environment, London, 1979,* 408–411. Edinburgh: CEP Consultants.

Chemistry of epicuticular wax

This study of the chemistry of epicuticular wax (ITE 710) forms an extension of the work of the ITE sulphur project group, based at Bush and Banchory, on the effects of air pollution on trees. Most plant surfaces are covered by a layer of wax which serves to conserve moisture and also acts as a physical barrier to attack by insects and fungi. Although direct effects of pollutant gases on plants may be caused by the intake of the pollutant through the stomata, there may also be more subtle effects on the relatively inert aerial surfaces of plants. These, in turn, may affect the response of the plant to its environment, whether through increased cuticular transpiration, or by an increased risk of infection.

Differences between Scots pine (provenance Altyre) growing at a polluted site in northern England and an unpolluted site in south-east Scotland have been considered (ITE 583). These studies have shown that transpiration increases with age and with air pollution. These changes are consistent with those in the surface structure of the epicuticular wax, as observed by scanning electron microscopy (Fowler *et al.* 1980). The aim of the present research is to establish whether these physical changes are related to chemical changes in the epicuticular wax.

During 1980, analytical methods have been developed which permit study of the composition of epicuticular wax from Scots pine. After removal into chloroform solution, the wax is separated into different classes of chemical compound by thin-layer chromatography. Long-chain aliphatic alkanes, alcohols, acids and esters with between 21 and 33 carbon atoms are present, together with more complex triterpenoid compounds (Schuck 1972). Individual fractions are then analysed by gas-liquid chromatography with temperature programming.

In addition to analysis of the wax, a small chamber has been constructed to study the reactions between pollutant gases and epicuticular wax in an attempt to identify the types of chemical reaction which may occur on leaf surfaces.

J. N. Cape

References

Fowler, D., Cape, J. N., Nicholson, I. A., Kinnaird, J. W. & Paterson, I. S. 1980. The influence of a polluted atmosphere on cuticle degradation in Scots pine (*Pinus sylvestris*) In: *Ecological impact of acid precipitation,* edited by D. Drablos and A. Tollan, 146. As, Norway: SNSF.

Schuck, H. J. 1972. Die Zusammensetzung der Nadelwachse von *Pinus silvestris. Flora (Jena)*, **161**, 604–622.

Micro-analysis by XRFS

Studies into the reasons for changes in population size of rare and threatened species of butterflies (ITE 393) have shown that there is a need for identification characteristics which can be used to determine the origin and dispersion of the butterflies. Two chemical groups, which have been used for 'finger-printing' some invertebrate populations, include isoenzymes and mineral elements, and work is now under way on the feasibility of using them in this project. As far as the mineral elements are concerned, the use of X-ray fluorescence spectrometry (XRFS) has distinct advantages, not least the possibility of being able to determine a large number of elements without destroying the sample. However, the small weight of individual butterflies creates a problem because of the difficulty of compressing the sample into a thin matrix disc of the diameter accepted by the spectrometer.

A procedure has been devised in which a sample (2–3 mg) is first finely ground using a tungsten-carbide micro ball-mill. The powder is then carefully spread on to a piece of self-adhesive tape covered by a one inch template. Since the cover of the adhesive over the film is so even, it is possible to spread the sample powder by blowing the sample across the film, to give, in effect, an exceedingly thin disc of even thickness.

X-ray fluorescent intensities are proportional to the amount of the mineral element present after correcting for the weight of the sample. The method is calibrated using material of a similar composition to the sample which has been separately analysed using wet chemical techniques.

During the development of the method, difficulties were encountered because the background levels of some of the elements of interest varied between different rolls of tape, even of the same make. Given the consistency of the materials used and of the manufacturing process, it would appear that the contamination is picked up by the adhesive from atmospheric particulates. Removal by prior cleaning and chemical treatment has so far proved ineffective, so rolls have to be tested initially to select those which are suitable.

J. A. Parkinson

Radionuclides in terrestrial ecosystems

Three research topics, funded by the Department of the Environment, are now being examined:

1. Radionuclide behaviour in salt marshes.
2. Temporal and spatial variations of radionuclide concentrations in soil.
3. Transfer of radionuclides from sea to land by birds.

Following a pilot study of the main ungrazed salt marsh site on the north bank of the Esk in Cumbria (ITE Annual Report 1979), a grid of 100 sampling points was established. At each point, the vegetation was described and samples of vegetation and the top 1 cm of sediment were collected (Cover photograph). Indicator species analysis of the vegetation data identified 6 main plant communities, with bare sediment giving a separate category (Table 38). These 7 sampling groups occurred in zones approximately parallel to the estuary. Vegetation which was immersed periodically by the tide was considerably more radioactive than other vegetation, counts varying greatly with plant community. The radioactivity of the underlying silt was less variable and higher. Below high tide level, radioactivity was noticeably higher under the vegetation than in the bare sediment. Concentrations of the main alpha- and gamma-emitting radionuclides in the samples are now being measured and will be assessed in relation to vegetation type, location on marsh, and various environmental variables. A similar study will be carried out on a grazed marsh where the emphasis will be on transfer of radionuclides from vegetation to grazing animals to man. Other transfers, *via* sheep grazing in particular, will also be examined.

Statistical analysis of soil radionuclides and environmental data collected by Dr. P. A. Cawse of the Atomic Energy Research Establishment (AERE) Harwell (ITE Annual Report 1979) has now been completed and is being written up. The gamma spectra of some contrasting Cumbrian soils have been examined prior to further studies of radionuclide behaviour in soils. Of the gamma-emitting pollutant nuclides, only ^{137}Cs has so far been detected in significant amounts in the inland soils. It is well known that radionuclides are transferred from sea to land in west Cumbria. Birds feeding on marine organisms, which are rich in radionuclides relative to concentrations in terrestrial materials, may make some contribution to this transfer. Since little information exists on radionuclides in birds and their eggs, and on transfer of radionuclides by birds, over 400 samples of droppings, regurgitated pellets and carcasses of 14 species have been collected for analysis from the Ravenglass and Morecambe Bay areas. By the end of 1981, well over 1 000 samples will have been collected. Each sample is being screened for alpha- and gamma-radioactivity and then a selection of samples will be examined by spectrometry and the results assessed in relation to possible pathways to man. Droppings examined to date have total gamma-counts ranging from background to about 8 times the background count.

Table 38. Total gamma radioactivity for vegetation and the underlying sediment from a Cumbrian salt marsh.

Vegetation type	Cps ± SE for energies c 90—2 000 KeV g^{-1} oven-dry matter		n
	Vegetation	Sediment	
1. *Agropyron*, above high tide mark	0·09 ± 0·046	3·8 ± 2·09	3
2. *Juncus*, open stand around high tide mark	1·2 ± 0·26	8·4 ± 0·37	3
3. *Juncus* + *Plantago*, around high tide mark	1·4 ± 0·37	7·0 ± 0·90	4
4. *Armeria* + *Plantago* + occasional *Halimione*	4·5 ± 0·53	7·0 ± 0·32	23
5. *Armeria* + *Plantago*	3·6 ± 0·25	7·4 ± 0·32	26
6. *Halimione*	2·3 ± 0·22	7·9 ± 0·22	25
7. Bare sediment	–	3·0 ± 0·32	16

Future investigations to be developed by the radionuclide group include an extension of the grazing studies to look into transfer routes to man via sheep. It is also intended to examine the significance of the soil-plant cycling process and the distribution of radionuclides within the plant.

K. L. Bocock, A. D. Horrill and V. P. W. Lowe

^{129}Iodine in the terrestrial environment

(This study was partly supported by the Commission of the European Communities (CEC) through the National Radiological Protection Board)

^{129}Iodine has a half life of $1{\cdot}6 \times 10^7$ years, and is released in waste material from nuclear fuel processing plants. Little information is available directly relating to this isotope, and therefore all isotopes of iodine were studied in order to predict the fate of ^{129}iodine in the terrestrial environment.

The distribution of this isotope is primarily dependent on the location of the discharge and surrounding environment, the levels, patterns and form of release, and the prevailing climatic conditions. At present, most of the ^{129}iodine originates in effluent which is generally discharged into the sea, and a fraction of this becomes suspended in the atmosphere, most of which then enters the terrestrial environment through precipitation.

Vegetation accumulates a major proportion of its ^{129}iodine intake through foliar absorption. Uptake from the roots accounts for less than 10% of the entry in the short term. Most of this iodine ultimately accumulates in the roots, or is transferred to soil through litter and leaching. Certain species appear to be more efficient accumulators of iodine than others, depending on plant density, foliage form and leaf texture. For example, coniferous species in general contain higher levels of iodine than deciduous species.

The limited date available on ^{129}iodine in soil have shown that it is concentrated mainly in the litter and upper soil layer. This concentration relates to the strong retention by humic fractions, and this, together with the high absorption capacity of clay, influences profile distribution. The chemical form of the solution iodine also has an effect on the degree of soil absorption. In general, it appears that equilibrium of ^{129}iodine in soil is a slow process, with the soil acting as a sink.

Animals readily assimilate iodine, which concentrates in the thyroid. Insufficient data are available to determine the amounts of ^{129}iodine transferred to man through meat products, but it is known that one of the most important pathways to man is through milk.

Aquatic biota act as concentration agents for ^{129}iodine entering the aquatic environment and most of this ultimately accumulates in the organic sediment, although some may find its way to man through edible aquatic fauna.

S. E. Allen and A. P. Rowland

Open-top chambers

To enable long-term controlled experiments to be carried out on the effect of gaseous pollutants on forest trees (ITE 380), the development of suitable exposure chambers was undertaken by the engineering services. These chambers had to be constructed from transparent material which would not deteriorate appreciably in the life time of the experiment, to be easy nd reasonably cheap to produce in quantity, and to have air delivered to the chamber from an external blower which could be fitted with an efficient filtering system to remove gaseous pollutants so that controls could be included in the experiments. To date, cylindrical chambers approximately 0·8 m^3 and approximately 1·7 m^3 have been constructed from heavy-duty 'Novolux' corrugated sheet fitted inside 2 heavy section aluminium rings. The top opening is fitted with a truncated cone of transparent sheet, with an opening approximately equal to half the area of the cylinder section. This design appears to maintain a positive flow of air out of the chamber, and excludes only the lightest rain. The 'open top' chamber is light and strong and can be assembled on site from pre-fabricated components. The fan-filter unit proved to be more of a problem: to achieve the desired rate of air changes in the chamber required the centrifugal fan to draw a large volume of air through a filter-bed of activated or chemically impregnated carbon, whilst maintaining air in contact with the carbon for a sufficient length of time to ensure the removal of the gaseous pollutants (resonance time). Prototype chambers have now been constructed at Bangor and transferred to Edinburgh for site tests.

G. H. Owen, G. Hughes and G. B. Elphinstone

Cotton strip fraying machine

Simple assessment of cellulose decomposition by measuring the loss of tensile strength of standard cotton strips placed in the soil (ITE Annual Report 1979, p 113) requires the strips to be frayed to a standard size prior to exposure. The method previously employed relied on manually clamping a cut piece of cloth between 2 rectangular plates and removing the exposed warp threads either side of the plates by wire-brushing. To enable a large number of strips to be processed semi-automatically and reduce the effort involved, a machine was designed and constructed. It is a simple but novel design consisting of a pair of pneumatic jaws and a number of matching plates which enable several cotton strips to be loaded and clamped at the same time. A motor-driven rotary wire brush combs out the cotton strands to produce standard size strips. The machine is easy to operate and gives reproducible results with the minimum of operator effort.

D. G. Benham

Use of a dye technique to determine pore space in soil thin-sections by image analysis

The percentage area of pore space in soil thin-sections is a useful measure of soil porosity and compaction. It can be measured by point-counting, which is very time-consuming, or by image analysis. Apart from being much simpler in operation, the latter method is more accurate but requires expensive instrumentation. However, a Quantimet 720 Image Analyser was available at Merlewood, having been obtained for recording alpha-tracks in materials collected in connection with the radionuclide programme. This machine allows a test specimen to be scanned, the image displayed on a television screen and measurements of an area made on different levels of greyness set by the operator. The image is divided into 500 000 picture points which are used as a basis for subsequent calculations by the analyser. An editing technique can be used to modify the image if the contrast is unsatisfactory.

The usual method of examining soils with an image analyser uses a photographic technique (Murphy *et al.* 1977). With transmitted light, it is difficult to distinguish the difference in greyness between a colourless crystal, eg quartz, and a pore space. The soil section is therefore under-exposed on to high-contrast paper using a photographic enlarger which makes it possible to achieve tonal differences through dispersion. The disadvantage of this method is that under-exposure can result in the loss of fine pores, and in some soils it is not possible to eliminate all the sand grains by adjusting the exposure; under these conditions, the image requires extensive editing.

As part of a National Coal Board (NCB) contract (ITE 727), in which restored soils on open-cast coal mining sites are compared with similar undisturbed soils, there was need for a method which gave improved particle/pore discrimination. In the method which has been developed, the soil sample is impregnated under vacuum with polyester resin in which a large amount of Sudan Blue dye has been dissolved. This is necessary to leave sufficient colour in the background resin when the soil section has been ground down to 0·03 mm. The section is then directly scanned, adjusting the level of greyness so that pore space and transparent minerals are measured. This image is stored in the editor.

Without disturbing the original, a yellow filter is inserted between the section and the camera lens so that the pore image increases in optical density relative to the transparent minerals. The machine can now distinguish between minerals and pore space, and, by comparing this last image with that in the editor, a direct measurement of pore space is possible. The method has the advantage of being able to use the thin-sections directly without an intermediate photographic stage, and also eliminates errors due to contrast difficulties, and reduces the amount of editing required with some soils.

C. Quarmby and Aldyth A. Hatton

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A portable data logging system

During the year, work has been in progress on the development of a portable data logging system to measure and record temperatures using a simple radio-telemetry technique. The recording of this information is required in research on the foraging habits of grey squirrels (ITE 606). Each squirrel has a collar containing a radio-transmitter that emits a pulsed carrier wave signal, the pulse interval of which is related to temperature.

The logger has been designed and built around an RCA Cosmac micro-processor to ensure low power operation, and is to be used in conjunction with a commercially-built, multi-channel, radio-tracking receiver. Data are recorded magnetically, using phase encoding, on a miniature digital cassette recorder. The functions of the logger are as follows:

1. to provide a real-time clock and insert time as part of the recorded data;
2. to switch the receiver on, and activate the measurement and recording system for a preset time each day;
3. to allow entry, *via* a keyboard, of operating parameters and to display these or to display current time or the pulse interval time of the signal last measured on a liquid crystal display;
4. to monitor each receiver channel in turn for the required time, and check that the correct channel has been selected;
5. to measure the pulse interval of each transmitter to within 0·01 seconds over the range 0·3 to 2·5 seconds and reject any poor measurements caused by noise or weak signals;
6. to store all data in memory until sufficient information is obtained to justify turning the recorder on and outputting the data to it.

A 1K byte software program has been written, using assembly language, for running on the logger to perform these functions. The program is held in ultra violet erasable read-only memory. To allow programming of these memories, a programmer has been built for use with a Motorola micro-processor development system. A cross-assembler has been written for the PDP 11/34 at Bangor, so that assembly language programs can be converted to Cosmac machine code. This cross-assembler is also capable of inserting various 'housekeeping' routines, when required, into the program listing.

The pulse interval measurement is performed in software by the micro-processor. During the time spent monitoring a particular channel, up to 32 pulse intervals are measured and stored. These times are then averaged and a limit of ± 12·5% placed on the mean. As a check against missed pulses caused by a weak signal or spurious pulses caused by noise, the original pulse interval times are compared with the mean and any measurements outside the limits are rejected. Providing there are enough accepted measurements, they can be averaged and the new mean taken as the pulse interval time for that channel.

A translation and interface unit is also being built for reading the recorded tapes into a PDP 11/34 computer (at Monks Wood) for processing. Although the logger is being developed for the squirrel project, there is a possibility of using the design for other projects involving radiotelemetry.

C. R. Rafarel and D. I. Thomas

Culture Centre of Algae and Protozoa

General review

The past year has been one of change for the Centre, with the retirement after many years' service of E. A. George, the virtual founder of the collection in the University of Cambridge Botany School in 1947, based on material gathered by E. G. Pringsheim in Prague since 1928. The collection of algae and protozoa is now probably the largest in the world, comprising some 2 500 strains. As a 'new boy' replacing such a distinguished predecessor as Mr. George (in August 1980), my feelings were divided between pleasure and trepidation. Fortunately, the latter emotion has so far proved unnecessary; thanks to the secure foundation provided by Mr. George, and the loyal and friendly support of all the Centre's staff, CCAP has thus far survived the trauma and continues to fulfil its 3 chief roles: 1. maintenance and supply of strains of taxonomic importance and proven usefulness for research and teaching, 2. dissemination of information about them, and 3. research into taxonomy, structure and function of these always fascinating and often beautiful small creatures.

Much of the current research is described in the following 3 contributions. In addition, a major effort is being made by Dr. J. G. Morris and Mrs. G. Coulson to achieve successful cryopreservation of the more refractory organisms. About 500 strains are now preserved, but many more remain to be frozen with the necessarily high survival rate. Attempts to freeze encysting amoebae are on the brink of success, but the ciliate. *Tetrahymena* is proving more difficult. The mechanisms of freezing damage are also being studied, and Dr. Morris describes elsewhere in this Report (see page 117) a fruitful visit to Michigan State University. Dr. Morris also contributed to a workshop organized by the United Kingdom Federation of Culture Collections and the Systematics Association in London during September, and has written a booklet on cryo-preservation now published by ITE. Drs. J. H. Belcher and E. M. F. Swale are preparing a similar booklet on dinoflagellates, following their 2 earlier publications on river phytoplankton and freshwater algae, and yet another is described by Dr. Page in his contribution below. The electron microscopy unit, run by K. J. Clarke with the part-time assistance of Mrs. S. F. Cann, continues to provide an essential service to the Centre's taxonomic and morphological research, with 10 regular users of the new Jeol JEM 100CX Temscan; this instrument has settled in and the scanning mode should soon be operational. A freeze fracture/freeze etch method for examining cells is being developed by K. J. Clarke and Dr. Morris, to help in studying cell membrane damage during freezing.

Maintenance and supply of cultures continues unabated; 4 322 cultures were despatched to many countries in the 12 months November 1979 – October 1980. To increase efficiency and flexibility, the protozoa and marine sections have been combined under the joint curatorships of J. P. Cann and N. C. Pennick, assisted by Mrs. S. F. Cann and A. M. Rodel. A Porton EDL safety cabinet is now used for handling potentially pathogenic amoebae, 2 new strains of ciliates have been isolated from a local pond and clones cultured, and parasitic trypanosomes (not infective to man or domestic animals) have been introduced into the repertoire – including some isolated from East Anglian bats. The collection of marine algae donated some 10 years ago by Dr. R. W. Butcher, originally consisting of 717 strains, has finally been integrated into the main stock, after elimination of duplicate and undefined material. Natural seawater, a highly variable product, is no longer used in media, proprietary synthetic sea salts having been substituted. In the freshwater section, Mrs. E. A. Leeson (Curator) and Miss L. C. Ray are systematically screening about 1 100 strains for possible contamination or other irregularities, a daunting but worthwhile task made somewhat easier by the introduction of a laminar air flow sterile cabinet. The computerisation of taxonomic and bibliographic data, mentioned by Mr. George in last year's report, is being expedited by the new library and information officer, Mrs. A. Asher, and D. F. Spalding. Dr. H. Preisig, from Zurich, has been a welcome visitor throughout the year, working with Dr. D. J. Hibberd on structure and taxonomy of Chrysophyceae. The Centre has been pleased to accommodate other distinguished workers for shorter periods, notably Dr. R. A. Lewin of the Scripps Institution of Oceanography in California.

J. R. Baker

Systematics of the Eustigmatophyceae

The Eustigmatophyceae is a very small algal class, now containing only 12 species. All are walled, non-motile unicells. They are distinct from the Xanthophyceae (yellow-green algae), the class from which they were segregated (Hibberd & Leedale 1972), and all the remaining classes of algae, both structurally and in their photosynthetic pigment composition (Whittle & Casselton 1975). The form of their motile reproductive stages (zoospores) when these are produced is particularly unusual, and the vegetative cells of most species also have a number of distinctive characters.

Separation of the Eustigmatophyceae created a variety of taxonomic and often complex nomenclatural problems. These have now been resolved in a recently completed revision of the systematics of the group (Hibberd in press). Revision was needed at every taxonomic level, from division to species. At the higher levels, Eustigmatophyta and Eustigmatophyceae are proposed as typified names for the division and class respectively, both based on the new genus *Eustigmatos*. Such typification of higher taxa is now permissible under the most recent (Leningrad) Code of Botanical Nomenclature. Since the number of known species is so small and all are walled unicells, they are placed in a single new order, Eustigmatales. This order is divided into 4 families, 3 of which are new, differentiated by vegetative cell structure, ability to produce motile cells and motile cell structure. Eustigmataceae have more or less isodiametric free-floating cells and zoospores with a single emergent flagellum; Chlorobotryaceae have spherical cells in pairs, surrounded by lamellate mucilage, but produce no zoospores; Pseudocharaciopsidacea have ovoid/ellipsoidal cells, capable of becoming attached by a stipe, and have zoospores with 2 emergent flagella; and Monodopsidaceae, which produce no zoospores, have no lamellate mucilage and are all less than 10 μm in diameter and mostly less than 5 μm. At the lower levels, 2 new genera and 9 new species are established, 7 of the latter being new combinations.

The ecology of eustigmatophytes roughly follows their classification into families based on structural criteria. Eustigmataceae occur mainly in soils, particularly those in colder regions, though one species has been found to be the most common alga fouling swimming pools in a survey in the area of Phoenix, Arizona (Adamson & Sommerfeld 1978); Pseudocharaciopsidaceae are apparently rare in freshwater, though they have probably been confused with species of similar external form in the chlorophycean genus *Characium* and the xanthophycean genus *Characiopsis*; *Chlorobotrys regularis*, presently the only species in the Chlorobotryaceae, is a characteristic component of the algal flora of *Sphagnum* bogs; and Monodopsidaceae are planktonic in both freshwater and neritic marine habitats, especially those with a high nutrient loading.

It is likely that many more eustigmatophytes remain to be described or recognised as such, and the new classification should serve as a foundation for future studies and help to eliminate confusion over the naming of strains used in biochemical or physiological studies.

Future research on this group at CCAP will be concentrated on very small azoosporic forms of the type placed in the Monodopsidaceae. This is the most artificial of the 4 eustigmatophyceaen families, being defined by exclusion rather than by positive characters. Approximately 30 strains which appear to belong in this family are in cultivation in various laboratories including Woods Hole Oceanographic Institution, the Scottish Marine Biological Association and other culture collections, but they have either not been formally classified, being known only by strain numbers, or are wrongly named. Because of their small size, they cannot be distinguished with certainty from members of the Chlorophyceae—the true green algae—except by pigment analysis or ultrastructural study. All of these strains are now being maintained at CCAP, together with a number of new isolates, both freshwater and marine. These small forms are of particular interest because they can, unlike most other eustigmatophytes, occur in vast numbers, often forming blooms. Actual cell numbers are not often recorded, but in the Great South Bay area of Long Island, New York, counts of over 10 million cells ml^{-1} have often been exceeded (Ryther 1954), and in Chew Valley Lake in the Mendips, a water supply reservoir, a concentration of over 600000 cells ml^{-1} has been measured (Bays 1969). In the former area, the persistent blooms have reduced the recreational value of the affected region and have been implicated in the failure of the oyster industry in Great South Bay, while, in the latter, the very small cells passed into the public water supply at a concentration of ca 100000 cells ml^{-1} causing green coloration and turbidity. The largest concentration recorded in Britain is over 22 million cells ml^{-1} from The Fleet, a brackish lagoon behind Chesil Beach in Dorset. Concentrations such as these and the problems they cause are probably grossly under-recorded owing to the very small size of the organisms and the fact that they cannot be identified. It is hoped that the projected study will eventually form a basis for the classification of these minute green specks, though biochemical methods may be needed if insufficient structural characters are available.

The short history of study of the Eustigmatophyceae provides a good example of an initially purely academic study pointing the way to a potentially 'useful' area of research which could not sensibly have been approached in isolation.

D. J. Hibberd

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Phytoplankton in the tidal Thames

As is well known, the water quality of the lower Thames has improved dramatically over the past 10 years with a resulting increase in the populations of invertebrates, fish and birds. The aim of the present study, undertaken with the help of the Thames Water Authority, is to obtain some idea of the composition and amount of the planktonic algae in the estuary from the upper limit of tidal influence at Teddington Weir (above which the water is completely fresh) down to the sea at Barrow Deep, beyond Foulness, where the salinity is almost that of offshore seawater.

There is little information about the phytoplankton of this stretch of the river, the few earlier observations being unsatisfactory in that nets were used for sampling and these retained only the larger organisms. For the last 3 years, monthly dip samples have been collected by the Authority from 6 stations: Teddington (below the weir), London Bridge, Crossness, Gravesend, Southend and the Barrow Deep. The samples are fixed with iodine and concentrated by sedimentation, a method enabling the smallest forms to be examined.

Preliminary results have shown that, during most of the year, the dominant organisms are small centric diatoms and that these form 3 distinct populations. At Teddington, freshwater species predominate, mainly those belonging to the genera *Stephanodiscus* and *Cyclotella*. From London Bridge to Gravesend, the dominant is *Melosira moniliformis,* which seems to thrive under the conditions of intermediate salinity characterising this stretch of the river. The *Melosira* population is present throughout the year, contrasting with the communities above London Bridge which are at their maximum density in early summer and virtually disappear in the winter. Samples from Southend and the Barrow Deep show an irregularly fluctuating population of salt-water forms, with small species of *Thalassiosira* far outnumbering the larger diatoms usually considered the major constituents of marine phytoplankton. The boundaries of the 3 populations are fairly distinct, and move a little up or down the river apparently in accordance with salinity changes mainly due to the volume and rate of flow of freshwater over Teddington Weir.

The cells of *Thalassiosira* and other centric diatoms which dominate the phytoplankton at the seaward end of the estuary range from 20 μm down to 3 μm in diameter, and belong mainly to a number of recently described species. At least 2 others appear to be undescribed. The estuary seems to be particularly favourable to these forms, probably because of the mingling of seawater with water of the river enriched with plant nutrients from sewage outflows. The comparative scarcity of the above species in more open marine habitats, as inferred from the literature, has been confirmed this summer by the examination of a number of dip samples from various sites around the British coast.

J. Hilary Belcher and Erica M. F. Swale

Free-living protozoa

Smaller naked amoebae, which have been shown to affect levels of bacterial populations in soil, are ubiquitous not only in freshwater and soil but also in coastal and estuarine benthic habitats. However, taxonomic information has been inadequate for studies of trophic relationships or other problems involving marine Gymnamoebia (naked lobose amoebae). As a result of the first survey of British marine Gymnamoebia, workers who are not specialists in the group can now identify the more important genera by surface fine structure, even in pellets of mixed material or, in some cases, by brief light-microscopical observations. More detailed light-microscopical studies are necessary for identification to species. The usefulness of surface fine structure is an especially welcome finding because it is recognised as more objective and less difficult in the hands of a non-specialist than some light-microscopical characters seem to be. Several publications, including a key to marine species of one genus, have appeared, and others are in preparation (see list of references below). A key to marine amoebae, particularly of British waters (though many are cosmopolitan) and based on both light- and electron-microscopy, will be prepared in the near future. Although this key will emphasise bacteria-feeders, some amoebae included, as well as others not yet adequately investigated, feed on algae and small protozoa.

The survey of marine amoebae is part of the broader taxonomic work on free-living Gymnamoebia. Another interesting finding associated with the marine investigation has been the isolation from estuaries of amoebae which thrive on freshwater media but do not grow on the marine media on which the more truly marine organisms from the same collected samples grow. Some experiments have been conducted to determine the degree of euryhalinity of such organisms, similar to previous experiments to determine the dilution tolerated by amoebae which are more at home in salt water.

Larger amoebae from freshwater have also been examined in the continuing studies of Gymnamoebia. One is *Mayorella viridis*, the only naked lobose amoeba known to contain zoochlorellae. Because of the importance of large freshwater amoebae in cell biology and the uncertainty about their taxonomic relationships, slides prepared early in this century by the Swiss worker Eugène Penard and now held in the British Museum (Natural History) have been re-examined. These include some rare multinucleate amoebae, some probably found in soil as well as freshwater. Modern optical equipment and photomicrography made it possible to solve some taxonomic problems and present the evidence from these slides.

A more general problem, related to the role of CCAP as a supplier of cultures for teaching, is that of schools and teacher training colleges which are not able to buy protozoa routinely for teaching, because of economic difficulties, distance from the supplier, or unsatisfactory transportation. Recognition of this problem, particularly in developing countries, has led to the production of an ITE publication, *The Culture and Use of Free-living Protozoa for Teaching*. This booklet is based on CCAP's long experience in cultivating diverse free-living protozoa, on experiments to devise methods suitable to minimal equipment and temperatures higher than those of northern Europe, and on the author's experience in teaching. All the procedures are, of course, applicable in temperate climates. These simple methods will enable teachers to demonstrate fundamental biological processes, conduct experiments, and give students some acquaintance with the organisms. They include some methods never before used for culturing protozoa, such as the highly successful use of dried maize kernels and natural water as a medium for some of the most interesting ciliates.

F. C. Page

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DIRECT OBSERVATIONS OF CELLS DURING FREEZING AND THAWING

Previous ITE Annual Reports (1978, pp 36–37; 1979, pp 127–128) have included accounts of empirical methods of preventing damage to cells during freezing and thawing, and the beginning of a study of the mechanisms of this injury. Knowledge of the process is an essential prerequisite of a more rational approach to the evolution of techniques for successful cryopreservation of algae and protozoa.

Observation of cells during freezing and thawing is a valuable aid in understanding the cellular response to these processes. However, there are many problems associated with microscopy at sub-zero temperatures. I have been fortunate to use a microscope system developed by Dr. J. McGrath in the Department of Mechanical Engineering at Michigan State University. In this system, the temperature of the microscope stage and the rate of change in temperature are very accurately controlled between +50 and −100°C, and rates of cooling and warming are linear. Results are recorded on colour videotape or on 35 mm film for subsequent playback and analysis.

During the freezing of biological systems, only a proportion of water is converted into ice; this removal of liquid water increases the concentration of solutes in the residual aqueous phase. As the temperature is further reduced, more ice forms and the residual aqueous solution becomes increasingly concentrated. One feature which has become apparent during the present study is the effect of freezing on dissolved gases. During cooling, the solubility of gases increases; however, when liquid water is removed in the form of ice, the gases may be supersaturated at that temperature and will come out of solution in the form of bubbles. Therefore, a 3 phase system of ice, residual aqueous solution saturated with gases and containing concentrated solutes and gas bubbles coexists.

What happens to cells in this system? Most cell types can be subcooled without any deleterious effects, injury occurring only with the formation of ice. At high sub-zero temperatures, biological membranes are an efficient barrier to ice crystal growth and extra-cellular ice does not initiate nucleation within the cell. There is no evidence of mechanical injury to cells by extracellular ice. The damaging effects of freezing and thawing are associated with the formation of concentrated solutions. Following extracellular freezing, the interior of the cell is at a much lower ionic concentration than the surrounding solution and, to maintain thermodynamic equilibrium, water must be lost from the cell. There are 2 ways by which this loss is possibe: 1. water can move osmotically from the cell to the hypertonic solution around it; 2. liquid water can be removed by formation of intracellular ice.

The morphological response of cells is largely dependent upon the rate of cooling. At low rates of cooling, there is sufficient time for osmotic equilibrium to be maintained by cellular shrinkage. As the rate of cooling is increased, the cells are exposed to hypertonic solutions for shorter periods and there is less time for osmotic dehydration to occur. Thus, the cell interior becomes increasingly supercooled and the probability of nucleation from extracellular ice increases (Figure 65). At intermediate rates of cooling, cells may either shrink osmotically or intracellular ice formation may occur; these differences are due to heterogeneity in the cell population. For any cell, the actual rate of cooling at which intracellular ice formation occurs is dependent on the permeability of the cell to water and on its surface area to volume ratio.

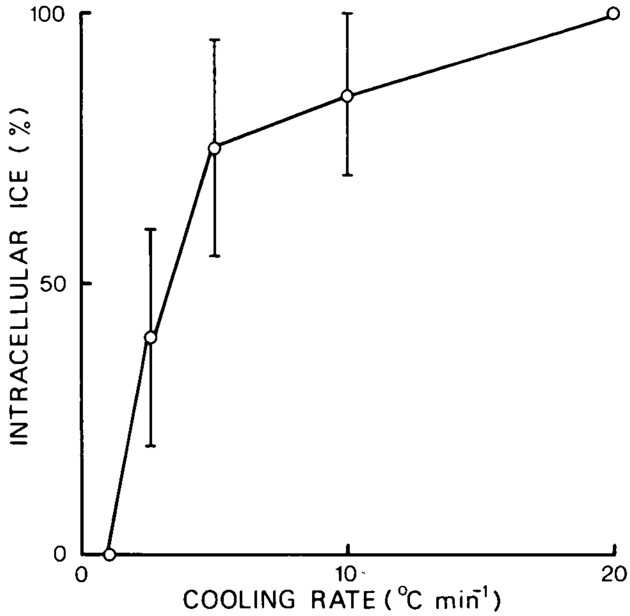

Figure 65 Probability of intracellular ice formation in Spirogyra *at different rates of cooling.*

In Plate 32, the response of 2 filaments of the green alga *Spirogyra* during cooling and warming is illustrated. Nucleation of extracellular ice occurred at −2°C; cells were then surrounded by concentrated growth medium. Gas bubbles were seen to form between crystals of extracellular ice. As the temperature was lowered, one filament lost water osmotically and plasmolysed. During thawing, this protoplast partially rehydrated, but was obviously damaged. In the other filament, only a small amount of shrinkage occurred, and, consequently, the cell became supercooled. At −7·5°C, ice formed within the cells, as visualised by a sudden darkening of the cellular contents. This is due to the presence of many small crystals of ice which interfere with the passage of light through the cell. It was confirmed that nucleation of ice within cells is initiated from the extracellular compartment. When ice forms within one cell of a filament, it is transmitted to adjacent cells *via* cellular connections. During thawing, small bubbles became apparent within the filament at −5°C; these increased in size during further warming and sometimes persisted after thawing. It is assumed that, when intracellular ice forms, many small gas bubbles are entrapped between crystals of intracellular ice. During thawing, these bubbles coalesce and eventually return to solution. In cells which dehydrate during cooling, no gas bubbles appear within the cell upon thawing. The contribution of gas bubbles, both intra- and extracellular, to cellular injury is currently being investigated.

G. J. Morris

Projects

The listing by Subdivisions also shows the number of the Station at which the Project Leader is located:

1 Monks Wood
2 Merlewood
3 C/o University of East Anglia, Norwich
4 Furzebrook
5 Edinburgh, Bush
6 Edinburgh, Craighall Road
7 Banchory, Brathens
8 Banchory, Blackhall
9 Bangor
10 Biometrics, Cambridge
12 CCAP Cambridge

Key for symbols used against project number

@ NCC contract
+ DOE contract
£ Other contract
! PhD or other student project
$ Visiting worker project
* Proposal, not yet approved by Management Group (NB Projects are not assigned to a Subdivision until they have been approved)

listed by Subdivisions as at 31st January 1981

VERTEBRATE ECOLOGY SUBDIVISION

			Code
54	Red deer ecology on Rhum	V. P. W. Lowe	2
59	Taxonomy of the red squirrel	V. P. W. Lowe	2
67	Prey selection in redshank	J. D. Goss-Custard	4
68	Dispersion in waders	J. D. Goss-Custard	4
104	Distribution and segregation of red deer	B. W. Staines	7
106	Red deer food studies	B. W. Staines	7
111	Population dynamics of red deer at Glen Feshie	B. Mitchell	7
116	Freshwater survey of Shetland	P. S. Maitland	6
117@	Freshwater survey of Great Britain	P. S. Maitland	6
123	Zoobenthos at Loch Leven	P. S. Maitland	6
124	Distribution & biology of fish in Great Britain	P. S. Maitland	6
136	Hen harrier study in Orkney	N. Picozzi	8
138	Puffin research	M. P. Harris	7
159	Upland bird project	D. C. Seel	9
209@	Vertebrate recording schemes	H. Arnold	1
291@	Population ecology of bats	R. E. Stebbings	1
292@	Specialist advice on bats	R. E. Stebbings	1
322	Dispersal of otters	D. Jenkins	7
363	Dispersion of field voles in Scotland	W. N. Charles	6
386	Behaviour and dispersion of badgers	H. Kruuk	7
391	British mammals—the red fox	V. P. W. Lowe	2
441	Oystercatcher & shellfish interaction	J. D. Goss-Custard	4
442	Ecology of capercaillie	R. Moss	8
460	Interaction of gulls and puffins	M. P. Harris	7
461@	Puffins and pollutants	M. P. Harris	7
479	Red deer in production forests	B. W. Staines	7
499	Classification of Cervidae	V. P. W. Lowe	2
524	Fluoride in predatory mammals	K. C. Walton	9
525	Fluoride in predatory birds	D. C. Seel	9
528	Red deer populations in woodland habitats	B. Mitchell	7
543!	Population ecology of the red squirrel	V. P. W. Lowe	2
546£	Impact of Craigroyston scheme on Loch Lomond	P. S. Maitland	6
619	Small rodents in a Sitka spruce plantation	A. G. Thomson	9
636	Song bird density & woodland diversity	D. Jenkins	7
638	Monitoring otters at Dinnet	D. Jenkins	7
676	Ecology of lampreys in Loch Lomond	P. S. Maitland	6
687	Radio location & telemetry development	T. Parish	7
705£	Impact of barytes mine project	P. S. Maitland	6
715	Shetland otters	D. Jenkins	7
729	Habitats of coastal otters in E. Scotland	D. Jenkins	7
730	Analysis of coastal otter faeces in Scotland	D. Jenkins	7
733	Plant fragments in diets of upland herbivores	W. N. Charles	6
734	Estimation of seabird numbers by random counts	M. P. Harris	7
735	Oystercatcher population dynamics	M. P. Harris	7

INVERTEBRATE ECOLOGY SUBDIVISION

65	Invertebrate population studies	S. McGrorty	4
185	Effect of urbanisation	B. N. K. Davis	1
188	Woodland invertebrates	R. C. Welch	1
202	The Roman snail	E. Pollard	1
204@	Assessing butterfly abundance	E. Pollard	1
211@	Lepidoptera distribution maps scheme	J. Heath	1
223	European invertebrate survey	J. Heath	1
229	Ecology/taxonomy of Spanish Hemiptera	M. G. Morris	4
230	Cutting experiment (Coleoptera)	M. G. Morris	4

231	Barton Hills grazing experiment (Coleoptera)	M. G. Morris	4
232	Butterfly studies at Porton Range	M. G. Morris	4
233	Cutting experiment (Hemiptera)	M. G. Morris	4
234	Grassland management by fire	M. G. Morris	4
236	Invertebrate populations in grass sward	E. Duffey	1
241	The fauna of box	L. K. Ward	1
243	Scrub succession at Aston Rowant NNR	L. K. Ward	1
255	Ecology of *Myrmica* species	G. W. Elmes	4
256	Protein electrophoresis	B. Pearson	4
262	Digestive enzymes	A. Abbott	4
270	Distributional studies on spiders	P. Merrett	4
273	Productivity of *S. magnus*	N. R. Webb	4
274	Physiology of soil fauna	N. R. Webb	4
295	Survey of juniper in N. England	L. K. Ward	1
296	Scrub management at Castor Hanglands	L. K. Ward	1
309	Phytophagous insect data bank	L. K. Ward	1
345	Spiders in East Anglian fens	E. Duffey	1
400	The large blue butterfly	J. A. Thomas	4
403	The black hairstreak butterfly	J. A. Thomas	4
404	The brown hairstreak butterfly	J. A. Thomas	4
405	Fauna of pasture woodlands	P. T. Harding	1
406	Non-marine Isopoda	P. T. Harding	1
407	British Staphylinidae (Coleoptera)	R. C. Welch	1
414	Hartland Moor spider survey	P. Merrett	4
469	Scottish invertebrate survey	E. Duffey	1
470	Upland invertebrates	A. Buse	9
500	Recolonisation by spiders on Hartland Moor	P. Merrett	4
509!	Wood white butterfly population ecology	M. Warren	1
519	*Myrmica sabuleti* and *M. scabrinodis*	G. W. Elmes	4
527	Long-term changes in zooplankton	D. H. Jones	6
547	Study of the genus *Micropteryx*	J. Heath	1
557@	Terrestrial & freshwater invertebrate surveys	P. T. Harding	1
568	Subcortical fauna in oak	M. G. Yates	4
569	Insect fauna of *Helianthemum* & *Genista*	B. N. K. Davis	1
570	Studies on fritillary butterflies	E. Pollard	1
577	Predation of freshwater zooplankton	D. H. Jones	6
592	Spatial organisation of zooplankton populations	(Suspended)	6
615@	Fragmentation of heaths & invertebrates	N. R. Webb	4
628	Colonisation of limestone quarries	D. Park	1
641	Invertebrate fauna of *Nothofagus* & *Quercus*	R. C. Welch	1
644	Breeding success & survival in the common toad	C. J. Reading	4
656@	Marine invertebrate recording schemes	H. Arnold	1
657	Biological Records Centre — general	J. Heath	1
660	Simultaneous butterfly population studies	J. A. Thomas	4
686	Aerial dispersal in spiders at Minworth	E. Duffey	1
689	Insect fauna of the stinging nettle	B. N. K. Davis	1
690	Plant succession in a limestone quarry	B. N. K. Davis	1
691	Urban climate and invertebrate ecology	B. N. K. Davis	1
694	Zooplankton communities in freshwater lakes	D. H. Jones	6
708!	Structure of spider communities on heathland	P. J. Hopkins	4
709	Techniques for rearing the large blue butterfly	J. C. Wardlaw	4

ANIMAL FUNCTION SUBDIVISION

137	Sparrowhawk ecology	I. Newton	1
181@	Birds of prey and pollution	A. A. Bell	1
193	Stone curlew and lapwing	N. J. Westwood	1
199	Avian reproduction and pollutants	S. Dobson	1
289	Pollutants in freshwater organisms	F. Moriarty	1
413	Breeding biology of the cuckoo	I. Wyllie	1
444	Endocrine lesions in birds	S. Dobson	1

455	Heavy metals in avian species	D. Osborn	1
559	Ecophysiology of the rabbit	D. T. Davies	1
590	Pollutants and the grey heron	J. W. H. Conroy	1
606	Grey squirrel damage & management	R. E. Kenward	1
630	Stress in birds	A. Dawson	1
655 +	Biological health monitoring	F. Moriarty	1
692	Goshawk population dynamics	R. E. Kenward	1
728	Kestrels in farmland	A. Village	6
731$	Farmland habitat & bird species diversity & nos	G. W. Arnold	1

GROUSE AND MOORLAND ECOLOGY

129	Red grouse and ptarmigan populations	A. Watson	8
130	Management of grouse and moorlands	A. Watson	8
131	Golden plover populations	A. Watson	8
132	Monitoring in the Cairngorms	A. Watson	8

HEATHLAND SOCIAL INSECTS

252	Hartland Moor NNR survey	M. V. Brian	4
253	*Tetramorium caespitum* populations	M. V. Brian	4
258	Degree of control by queen ants	M. V. Brian	4
370	Exp. reduction of inter-species competn in ants	M. V. Brian	4
371!	Regulation of sexual production in *Myrmica*	E. J. M. Evesham	4

PLANT BIOLOGY SUBDIVISION

2	Meteorological factors in classification	E. J. White	5
82	Seed produced by montane plants	G. R. Miller	7
102	Mountain vegetation populations	N. G. Bayfield	7
158	Community processes (physiology)	D. F. Perkins	9
160	Fluorine pollution studies	D. F. Perkins	9
208@	Botanical data bank		1
246	Physical environment, forest structure	E. D. Ford	5
247	Physiology of flowering	K. A. Longman	5
249	Morpho-physiological differences	M. G. R. Cannell	5
265	Regeneration on lowland heaths	S. B. Chapman	4
266	Root dynamics of *Calluna vulgaris*	S. B. Chapman	4
269	Autecology of *Gentiana pneumonanthe*	S. B. Chapman	4
346	Genecology of grass species	A. J. Gray	4
359	Fibre yield of poplar coppice	M. G. R. Cannell	5
410	Tundra plants (bryophytes)	T. V. Callaghan	2
411	Taxonomy of bryophytes	S. W. Greene	5
451	Analysis of S. Georgian graminoids	T. V. Callaghan	2
552£	Carbon as a renewable resource	T. V. Callaghan	2
575	Regeneration & growth of bracken rhizomes	R. E. Daniels	4
576	Genecological variation in *Sphagnum*	R. E. Daniels	4
583 +	Scots pine leaves in polluted atmospheres	D. Fowler	5
640£	Field studies on natural vegetation	T. V. Callaghan	2
648	Highcliffe stabilization trials	A. J. Gray	4
649	Demographic genetics of *Agrostis setacea*	A. J. Gray	4
674£	Plant species for energy in Great Britain	T. V. Callaghan	2
702	Selection of frost-hardy trees	M. G. R. Cannell	5
710 +	Airborne pollutants & Scots pine	J. N. Cape	5
720	Fruitbodies of mycorrhizal fungi	J. Wilson	5
721	Dry matter in forests: world review	M. G. R. Cannell	5

PLANT COMMUNITY ECOLOGY SUBDIVISION

1	Semi-natural woodland classification	R. G. H. Bunce	2
9	Monitoring at Stonechest	J. M. Sykes	2

14	Tree girth changes in 5 NNR's	A. D. Horrill	2
55	Establishment of trees at Moor House	A. H. F. Brown	2
75	Control of *Spartina*	D. G. Hewett	9
77	Cliff vegetation methods	D. G. Hewett	9
78	Management of sand dunes in Wales	D. G. Hewett	9
92	Grazing intensities causing change	D. Welch	7
93	Assessing animal usage in N.E. Scotland	D. Welch	7
95	Importance of dung for botany change	D. Welch	7
163	Ordination and classification methods	M. O. Hill	9
165	N. Wales bryophyte recording	M. O. Hill	9
225·	Population studies on orchids	T. C. E. Wells	1
227	Sheep grazing on chalk grass flora	T. C. E. Wells	1
228	Effect of cutting on chalk grassland	T. C. E. Wells	1
242@	Establishment of herb-rich swards	T. C. E. Wells	1
340	Survey of Scottish coasts	D. S. Ranwell	3
360£	Trees on industrial spoil	J. E. Good	9
367	The Gisburn experiment	A. H. F. Brown	2
374	Sand dune ecology in East Anglia	L. A. Boorman	1
377	Environmental perception studies	J. Sheail	1
380+	Monitoring of atmospheric SO_2	I. A. Nicholson	7
381	Plankton populations in Loch Leven	(Suspended)	6
389	Management effect in lowland coppices	A. H. F. Brown	2
417	Silvicultural systems—N. Ireland experiment	A. H. F. Brown	2
424	Ecological survey of Britain	R. G. H. Bunce	2
426	Modelling of sulphur pollution	I. A. Nicholson	7
452+	Foliar leaching and acid rain	J. W. Kinnaird	7
453	SO2 dry deposition in Scots pine forest	I. A. Nicholson	7
454	NCC monitoring of woodlands	J. M. Sykes	2
463	Age class of amenity trees	J. E. Good	9
466@	Ecology of railway land	C. M. Sargent	1
467	Roadside experiments	C. M. Sargent	1
483	Scottish deciduous woodlands	R. G. H. Bunce	2
539	Phragmites "dieback"—Norfolk Broads	L. A. Boorman	1
549@	Monitoring in native pinewoods	J. M. Sykes	2
567+	Coastal dune management guide	D. S. Ranwell	3
573+	Amenity grass—stage 2		1
584	Nutrient loading, phytoplankton & eutrophication	A. E. Bailey-Watts	6
585	Diatom ecology	A. E. Bailey-Watts	6
586	Freshwater phytoplankton periodicity	A. E. Bailey-Watts	6
599@	Bracken & scrub control on lowland heaths	R. H. Marrs	1
602	Modelling sports turf wear	T. W. Parr	1
626	Welsh wetlands survey	D. F. Evans	9
633	Water level & vegetation change—Kirkconnell Flow	J. M. Sykes	2
634	Field plot survey—Monks Wood		1
650	Amenity grass irrigation		1
665	Coastal management	D. S. Ranwell	3
666	Coastal publications	D. S. Ranwell	3
669	Interaction of grazing & air pollution	T. W. Ashenden	9
683	Monks Wood symposia—Area & isolation	M. D. Hooper	1
684£	Mapping Broadland vegetation with aerial photos	R. M. Fuller	1
697	History of pollution & pesticides	J. Sheail	1

SOIL SCIENCE SUBDIVISION

4	Soil classification methods	P. J. A. Howard	2
17	Meathop Wood IBP study	J. E. Satchell	2
39	Phosphorus turnover in soils	A. F. Harrison	2
45	Tundra biome IBP study	O. W. Heal	2
61	Variation in growth of birch and sycamore	A. F. Harrison	2
88	Plant establishment in shrubs	J. Miles	7
89	*Calluna-Molinia-Trichophorum* management	J. Miles	7

90	Birch on moorland soil and vegetation	J. Miles	7
148	Soil erosion on Farne Islands	M. Hornung	9
153	Mineralogical methods	A. Hatton	9
245	Genetics of *Betula* nutrition	J. Pelham	5
358	Earthworm production in organic waste	J. E. Satchell	2
364	Early growth of trees	A. F. Harrison	2
398	Upland land use	O. W. Heal	2
431	Soil change through afforestation	P. J. A. Howard	2
432	Effect of birch litter on earthworms	J. E. Satchell	2
438	Ecology of *Mycena galopus*	J. C. Frankland	2
471	Soils of Upper Teesdale	M. Hornung	9
521	Mathematical modelling in Cumbria	O. W. Heal	2
522 +	Ecology of vegetation change in uplands	D. F. Ball	9
533	Podzolic soils	P. A. Stevens	9
534	National land characterisation	D. F. Ball	9
541	Marginal land in Cumbria	C. B. Benefield	2
551	Overseas liaison activities	J. E. Satchell	2
554	Cumbria land classes and soil types	J. K. Adamson	2
561	Soil fertility	M. Hornung	9
589	Microbial characteristics in soils	P. M. Latter	2
594	Geochemical cycling	M. Hornung	9
654	Status of mycorrhizas in soil	J. Dighton	2
673	Nutrient transfer efficiency of mycorrhizas	J. Dighton	2
714	Role of forest vegetation in pedogenesis	P. J. A. Howard	2

DATA AND INFORMATION SUBDIVISION

216	Register of NNRs	G. L. Radford	9
306	Statistical analysis of spatial patterns	P. Rothery	10
307	Index of eggshell thickness	P. H. Cryer	10
308	Data from multi-compartment systems	P. H. Cryer	10
365	Competition between grass species	H. E. Jones	2
376	Statistical training	C. Milner	9
402	Biometrics advice to NERC	M. D. Mountford	10
434	ITE computing services	C. Milner	9
457	Grazing models	C. Milner	9
496	Data processing services at Monks Wood		1
512	National collection of birch	A. S. Gardiner	2
514	British birch publication	A. S. Gardiner	2
529	Biological data bank		1
530	Laser scan mapping system		1
531	Statistical & computing advice, Furzebrook	R. T. Clarke	4
556	Estimation in acid rain	K. H. Lakhani	1
564	British Hydracarina – mainly of mosses	N. Hamilton	2
565	Bibliography of Shetland	N. Hamilton	2
566	Islands: biogeographic analysis	N. Hamilton	2
574	Potential for fuel cropping in upland Wales	D. I. Thomas	9
579	Woodland research conference	A. S. Gardiner	2
591	Terrestrial Environment Information System	B. Wyatt	9
609£	Biological classification of UK rivers	D. Moss	9
612	Analysis of common birds census	M. D. Mountford	10
613	Computerization of ITE/NERC costing procedure	M. D. Mountford	10
614	Numerical classification	M. D. Mountford	10
621	Models of rabies epidemiology	P. J. Bacon	2
622	Applications of systems analysis	P. J. Bacon	2
623	Entity, attribute, relationship of data bases	P. J. Bacon	2
624	Population genetics	P. J. Bacon	2
642	Physics of freshwater systems	I. R. Smith	6
645	Effects of soil chemistry on decomposition	D. D. French	7
646	Statistical consultancy service at Bangor	D. Moss	9
647	Dipper territory and population models	D. Moss	9

663	Estimation of abundance of populations	M. D. Mountford	10
664	Computing/statistical service at Banchory	D. D. French	7
668	Biometrical consultancy	M. D. Mountford	10
670	Statistical advice & computing at Edinburgh	R. I. Smith	5
671	Analysis of BRC data	G. L. Radford	9
672	Computing facilities at Bangor	G. L. Radford	9
685$	Bracken grassland ecosystems	L-Z Chen	2
688£	Modelling of River Lambourne	P. J. Bacon	2
699	Checklist of computer programs	D. K. Lindley	2

CHEMISTRY AND INSTRUMENTATION SUBDIVISION

52	Biological studies at Glomeris	K. L. Bocock	2
62	National plant nutrient survey	H. M. Grimshaw	2
378	Chemical data bank	S. E. Allen	2
481	Monitoring & chemistry of aquatic pollutants	K. Bull	1
484	Chemical technique development	M. French/D. Roberts	2
485	Chemical support studies	S. E. Allen	2
486	Engineering development	G. H. Owen	9
487	Microprocessor development studies	C. R. Rafarel	9
489	Glasshouse and nursery maintenance	R. F. Ottley	5
490	Photographic development	P. G. Ainsworth	1
491	Radiochemical development	J. A. Parkinson	2
553+	Radionuclide pathways	K. L. Bocock	2

CULTURE CENTRE FOR ALGAE AND PROTOZOA

445	Systematics & distribn of smaller algae & protozoa	J. H. Belcher	12
446	Cytology of protists	D. J. Hibberd	12
447	Freshwater and marine amoebae	F. C. Page	12
449	Preservation of cultures	G. J. Morris	12
610	Computerization of CCAP records		12
723	Characterization of Trypanosomes from bats	J. R. Baker	12
724	Study of Trypanosoma of wild British animals	J. R. Baker	12

DIRECTORATE

203	The Cinnabar moth	J. P. Dempster	1
393	Isolation effects in butterfly populations	J. P. Dempster	1
408+	Arboriculture: selection	F. T. Last	5
503	Development of systems analysis	J. N. R. Jeffers	2
504	Markov models	J. N. R. Jeffers	2
508	Botanical variation in elm	J. N. R. Jeffers	2
511	Landscaping at Swindon	F. T. Last	5
517	Primary productivity in woodlands	J. N. R. Jeffers	2
518£	UNESCO MAB information system	J. N. R. Jeffers	2
526+	Biological monitoring in Forth Valley	F. T. Last	5

LIST OF PROJECTS FOR APPROVAL BY MANAGEMENT GROUP

562*	Data processing services at Merlewood	D. K. Lindley	2
582*	Interaction between tree crops & ground flora	M. O. Hill	9
595*	Competitive ability in grasses	M. D. Hooper	1
596*	Demography of tree species	M. D. Hooper	1
625*	Effects of clear felling in upland forests	M. Hill	9
653+*	Biological surveillance of standing waters	P. S. Maitland	6
658*	Soil maps	P. A. Stevens	9
659*	Grass seedling/soil moisture	T. W. Parr	1
681*	Invertebrate communities & metal pollution	M. D. Hooper	1
682*	Impact of extracting underground water	M. D. Hooper	1
693*	Plant species establishment in grassland	L. A. Boorman	1

695*	Effects of mycorrhiza on tree growth	F. T. Last	5
696*	"Ecology in the 80's" symposia	J. N. R. Jeffers	2
698*	Population studies of zooplankton	L. May	6
700+*	Ecological guidelines for locational strategies	G. L. Radford	9
701£*	Severn barrage study	C. Milner	9
703*	Plant community age development at Orfordness	R. M. Fuller	1
704!*	Atmospheric pollutants and tree growth	P. Freer-Smith	5
706*	Plankton spatial distribution	A. E. Bailey-Watts	6
707+*	Species establishment in new town woodlands	L. A. Boorman	1
711*	Tree growth and climate	A. Millar	2
712$*	Organic matter quality & tree growth	K. Van Cleve	2
713*	Use of vegetation in stabilising earth cliffs	L. A. Boorman	1
716+*	Ecological survey & rural land use planning	O. W. Heal	2
717*	Collection of birch provenances by land classes	A. S. Gardiner	2
718@*	Impact of drainage on wildlife	J. Sheail	1
722*	The ecology of the spider *Eresus niger*	P. Merrett	4
725£*	Conserving lions in Gir Forest, India	B. W. Staines	7
726*	Restoration of heathland vegetation	R. H. Marrs	1
727£*	NCB soils contract	M. Hornung	9
732@*	NCR site information system	G. L. Radford	9
736$*	The development of some ecosystem models	Q. Cui	2
737*	Populn dynamics of *Pardosa monticola* spiders	R. G. Snazell	4
738!*	Soil nutrients & climate at Moor House	J. Hatton	2
739*	Aquatic pollutants	C. P. Cummins	1
740*	Spatial data symposium	R. M. Fuller	1
741!*	Distribn of morphological variatn in birch	S. Stewart	2
742*	Populn fluctuations in annual legumes	C. G. Preston	1

Staff List 1 March 1981

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HEO Mr E. C. J. Clapp
EO Mr A. P. Cooke
EO Mr M. J. Easterbrook
PS Mrs G. M. Waterfall
CO Miss L. M. Barrett
CO Miss K. A. Hale
CO Mrs R. J. Rumbelow
CA Miss S. Jackson
Sp/Typ Mrs E. M. Chambers (PT)

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SSO Mr P. H. Cryer
SSO Mr P. Rothery
SSO Mr D. F. Spalding

Publications and Liaison Officer
PSO Mr M. J. Woodman

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Publications

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listed by customer organisations for 1980

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Customer	*Project No*	*Project Title*
Nature Conservancy Council	719	Event recording scheme
	732	NCR site information system
	549	Pinewood monitoring
	466	British Rail land
	204	Monitoring population changes
	291/2	Population ecology of bats
	615	Fragmentation of heaths and invertebrates
	599	Bracken control on heaths
	138, 181, 461	Toxic chemicals and pollution
	718	Effects of drainage on wildlife
	208/9/11, 557	
	656(pt)	Recording of data on individual species
	117	Synoptic survey of freshwater systems
	242	Herb rich swards
Department of Environment	522	Ecology of vegetation change in uplands
	408	Arboriculture
	573	Amenity grass
	567	Vegetation to combat coastal erosion
	437	Ecological study of Wash borrow pit
	369, 380, 452	
	583	Sulphur pollution
	553	Radionuclides in the terrestrial ecosystem
	609	River communities (joint FBA)
	655	Biological health monitoring
	526	Biological monitoring in the Forth Valley
	161 (pt)	Fluorine pollution (via Welsh Office)
Energy Technology Support Unit	701	Severn Barrage desk study
(Department of Energy)	640	Field studies on natural vegetation
National Coal Board	360	Tree planting study
	—	Soil compaction on open cast sites
Welsh Office	161 (pt)	Fluorine pollution
National Radiological Protection Board	667	Radio-iodine 129 study
W J Cairns & Partners	705	Impact of barytes mine
North Scotland Hydro-Electric Board	546	The ecology of Loch Lomond in relation to the Craigroyston pumped storage scheme
Christchurch Council	648	Highcliffe coastal protection
Anderson Semen & Houston	—	Cairngorms ski lift impact study
Merseyside Council	—	Vegetation survey of reclaimed marshland
Broads Authority	684	Mapping Broadland vegetation using aerial photographs
Shetland Oil Terminal Environment Group	715	Shetland otters
UNESCO	—	Information systems
European Economic Community	380	Sulphur pollution
Overseas Development Administration	248	Tropical hardwoods

Expected level of income from Commissioned work for the financial year 1980/81

	(£1,000)
Nature Conservancy Council	352
Department of Environment	415
Other Government Departments	130
Other UK organisations	70
Overseas customers and contracts	40
	1,007

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