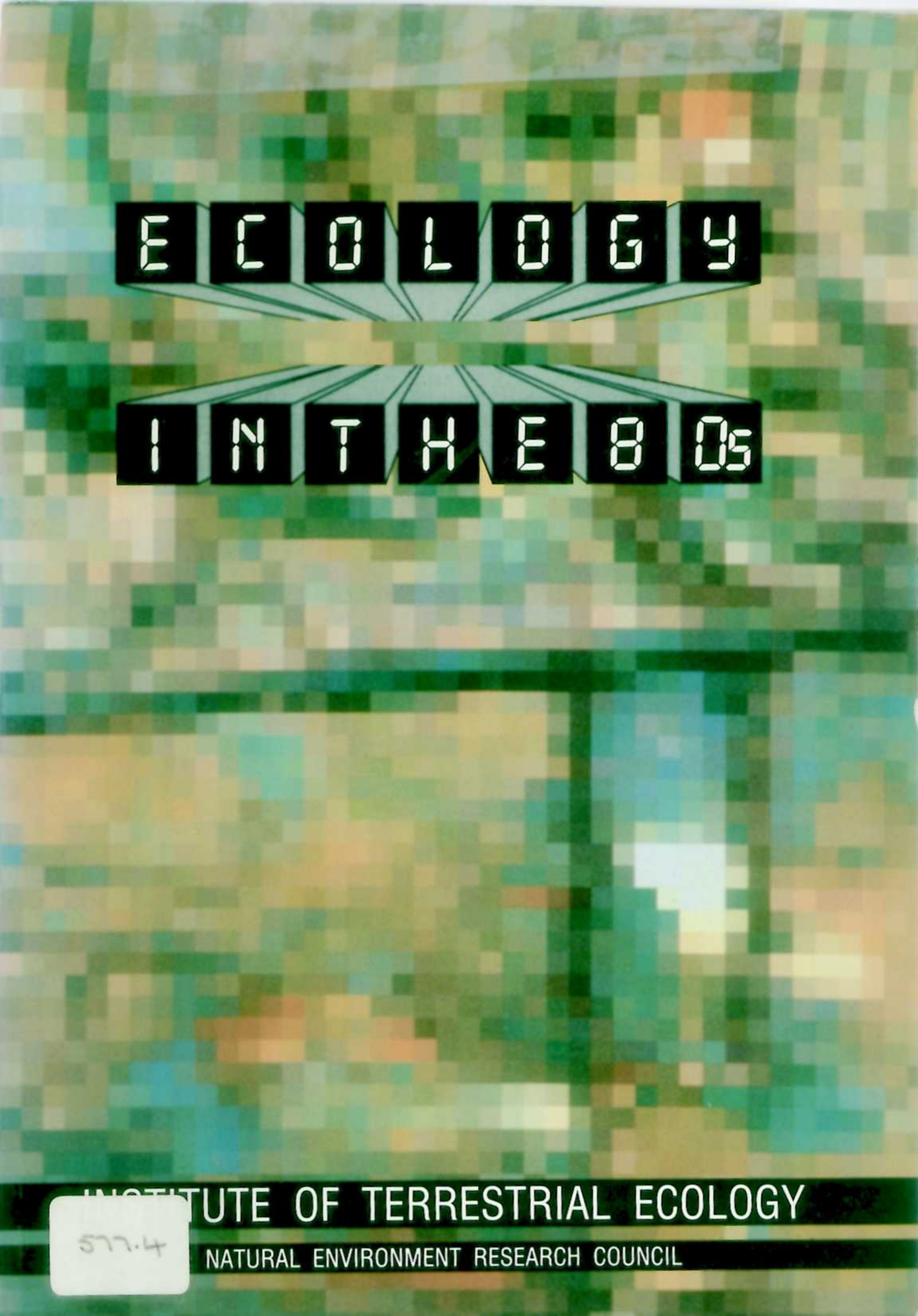

ECOLOGY IN THE 80s

INSTITUTE OF TERRESTRIAL ECOLOGY

NATURAL ENVIRONMENT RESEARCH COUNCIL

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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 14 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.

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INTRODUCTION

J N R Jeffers - Director
Institute of Terrestrial Ecology

Early in 1983, I invited a number of distinguished persons to contribute to a publication to be entitled "Ecology in the 80s". The intention was to capture a wide variety of views on the principal ecological problems of the present decade, together with some indication of the ways in which these problems might be solved. Each of the persons invited to contribute was left completely free to structure his contribution in any way he liked; most asked for guidance about the length of the contribution required, but did not otherwise seek any guidance about the structure of the contribution.

Inevitably, many of the persons invited to contribute were unable to do so because of lack of time, commitment to other tasks, etc. Characteristically, however, some of the busiest people responded enthusiastically, and subsequently found the time to make the contributions which are contained in this short publication. I am extremely grateful to them for the way in which they responded to my invitation, and for the very open way in which they have expressed their views on current ecological and environmental issues.

This short book then contains a number of separate contributions from persons actively involved with environmental concerns. None of them had seen the contributions made by the others, or, indeed, had any idea of the identity of the individuals concerned. Their views, therefore, represent a sample of the views held by an environmentally informed section of the British community.

ECOLOGY OBSERVED

Lord Flowers - Rector
Imperial College of Science and Technology

In common with most people, I first became aware of ecology in the late 1960s. I had come across one or two fellow academics who called themselves ecologists, but assumed that they were simply natural historians by another name. Then came the dramatic public surge of interest in pollution, over-population, conservation and other environmental issues. Ecology, overnight, became a household word, and today is frequently used to embrace a variety of disparate attitudes and beliefs, too often charged with political and emotional overtones. It has also become associated with an ill-defined, and at times rather "folksy", conventional wisdom about man and nature that is sometimes completely at variance with scientific knowledge.

My own professional interest in the subject began with my appointment as Chairman of the Royal Commission on Environmental Pollution. One of the topics we addressed in the Fourth Report of the Commission was the training of environmental scientists. It seemed to us that, while broadly-based training in environmental issues had its place, the need in the coming years was to emphasize the value of first degree education in the relevant basic disciplines. Ideally, this should provide the theoretical background to which further knowledge, acquired from practical experience or post-experience courses, can best be added. Among the important disciplines we had in mind was biology, and in particular ecology as a branch of biology. I am pleased to say that we have been able to go a good way towards that ideal in recent years. Our own Master's programme in Environmental Technology at Imperial College, for example, takes some 30-40 graduates each year with a wide range of first degrees and postgraduate experience. About a third are biologists and they receive further course and thesis work, which emphasizes the application of ecology to practical problems, as well as being exposed to such topics as environmental law and economics. Their subsequent employment record suggests that there is a steady demand for people with this kind of background - in industry, national and local government, and research.

Over the past 10 years, I have also begun to learn more about ecology as a science, as opposed to its more popular manifestations. It has gone through a dramatic transformation in recent times, partly through the expansion of empirical knowledge derived from an increasingly broad range of field research (to a large extent made possible by the greater funding that has followed public appreciation of the value and importance of ecology), and partly through the development of more sophisticated ecological theories. This transformation has been effected by the introduction of mathematical analysis, applied to the study of the dynamics of ecological systems, in much the same fashion as engineers and physicists (such as myself) have tackled inanimate systems. I have noted with considerable interest the growing involvement of people from mathematics and the physical sciences in the development of modern ecology. An example is Robert May from Princeton, a Visiting Professor in Ecology at Imperial College, who only a decade ago was a Professor of Physics at the University of Sydney.

From this kind of analytical approach has come a much more rigorous understanding of how ecological systems behave. In particular, mathematical ecology has exposed many of the critical factors responsible for the patterns of abundance observed in populations of organisms varying from yeasts to whales. It has given to population ecology a firm theoretical framework based on an understanding of how competition, predation, parasitism, and mutualism affect interacting species. This is encouraging, but 2 broad challenges still remain for the coming decade. First, there is the problem of singling out the major factors that shape the structure of natural plant and animal communities. Upon this, hinges the proper management of communities on the scale of tropical rain forests down to the most modest of nature reserves. Second, there is the challenge of applying fundamental ecological principles to problems in pest and disease management. For example, the efficient integration of different methods of pest control (Integrated Pest Management) is still in its infancy and the set of principles for this integration has yet to be properly codified. It requires the development of a theoretical framework incorporating aspects of population dynamics and genetics, in which the interaction of natural enemies, insecticides and other potential control measures can be examined.

However, I am not sure that all that has been done in the name of modern, systems-orientated ecology has been enlightening and productive. The initial recognition of widespread and growing ecological problems led to a belief that the complexity of ecological systems necessitated a matching complexity of response. In particular, the need to predict and assess the environmental impact of development projects resulted, in some quarters, in ambitious schemes for information gathering, and proposals for a corresponding growth of bureaucratic and legal institutions to gather, organize and judge the resulting information. While this activity has generated much that is of use about ecological systems, and has helped to solve a number of important problems, the prevailing impression today, particularly among British scientists, is that this approach tends to be costly and not very efficient. Much time and effort is devoted to pursuing completeness of information rather than a better understanding of the key variables and relationships. Studies have often adequately described the composition and structure of ecological systems, but there has been insufficient accompanying insight into their dynamics. For example, debate continues over whether the complexity of food webs is primarily determined by constraints of energy flow through the system, or by dynamic constraints whereby communities become less and less stable as further trophic levels are added. It must be an embarrassment to ecologists that such a fundamental question remains unresolved. One consequence of this approach is the tendency to elaborate detailed and cumbersome environmental regulation which, by ignoring the key dynamic features, either fails in its objective or is unnecessarily restrictive. Today, in the UK, a leaner approach to applied ecology is required, not only on methodological grounds, but also to cut the costs and help relieve the congestion endemic in our planning and regulatory procedures.

However, I am aware that this is no easy task. It needs to be remembered that ecology is still a comparatively young science. Although its origins are over 100 years old, it is only in the last 30 years that it has achieved academic prominence and begun to receive support comparable with other areas of science. One cannot expect to solve all the problems of the world in such a short time. It is also not surprising that many fundamental aspects of ecology are still in dispute. There is thus considerable disagreement among professional ecologists over the nature of some of the principal objects of their study, such as communities and ecosystems. For instance, there is a rather acrimonious debate now taking place, primarily in America, on whether competition or predation is the major determinant of the composition of animal communities. My ecological colleagues at

Imperial College assure me that such a polarized approach is unhelpful. Sometimes, competition between species dominates the structure of communities, sometimes it is the predation, sometimes both, and sometimes neither. This does not mean that communities are random assemblies of species - just that they are variable and the principles determining their organization are complex.

As a physicist, I am also constantly struck, not only by the complexity of ecological systems and the frequency with which they are characterized by pronounced non-linearities (which is common to physical systems), but also by their high degree of unpredictability. On top of the considerable variability imposed by such physical factors as the climate or the nature of the earth's crust, with which physicists also deal, there is the enormous unpredictability in response to such phenomena shown by individual organisms. Populations thus show both environmental and demographic stochasticity which makes the study of the principles governing populations all the harder. It also poses severe problems for applied ecologists where efficient management depends on reasonably reliable predictions about the impact of different kinds of intervention. Ideally, sound prediction requires a mathematical model of the system sufficiently detailed to mimic the natural populations involved. All manner of management policies can then be tested within this framework. In many situations, however, it may be simply impossible, impractical, or just too costly to acquire a high degree of prediction. The answer then may have to lie in designing management systems that are highly robust, and so relatively impervious to perturbations. Ecologists will need to gain a better understanding of the kinds of ecological process that provide buffers to stress and perturbation, and try to build them or their analogues into management systems. Needless to say, this is a considerable challenge in both intellectual and practical terms.

Thus, while much has been learnt since ecology "came of age" in the 1960s, there is a great deal of knowledge, of quite fundamental importance, that has still to be acquired before many important ecological problems can be solved. This will require adequate resources and funds, and a continuing priority for the subject, even though, in the popular eye, other scientific fashions may predominate.

Most of my understanding (such that it is) of this fascinating subject of ecology I have gained from informal discussions with Gordon Conway and Michael Hassell. I am grateful, too, for their generous help in the construction of this brief article.

ECOLOGICAL CHALLENGES IN THE 1980s

M W Holdgate - Director General of Research
Department of the Environment and Department of Transport

During the 1970s, ecology was in a situation of increasing paradox. One of the most crucial problems confronting the world community was how to give its peoples a higher standard of living without destroying the environmental resources without which that development could not be sustained. The planning of such "development without destruction" demanded new insights into the workings of both social and environmental systems. It required a capacity to evaluate natural resources, to understand the many factors governing their dynamics, to allow for uncertainty, and to prepare strategies that had a sound scientific base and were sufficiently flexible to be adapted in response to changing needs and circumstances. These are skills the ecologist is uniquely able to provide, and, in the late 1970s and early 1980s, ecology had a central part on the world stage - and even grew new political connotations.

Yet, at the same time, there were, in my view, alarming signs that ecology was in danger of becoming a scientific backwater. It shared this fate with whole-organism biology in general. Taxonomy - the foundation of any precise statement about similarities and relationships between animals and plants - had already been for many years the preserve of the dedicated or the eccentric. The intellectual focus of biology which in Darwin's time 125 years ago was concerned with the broad sweep of organic development on the planet, and the behavioural and genetic mechanisms behind it, had switched to the sub-organism and biochemical level. The paradox was thus that the world needed ecology more than ever, but that more and more outstanding scientists were preoccupied elsewhere. There are no Nobel prizes for ecology: only the prize of human survival.

This situation is not, in my view, yet another demonstration of scientific irresponsibility: with our alleged preference for stimulating intellectual gymnastics rather than useful application. There are good reasons for it. First, let us not deny that molecular biology is a subject of great fascination, and that humanity has much to gain from a closer understanding of the workings of genetic machinery and from its cautious manipulation. But, second, we have to recognize that ecology is an inherently difficult pursuit. It has to grapple with vast masses of unruly information. The information content of a square kilometre of tropical forest is immense enough to daunt anyone. Our systems of abstraction remain imperfect. Full species listing - a traditional approach - is beyond any biologist in the field, and due to lack of taxonomists would take decades at home. Those who bemoan the fact that tropical forests are being destroyed before the potentially useful species they contain are even described and catalogued need to reflect that, even if every species present were rescued and taken into cultivation or to a seed bank or zoo, it would take generations to evaluate them all. Quick abstractions - like the system developed in ITE whereby habitats can be grouped through analysis of topographic and geological features and the groups used to stratify vegetation recording - run into trouble when a high proportion of the taxa are unknown. In the International Biological Programme, faced with such dilemmas, we used vegetation structure for comparative purposes, but abstractions based on physiognomy reject much of the most important biological information.

Subjective systems based on dominant species are little better. We are not agreed on the value of indicators like biomass or productivity as field descriptors. The fact is that the ecosystem is a valid concept, but its characterization is so laborious that we have to fall back on highly simplified and selective descriptions of complexes of plants and animals in the field. We move to the mid-1980s with only broad-brush systems for characterizing environmental resources and for relating the findings of different ecologists in different areas.

It is not surprising that some of the keenest biological intellects have responded by withdrawing to the laboratory where the precise tools of the physicist and the chemist have been increasingly able to give new insights into the details of microstructure and process, with the timescale of investigation controlled by the investigator. The results of molecular biology have been of undeniable value and fascination. But where does this leave ecology?

To recite a truism, science advances to a great degree through the development, testing and modification of unifying theories. In cosmology, the recognition of the interrelationship of star types and the summary of their evolution in the Herzsprung-Russell diagram, and Hubble's demonstration of galactic recession brought about the unification of a vast range of observation and deduction. Plate tectonics has given us a unifying theory of crustal history over at least the past 2000 million years. Molecular biology is attractive as a research field because it offers the prospect of a theoretical foundation for relating the structure of molecules to the structure of organisms. A century ago, Darwin provided a unifying theory that made sense of much biological similarity, diversity and biogeography. To move forward, ecology needs its unifying theories.

We have seen some steps in this direction in recent years. MacArthur and Wilson's work on island biogeography was attractive because it related diversity to habitat complexity and to the dynamics of immigration specification and extinction. Work by ecologists like May, Southwood, Conway and many others is attractive because it has allowed the development of mathematical descriptions of population dynamics that have visible resemblances to nature. The formulation of the characteristics of r- and K-strategists, Connell and Slatyer's work on succession, Holling's spruce budworm study, and various theoretical analyses of relationships between stress and resilience were stimulating for the hope they hold out of other areas of unifying theory.

Many of these models are partial and simplified. Those of population interaction work best at the 2-species or 3-species level. They are far removed from models that provide descriptions and predictions of the behaviour of ecosystems. The needs of the world community are for insights into the dynamics of habitats and ecosystems, and for predictions of their response to natural change and the intervention of man - as a guide to development that is ecologically sound.

We also need a sounder basis for predicting the performance of species under changed circumstances, if we are to detect the potential use of newly discovered taxa, or those produced by plant and animal breeders and genetic engineers. (I was recently reminded by a colleague that Pinus radiata, confined in nature to a small area of California, had no obvious reason to be suspected as one of the world's most valuable plantation trees.)

Can someone provide an ecological Herzsprung-Russell diagram, with a means of characterizing ecosystems using descriptions that can be measured quickly, provide a reliable diagnosis of their place in the system, and provide a robust basis for prediction? No doubt, the descriptions will be more complex than those used to characterize a star. Sir Fred Hoyle is quoted as having once commented in a lecture that "a star is a very simple thing", only to be told from the back that he himself would look pretty simple at 50 parsecs. Perhaps we need a system for determining which features of ecosystems should stand out at the intellectual equivalent of 50 parsecs. Certainly, my view is that only through the development of unifying theories of ecosystem and population behaviour will we see ecology draw an increasing share of keen intellects, and contribute as it should to the wise use of the resources of the world.

ECOLOGICAL PROBLEMS IN THE 1980s: A FORESTRY REVIEW

G D Holmes - Director General
Forestry Commission

In responding briefly to a personal invitation to identify what I consider to be the main ecological problems of the decade, I feel the field is so vast that I cannot avoid being arbitrary in the selection of the issues.

Identification of key problems and research needs in ecology in the field of forestry has been the subject of debate at several important discussion meetings recently, and the items I shall discuss have much in common with those set out by others.

It is impossible to ignore the fact that ideas about the subjects that constitute matters of concern vary both with the climate of opinion and the state of our knowledge. Problems associated with the maintenance of particular types of broadleaved woodlands are examples of the former, acid rain is a good example of the latter. One doubts whether there is much that can be done, even with the most intelligent Delphi exercise, to foresee with any reliability changes in taste or the shape of new scientific developments. Were it otherwise, futurologists would be the captains of industry and the performance of government, the economy and much research would be totally different. However, it is desirable that a cool and rational look be taken at old problems to assess their current and likely future importance and that we try to identify future problems from our knowledge of the changes that are occurring in our ecosystems, or that we may expect from the experience of others. Hopes of achieving these aims must be tempered by recognition of the fact that the pace of change is growing and it is increasingly difficult to match research designed to answer today's problems with tommorow's emerging ones. Thus, in forestry, the last 60 years have seen a major extension of exotic trees on to ground which has not been surveyed and studied before. Equally, the growth performance and environmental effects of the tree species concerned are known only in outline. Meanwhile, the methods of establishing and treating these trees are changing as management requirements alter and as operational methods evolve.

Ecology can embrace almost everything connected with living matter, but I shall confine my views to the general need to study the interrelationships between forests and the various physical and biological aspects of the environment. Because forestry in Britain is a dynamic and expanding activity, a better understanding of these relationships is essential in order to guide and help policy-makers and forest managers in their decision-making. This short paper considers those ecological questions regarded as particularly relevant to British forestry at the present time, and these have been divided into 2 categories - first, the interaction of the forest with its immediate environment and, second, the interaction between forests and the interests of neighbours. This categorization of topics is arbitrary to the extent that all of them stem from the influence of the tree.

The effects of the forest on its immediate environment

The interaction between forests and soils

The interaction between forests and the soils on which they are growing is probably the most important area of ignorance. Foresters influence the soil by mechanical disturbance, by their choice of species, and by their silvicultural practices, including fertilizing, thinning, etc, as well as by their systems of harvesting and regeneration. There is much to be learned about the effects of these practices on soil processes. This is important both short term, in determining the production and vigour of the current tree crop, and long term because there is insufficient understanding to enable reliable predictions to be made of effects on the soil of the foresters' interventions over a rotation or more.

Considering the short and medium term aspects first, the topic demanding most urgent attention is that of nutrient cycling and, in particular, the processes of nitrogen mineralization and mobilization. The main need is for information on the effects of both thinning and felling practices on nutrient losses and changes of nutrient form, that is to say humus formation or mineralization. The emphasis given to the need for studies of nitrogen is deliberate since it appears that knowledge of the cycling of this major nutrient is fundamental to understanding the fertility status of many soils. Improved understanding of the role of phosphorus depends in part upon identifying the form in which this element occurs in growing stands. While no particular concern arises over potassium, it is quite possible that copper, manganese and zinc deficiencies may be identified, especially on peaty soils. In the field of nutrition, it is clear that more emphasis on the microbiological aspects of nutrient mobilization and immobilization is highly desirable. The emphasis in all such studies will be on the even-aged plantation, as this form of management will remain the dominant one for many decades. Mixtures of species are known to have interesting effects, and their role in nutrient cycling urgently requires elucidation.

On the side of soil physics, much current research is concentrated on the effect of clear-felling on soil and water changes, and some work is being done on the effects of mixtures of tree species on soil physical characteristics. A great deal more work is clearly required to unravel the effects of soil physical changes on tree root development. The state of knowledge in this field is based heavily on empirical work, with no real understanding of what are the effects on root development of different methods of drainage and drain maintenance. Such work is clearly of the highest relevance to devising methods of treatment that promise greater stability of trees in the wind, as well as conserving and enhancing the productive capability of the soil.

Overall, there remains a need to monitor soil processes in the forest. There are 2 purposes in this work. One is to be able to establish, by measurement, what are the best ways of achieving and maintaining the soil conditions suited to tree growth. The other is to be in a position to predict long-term influences in order to ensure that early warning is given of any processes that might be difficult to reverse.

Impact of forestry on vegetation

While, to a large extent, the vegetation is a manifestation of underlying soil characteristics, there is a particular interest attaching to sub-tree vegetation in forests from the wildlife conservation point of view. In so far as conservation is concerned with favouring a richer flora, more needs to be known about colonization of plantation forests by species which are recalcitrant entrants to the local flora. Equally, it is of concern to know what sort of break in a woodland's history will actually remove those species which are slow to recolonize.

Such studies may indicate the extent to which glades and the increased boundary:area ratio they create are useful in assisting the maintenance and entry of colonizing plants. Edge effect has, of course, important implications for fauna, and thus opens up a large area for ecological survey and analysis.

Interaction between forests and wildlife

It is a moot point whether some plants such as grasses, bracken and bramble do not have as big a direct effect on the forester's ability to regenerate crops as do certain animals. What is clear in any event is that the impact of animals on forests is often far more obvious and troublesome, and that the extension of habitat provided by forests is a major change in the country's wildlife scene. Far more understanding is called for of the biology of deer in the new mixes of habitat provided. This is as essential for management decisions concerning timber production from a wider range of species as for conservation reasons. In this latter connection, the study of the effects of afforestation, thinning practices and felling coupe design must also be extended to birds. This is not necessarily for any overt practical reason of management, but for the reason that the nature conservation and recreational interest that attaches to birds is often so great.

Tree phenology

Surprisingly little is known about the biological success of many introduced trees in the sense of their ability to reproduce and to survive under different competitive conditions. Thus, more information on flower and seed production and factors influencing periodicity would be of value, especially where, for reasons of species (and provenance) preference or cheapness, natural regeneration was favoured.

Tree health

The subject of protection from all non-mammalian organisms is an enormous one, and entomologists and pathologists face the extremely difficult task of explaining the causes of disease and infestation and predicting future outbreaks. The whole subject is notoriously difficult owing to the large number of variable factors at work, including that of genetic variability of the pest or disease organism. Among subjects that require work are variations in pathogen virulence, the possibility of new pathogens and pests on exotic tree species, and appraisal of the implications of clonal forestry. The relationship between plant nutrition and susceptibility to pests also deserves close attention.

Regional ecology

In land management practice, one is frequently faced with subjective value judgements and opinions on what constitutes good nature conservation in a particular region. Many species, both animal and plant, require for their sustention a particular patch size in their habitat, and it is highly desirable to know more of the implications of forest size and forest stand diversity for these plants and animals. Nevertheless, stand size, the length of edge, the virtues of broadleaved species, and the value of retaining old trees suggest themselves as the main topics on which more factual evidence would be valuable.

Broadleaved trees

The subject of broadleaves is an emotionally charged one and this feature provides a useful example of the danger of confusing conservation problems with the need for ecological research aimed at understanding systems. There are, however, many interests in broadleaves apart from those of the conservationists, notably those of the general public concerned with the traditional appearance of the landscape and with the attractiveness of diversity associated with the shape and colour of deciduous trees. Indeed, the special importance attached to broadleaves, and especially native species, raises interesting questions of psychology that constitute a deserving area of study in their own right. The recent increases in concern stem from a number of factors, including the loss of broadleaved trees in hedgerows following Dutch elm disease and the droughts of 1975 and 1976, and the recognition of changes, including those resulting from planting conifers on sites which have long carried broadleaved woodland.

Some of the problems that arise have been identified above, notably the maintenance of particular associations of plants with indigenous broadleaved species. Of course, the issues are wider than that, including the effects of broadleaved species on nutrient cycling, water uptake and their ecological significance for the food chain. The principal concern in all such work, as in the other fields listed, is to build up enough knowledge to be able to create and perpetuate the composition and structure of vegetation that society desires and the forester can provide.

The effects of forests on the interests of neighbours

Water

The effect of forest cover of different kinds and density on water yield and quality continues to pose questions to which land managers require answers. Concerning the effects of forest cover on water quantity, research recently set up in Scotland will provide a valuable addition to the store of information on hydrological effects of tree cover. Progress is needed, and is now being made, in process studies by miniaturizing the work which will permit estimation on small areas of precipitation, interception, re-evaporation and transpiration, and this will help fill gaps in knowledge relating to different combinations of trees and climatic regions.

In relation to water quality, the main concern from the point of view of water for drinking or industrial use concerns algal growth which can result from applications of phosphate to forest areas. The other problem on quality arises from changes in stream chemistry and biology as evidenced by fish populations. The causes of change are not well understood, and further work is needed on the mechanisms of these effects, especially in relation to streams on acid rocks.

Atmospheric pollution

The growth in atmospheric pollutant loads and their wider extension, combined with the awareness of the effectiveness of trees in combing out pollutants whether in gaseous or solid form, have led to a major upsurge of interest in the interactions between forests and air pollution. The subject deserves study in its own right as a factor in tree nutrition and in soil processes within the forest stand, but it is noted here because of the widespread concern that trees may be responsible for concentrating pollutants to the detriment of the quality of the water derived from forests. This topic clearly requires attention from a number of disciplines. The forest scientist's main contribution will probably come from clarifying the processes of concentration of pollution in the crown and the microbiological and chemical processes in forest soils.

Finally, the ecological effects of forestry other than those produced in the form of utilizable biomass are difficult to bring into account along with marketable products such as wood, food and sporting. So far as the outputs of forest ecosystems are concerned, it is clear that a more balanced view of the totality of effects of forestry on any other form of land use will only be taken if attention is paid to economic evaluation of the outputs. Parallel work by economists is therefore desirable alongside that of ecologists.

EXCELLENCE IN BRITAIN'S FORESTRY

J Campbell - Group Chief Executive
Economic Forestry Group

Summary statement

The world, with its increasing population, is placing unprecedented pressures on its natural resources, including its forests. There is a slow awakening of concern for the future of mankind, and a reaction against the pollution of our planet, with an increasing political impact. The developed nations, particularly Britain, have a responsibility to increase their self-sufficiency in timber and wood products to relieve the pressure on forests in developing countries. By a combination of state and private forestry, a degree of rationalism between the two, backed by co-ordinated research, Britain can demonstrate her excellence in forestry for the benefit of generations to come, by maintaining a sustainable ecological balance for the future of mankind. Being a forester, this contribution will be focused mainly on the long-term forestry aspects of ecology in the 1980s.

Introduction

"There is a real danger that in the year 2000 a large part of the world population will still be living in poverty. The world may become over-populated and over-urbanized. Mass starvation and the dangers of destruction may be growing steadily if a near major war has not already shaken the foundations of what we call world civilization" (The Brandt Report 1980).

"Deteriorating economic conditions already threaten the political stability of developing countries, further decline is likely to cause the disintegration of society and create conditions of anarchy in many parts of the world" (Common Crisis, The Brandt Commission 1983).

Whether you are a politician, a business man, a scientist, an economist, a trade unionist, or indeed a forester like myself, we must all share a common apprehension for the times in which we live which have prompted such statements. As consumers of the world's major resources on a massive scale, all of us in the developed world inevitably bear the greater responsibility for the future of mankind.

World issues

It is impossible for anyone to be truly isolated from the effects of the unprecedented change resulting from uncertain oil prices and a world recession. The management of change will therefore remain a major task facing individuals, organizations and governments during the next decade: change in science, technology, and attitudes towards conservation and the environment which will have increasing political impact in the "green vote". In meeting this challenge, we must face the inevitable reality of the growing interdependence of today's world. We expect a great deal from those among the younger generation who will soon carry the major political responsibility. We hope that their insistence in saving this world for people will overcome bureaucratic regulations and constraints. Substantial development in developing countries will be required if we are to make the change to a reasonably stable world sustaining 10-15 billion people by the next century. A fifth of the world's population is unable to obtain the calories it needs, and the World Bank estimates that this figure will continue to increase. Encroaching desert conditions in the Sahel region of Africa, south of the Sahara, threaten another disaster similar to the droughts of 1968-73 which killed one quarter of a million people and 3½ million cattle, and trees are still being cut faster than they can grow and be replaced. The industrialized nations will need to do much more to assist development in the Third World and to ensure in the long run the elimination of famine and under-nourishment.

A massive sustained educational programme to ensure an understanding of world issues becomes an essential element in any strategy to ensure a sensible balance between future development and conservation.

The world conservation strategy, with the aim of maintaining essential ecological processes, preserving genetic diversity and ensuring sustainable utilization of species and ecosystems, has had an accumulative effect on global issues. The incidence of acid rain caused by wind-blown sulphur dioxide damaging forests and eliminating fish life from some lakes and waterways in North America and in Europe has been regarded by many scientists as the world's most serious problem requiring world co-operation and global change in future industrialization. The 1983 Stockholm Conference focused attention on this problem and, more recently, Canada has been pressing hard for the USA to bring in legislation that will reduce acid rain by 50% by 1990. The West German government has recently lowered the amount of sulphur dioxide which may be emitted from power stations and industrial furnaces. The intention is to reduce the actual fall-out of sulphur dioxide in West Germany from the present 3.5 million tonnes to 1 million tonnes per annum. Heavily polluting older power stations, fuelled by hard and brown coal, will have another 10 years of life under the new regulations.

Czechoslovakia and East Germany, both burning local brown coal to make up for reduced oil supplies from the Soviet Union, face the same problems, and have recently signed an agreement to lower levels of sulphur dioxide emissions into the atmosphere.

The use of pesticides, herbicides and fungicides are a further global issue constantly brought home by such historical events as the banning of DDT or, more recently, the campaign against the further use of 247-T as a brushwood killer. Similarly, the concern about toxic waste has been focused on the disposal of radioactive nuclear material. No day passes without some reference in the media to these very issues, and general apprehension across the world is accelerating and reaching all countries, as instanced by the recent visit to Britain by a team of experts from the Beijing (Peking) Municipal Environment Protection Bureau.

In 1982, more than 450 park and protected area specialists from 68 countries called for global action to save the remaining natural areas of the world at the World's National Park Congress in Bali, Indonesia. "The benefits of nature's living resources that will be enjoyed by future generations will be determined by the decisions of today - ours may be the last generation able to choose large natural areas to protect." More recently, UNCTAD has moved to set up an International Tropical Timber Organization aimed at sustained management of the world's tropical rain forests, which are currently being destroyed so fast that each year an area the size of the Netherlands is lost, and only one hectare is being planted for every 10 hectares destroyed annually.

The World Wilderness Conference in Scotland in September 1983 is yet a further example, with a slightly different emphasis. There must be serious doubts as to whether the existing world machinery with deteriorating economic conditions can meet the challenge of the change that will be necessary to solve these problems. There is certainly little doubt that governments around the world will increasingly have to acknowledge the real pressures, particularly among the younger people, to ensure a future for generations to come.

The world's forests

In the form of coal, our first forests fuelled our industrial revolution in the 18th and 19th centuries; the forests of pre-history on which man made little impact covered most of the earth's surface. These forests have now been reduced to 30% of our land area. Of this, 46% is coniferous stretching principally across the northern hemisphere from North America through Europe to Russia; the remaining hardwood forest dominates the other regions, particularly South America, Africa and the Pacific South-West. The western world's dependence on oil is matched only by the dependence of the developing countries on their forests as a source of income, fuel and additional land for food production. The forests are cleared and burned, and the land cultivated until exhausted, the process frequently destroying the soil structure by erosion to the detriment of generations to come. Over 200 million peasants and tribesmen have no alternative but to live by this method of food production. The developed countries have an insatiable appetite for veneers and rare hardwoods for high quality timber products, now valued for export at over $7000M a year. At present, of about 300 potentially commercial tree species, a mere 20 hardwoods account for 80% of this export trade, and in many countries exploitation fellings merely leave the majority of trees behind as waste.

It is estimated that 2000 million people, ie three quarters of the population of the developing countries, depend on fuel wood and other traditional fuels for their daily domestic needs. Of these, 100 million are unable to satisfy their minimum energy requirements. A further 1050 million meet their needs by depleting the existing resources. The establishment of fuel wood plantations is therefore of high priority in many parts of the world, and this fact is slowly becoming recognized as instanced by the allocation of funds through the World Bank. It is estimated that, in addition to significantly improving farm productivity, we shall need to increase the planting of fuel wood plantations through communal and social projects by at least 5 times to over 50 million hectares by the year 2000, at a cost of over $\$2\frac{1}{2}$ billion per annum, if we are to contain the present forest destruction. Interest in wood energy by conversion to either liquid ethanol or wood gas has accelerated as the quest for alternative sources of energy is pursued. The chemical use of wood and biomass technology, reflected in its use in animal foodstuffs, etc, is poised to expand as costs become competitive with traditional sources of supply. Recent forecasts of world forest production demand and supply in 1990-2000 report that, by the year 2000, demand for industrial wood products will put considerable strain on supplies, and suggest that to meet this demand will require planting of between one and 2 million hectares of new softwood plantations every year over the next 20 years. Canada, the world's largest timber export nation, has recently recognized the urgency for more intensive forest management, and is to increase reforestation from 200 000 hectares in 1980 to 700 000 hectares by 1987, and funding from $200 million in 1980 to $600 million in 1987. Kenya, Malawi, Zambia, Chile and Portugal are nations all heading for self-sufficiency by intensive plantation management. Time is not on our side. Forests can no longer be regarded as a source of unlimited wealth to be tapped at will to meet short-term cash needs while taking the ecological benefits for granted.

The forester

Forests contribute to many uses, not only in creating a habitat for wild life, scenic beauty, and protection, but also offer the timber benefits from a whole range of wood products. The forester loves trees, and he realizes that when he plants a tree he becomes a partner with God in creativity, because a tree is not a symbol, it is life itself, and trees are a part of the quality of life. Only relatively recently have we seen man move from the forest environment into the concrete jungle. To a forester, concern for the environment is concern for forests and trees: trees to produce the raw material to sell to industry, hopefully at a profit, for processing into thousands of wood products used in our daily lives; trees to provide jobs in the countryside and to support a wife and family; and trees to provide the social and recreational opportunities for a rapidly expanding urban population.

The position in Britain

We have 1.77 million hectares of productive forest in Britain, with approximately half owned by the state through the Forestry Commission; there is a further 0.28 million hectares unproductive. This is merely 8% of our total land area, less than virtually all other European countries; EEC has 22.3%. Per head of population, we fall to one-tenth of the European average; we have 31 people per hectare, compared with the EEC average of 7.2. We currently import over 90%

of our requirements of timber and wood products at a colossal cost of well over £3,000 million per annum, and we are the second largest importer in the world.

Britain's position is likely to worsen considerably, and there is little doubt that this will seriously affect our balance of payments. Recently, the government has been prepared to recognize the environmental and industrial benefits of forestry for the future of the nation, and the introduction of the new grant scheme in 1981 and stability in the tax treatment of woodlands have now reversed the decline in private planting, with the result that there is a significant increase forecast.

Trends in ownership of forest lands in Britain

The oil price rise at the end of 1973 marked the turning point in the world's distribution of wealth on such a scale as to contribute to world recession and instability of monetary structures. The institutional and financial framework of world trade has been found inadequate to deal with problems on such a huge scale. Developing countries are seeking a new economic order. There has been a major shift in wealth away from industrialized countries in the west towards oil-exporting countries. It was not until 1979, as a result of substantial income from North Sea oil, that government income enabled the UK to achieve an improved balance of payments position. This is now threatened by a lack of competitiveness in our manufacturing industry and in the stagnant world market. The real wealth of the individuals in the private sector has declined, and, in spite of capital protection efforts by these individuals, there has been a considerable transfer of wealth into financial institutions, particularly pension funds, increasing by £6 billion per annum, and now estimated at £80 billion. This trend is likely to continue for the foreseeable future. There has also been a small but significant emergence of Naturalists Trusts in the purchase of small woodlands and, over the last 6 years, the Woodland Trust has raised £1 million for this purpose.

Ownership of Britain's forests is shared equally between the state and private sectors. Productive softwood forests extending to 1.2 million hectares are predominantly spruce and pine located in Scotland, 0.8 million hectares of which (65%) is managed by the Forestry Commission. Over the next 15 years, wood production from new forests is expected to double. The types of ownership within the private sector vary from personal and individual ownerships, and co-ownerships, to institutional ownerships; the latter will continue to dominate the market in established plantations, somewhat less pronounced in lowland broadleaved Britain and concentrated more in the upland areas where the higher financial yields are more likely.

An investment in forestry requires significant initial capital investment on which returns must match those which are available elsewhere, particularly from government gilt-edged index-linked investments. Seldom will institutional investors be interested in planting. Their interest is essentially long term in the larger blocks of good quality coniferous plantations. UK pension funds started investing in forestry in 1975. There are now 25-30 funds directly involved, and each year 2 or 3 new funds make their first investment. The total value of annual investment in forestry by pension funds is approximately £15 million and is increasing steadily. This practice is likely to accelerate with the disposals policy of the Forestry Commission, aimed to secure self-financing by raising £82 million over the next 5 years. Funds now own about 50 000 hectares of commercial plantations, equivalent to approximately 5% of all privately owned woodland. This land has a current value of around £100 million and a potential value at maturity of £250 million. Those funds who have purchased woodland generally seek to invest approximately 10% of their property portfolio, or up to 3% of their total portfolio, in forestry. Only a small number of funds have taken their forestry investment up to 5% of the total fund.

Rationalization of ownership and management to create compact, efficient forests able to support skilled staff will go a long way to encouraging further institutional investment. The ownership of other woodlands will remain with individuals, and therefore add to the diversity required for conservation of wildlife and a varied landscape. The institutions, although concerned primarily with yield and efficiency, will not be insensitive to pressures to practise sound long-term silvicultural policies, in order to ensure an ecological balance working with nature rather than against nature.

Some of the ecological problems of the 80s in Britain

What are the beneficial effects of coniferous afforestation in the uplands?

Is the planting of coniferous forests on marginal agricultural land improving soil structure and soil type, or indeed is the reverse true?

What is the long-term effect of heavy extraction on the structure of young forest soils?

How do we ensure that our forests will withstand windblow to reach the financially rewarding sawlog stage?

How can we maximize the use of natural nitrogen-fixing species such as alder, and what will be the most efficient ways of applying P and K?

How can we introduce mixtures into our pure plantations of spruce to avoid some of the disease hazards of the future?

What is the long-term effect of extensive new forestry plantings on water catchment areas in various parts of the country?

How do we manage our massive deer population in Scotland to protect the huge investment in both the state and private forests over the last 50 years? Lines of investigation might include:

> Why do some populations of deer not strip bark when others do?
>
> What triggers the deer to start bark-stripping?
>
> Is there a pattern of mixtures which might include sacrificial stripping of trees to take the pressure off the valuable spruce main crop?

How do we ensure that we perpetuate the broadleaved woodlands of lowland Britain with their ecological diversity?

How do we manage the grey squirrel to enable us to re-establish such species as beech and sycamore?

The Chilterns Plan which was established 10 years ago with its constraints has contributed to reducing the activity in the Chiltern beechwoods to such an extent that the replanting levels fall short of those necessary to maintain the valued beech landscape. Should it be re-examined?

How far can we expand the successful genetic engineering techniques from animals and plants to trees?

The questions one can pose are unending. What is certain is that they must be directed to ensuring not only efficiency in our forests, but also excellence in terms of their long-term value to people.

Excellence in Britain's forestry needs a package policy which might include the following:

1. A realistic environmental and conservation policy at international, national and regional levels incorporated in strategic plans, and backed by direct grants and appropriate tax relief to bridge the short-term economic gap.

2. The availability of a comprehensive multi-land use service covering conservation, forestry, agriculture, recreation and wildlife management in an attempt to establish sound multi-land use policies, where necessary within management agreements with the Nature Conservancy Council and local Naturalists Trusts.

3. An annual planting programme of 30 000 hectares of new forest each year in upland Britain, to increase national self-sufficiency and relieve the pressures on world forests, designed to increase ecological diversity, and to conserve amenity values.

4. Continued research to ensure sustaining ecological systems within the forest, built on the relationship between foresters as well as researchers: foresters able to observe and quantify the reaction of nature to our interventions; research directed not only towards

Britain's forests, but extended willingly to those developing countries on whose forests we depend for our imports.

5. A united and positive approach to communications, education and public relations by those involved in the future of the countryside and in the interests of the people.

6. A degree of rationalization of ownership and forest management at field level in Britain's forests to provide, under single management, forest areas large enough to support skilled wildlife and conservation teams working in harmony with foresters.

7. A willingness to help by aid, technical skills and research those developing countries able to respond with self help to practical encouragement.

Conclusion

Collectively, we are responsible for the development of the nation's natural resources to the maximum benefit of the majority of the population, not only the present, but the future. Only by a united, co-ordinated, and determined effort, can we hope to achieve excellence in Britain's forestry, to ensure the environmental and ecological benefits for our children, and the supplies of wood products which we all need in our daily lives.

CLIMATOLOGICAL ECOLOGY: PROGRESS AND PROSPECTS

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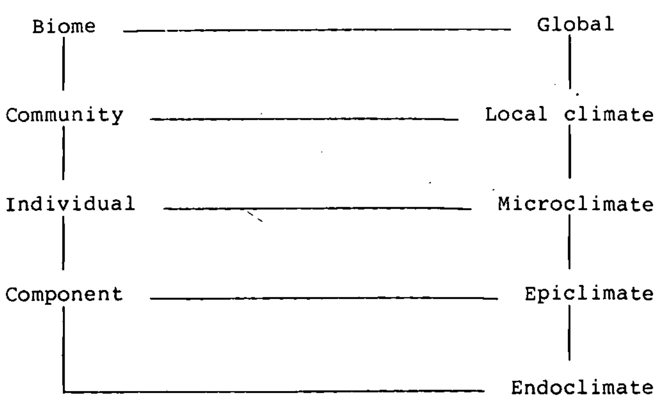
A scheme

Some years ago when I spoke at a BES Symposium on "Plants and their atmospheric environment", I produced a simple scheme to show how vegetation interacts with the atmosphere over a very wide range of scales (Figure 1). This scheme now provides a convenient starting point for a wider discussion of climate in relation to ecological systems and processes than I could include in the original paper. In trying to identify gaps in ecological research, I shall draw attention to ways in which ecologists might benefit from techniques and principles already developed in agricultural science.

Figure 1.



On a scale of hundreds of kilometres, the climate of a region is the main environmental factor determining what types of vegetation it can support and which species will be dominant. The distribution of biomass in relation to global climate is one of the major themes of ecology, but it is this theme which textbooks tend to treat descriptively and there is a need for a more quantitative account of how cycles of carbon, nitrogen and sulphur are related to physical constraints imposed by light, temperature and rainfall. We need better insights into converse processes, too - the impact of vegetation on the atmosphere. Until recently, meteorologists showed little interest in the physical state of the interface between land surfaces and the atmosphere, but models of the general circulation now under development suggest that vegetation and climate may be much more tightly coupled than was formerly supposed. The measurement and specification of surface wetness, roughness and reflectivity of extensive areas of vegetation have therefore assumed new significance.

Climatologists have also begun to ask questions about carbon dioxide exchange which ecologists have difficulty in answering. In particular, to forecast the rate at which the CO_2 content of the atmosphere is likely to increase over the next century, they need to know how much the uptake of carbon by photosynthesis will increase in response to a specified increase of carbon dioxide concentration - the β factor which at present has to be guessed from a few laboratory experiments in somewhat artificial conditions.

Local climate

Local climates are sometimes referred to as microclimates or as topoclimates when a specific feature of the landscape is implicated. Plant communities are often adapted to specific features of a local climate prevailing over distances in the order of 1-10 km. Relating community structure to local climate is often an empirical exercise because the right combination of physical and physiological records is not available. Parallel work in controlled environments is usually needed to disentangle the interaction of climatic elements, as in the study of vegetation on the north- and south-facing slopes of Lathkilldale by the UCPE, a rare experimental synthesis of climatology, soil science and plant ecology.

Microclimate

Contracting to the scale of metres, microclimatology has made major advance over the last 3 decades through studies on agricultural crops. Initially, microclimatologists were concerned to describe how temperature, water vapour, wind, and other elements change in space and time within a uniform stand. By working on stands extending over several hectares of level ground, they were then able to estimate, hour by hour, the rate at which water was lost by transpiration and the uptake of CO_2 by photosynthesis. This technique has been extended to even-aged forest stands, for example Thetford (Scots and Corsican pine) and Feteresso (Norway spruce). A few workers have measured fluxes of sulphur dioxide in the same way, for example over Scots pine at Devilla. Ammonia fluxes have been measured over agricultural crops.

Attempts to distinguish the contribution of individual layers of vegetation to gaseous exchange were less successful because the complex nature of turbulence in canopies was not properly understood. Progress is now being made with Markov chain models of diffusion which can be applied to the dispersion of pollen and fungal spores as well as to water vapour and carbon dioxide. Fortunately, for the purposes of modelling the behaviour of a uniform canopy, it is often possible to ignore the existence of separate layers and to treat foliage, at least in a monoculture, as if all processes of exchange were operating at a simple extensive surface - the 'so-called' big-leaf model.

Heterogeneous vegetation cannot be treated in the same way, either experimentally or theoretically. However, there are several ways in which current ideas about the response of crops to climate and microclimate could be applied to mixed stands with foliage in distinct layers. In the first phase, there is now substantial evidence that the rate of growth of annual crops growing in uniform stands is closely related to the capture of radiation. At least during vegetative growth, dry matter is accumulated at a rate which is nearly proportional to the rate at which radiant energy is stored by foliage.

The efficiency with which radiant energy is stored chemically appears to be conservative so that differences in maximum stand weight from season to season are mainly a consequence of differences in the fraction of available energy intercepted. This fraction depends on the development, maintenance and eventual senescence of the foliage.

Can the same type of analysis be applied to managed forests, to natural communities, to isolated plants? Methods have been proposed for measuring the interception of radiation by individuals, but such measures have rarely been related to growth. We do not know whether the efficiency of conversion for intercepted radiation is conservative for perennial species as it is for annuals. The whole subject is wide open for investigation by ecologists.

Epiclimate

Moving down to the scale of millimetres, I suggested the term epiclimate (surface climate) to describe conditions in the skin of air which surrounds leaves and other plant organs. One group of epiclimatologists in the UK has specialized on the primary effects of wind damage to vegetation. Distortion of epicuticular wax caused by leaf flexing was shown to decrease growth rate by increasing the rate of transpiration and the degree of water stress. The same group has shown how turbulence in the boundary layer of a leaf affects the release of spores. In terms of physical principles, much is known about the parameters which govern the capture of spores, pollen and other particles by elements of foliage. This knowledge has been used in models of epiclimatology for field crops, but seems to have made little impact on plant ecology.

The spectral quality of light is an aspect of epiclimate which has developed rapidly in the last decade. Because light which is scattered by leaves has a much larger far-red/red ratio than sunlight, it provides a signal detectable by the pigment phytochrome. Responses such as the inhibition of germination or the stimulation of hypoctyl elongation have been demonstrated in growth rooms but are much more difficult to monitor or to predict in the field because of the great variability of light quantity and quality in the epiclimate of leaves exposed to sunflecks.

Light quality has even been shown to affect the maturation of seeds on the mother plant, a good example of the type of study which is needed to extend our understanding of how plants in their natural environment respond to a very complex light regime.

Epiclimatology includes the study of stomatal responses to weather. This has become a major aspect of crop physiology, following the development of portable porometers for measuring stomatal conductance in the field. Much is already known about the complex ways in which stomata respond to changes in light and temperature, but attention has recently been focused on the significance of changes in the dryness of air as specified by the saturation vapour pressure deficit. Unlike light and temperature, this quantity cannot influence metabolism directly, but can operate by changing the water regime of plants and of individual groups of cells. In some species, stomata close as saturation deficit is increased because of a loss of water from peristomatal cells. This type of behaviour has obvious advantages for desert plants, but little is known about its general ecological significance.

Some stomata provide the main route by which plants absorb gases such as sulphur dioxide and ozone, and measurements of stomatal behaviour in the field are an essential component of programmes concerned with the ecological or agricultural effects of atmospheric pollution.

Endoclimate

Processes in the mesophyll are governed by climate on the smallest scale in Figure 1 - the endoclimate (interior climate) of cells and of intercellular spaces. It is probably impossible to measure any aspect of endoclimate directly, but several indirect methods are available. For example, no detector is small enough to measure the temperature of individual layers of cells within a leaf, but it can be shown theoretically that, when a lamina less than a millimetre thick is exposed to bright sunshine, the difference of temperature across the mesophyll is unlikely to exceed a few tenths of a degree Celsius.

In contrast, theory predicts that there must be large differences in the spectral quality of light across the mesophyll as a result of scattering and absorption by pigments, but the physiological significance of these gradients is unknown.

Mesophyll temperature governs the rates of metabolic processes in leaves, and physiologists have paid particular attention to the temperature dependence of photosynthesis and respiration. Much less is known about how the endoclimate of leaves and other organs determines rates of development as a consequence of differentiation at cellular level, and rates of extension as a consequence of cellular division and expansion. From recent work with agricultural species, both temperature and tropical, there is evidence that rates of development and of extension are usually much simpler functions of temperature than might be expected from text-book treatments in terms of molecular energy. Rates of germination, for example, increase linearly with (constant) temperature from a base at which there is no germination to an optimum at which the rate is maximal and beyond which the rate decreases. These observations have revived old ideas about 'cardinal' temperatures, and particularly about the existence of a base temperature below which development stops. When the development rate is proportional to temperature measured above an appropriate base, it is possible to combine time and temperature in a single variable, mathematically an "accumulated temperature" but biologically a measure of time as perceived by a plant. The relation between temperature and germination is much more complex in species which respond to the amplitude of temperature fluctuations as well as to mean temperature. Nevertheless, there must be considerable scope for applying the concept of 'thermal time' to the development of uncultivated plants.

Another aspect of endoclimate, explored by analysis rather than by direct measurement, is the intercellular CO_2 concentration of leaf tissue. Recent laboratory work, supported by field studies, suggests that stomatal control of gas exchange in some species may operate to maintain internal CO_2 at a concentration which is conservative if not precisely constant, when there are changes in irradiance and other environmental factors. A primary consequence is that the rate of carbon assimilation is nearly proportional to the transpiration rate and inversely proportional to the saturation deficit of the ambient air. A more complex secondary consequence is that the ratio of dry matter production to water extraction is optimized. Work in this area was formerly confined to the laboratory because of the size and weight of gas analyzers. Portable analyzers are now available for measuring the CO_2 exchange of foliage in the field, opening up many opportunities for work on natural vegetation.

Where now?

This review of the prospects for a wider climatological input to ecology has concentrated exclusively on plants. No-one believes that the animal kingdom is immune from the impact of weather, but few ecologists have begun to explore the complex ways in which climate interacts with food supplies, competition and behaviour to determine the survival and reproductive capacity of vertebrate and invertebrate species. The principles of heat loss in relation to internal and external insulation are well known from work on livestock, and Gates and his colleagues in the USA have shown how they can be applied to determine favourable "climatic niches" for a number of poikilotherms and homeotherms. In Europe, this type of study is rare and there is a large gap in our understanding of how population changes depend on weather anomalies both within and between seasons.

In agricultural science, both plant and animal physiologists have made substantial progress in understanding how growth and reproduction depend on the physical environment. Progress has been most rapid when laboratory and field work has been well integrated and underpinned by formal analysis. Many of the concepts which have emerged from work in growth rooms and in field experiments are ready to be extended to less managed or to unmanaged systems where the environment is more complex and more difficult to monitor. There are at least 3 strong reasons why it is opportune for ecologists to become more concerned with the study of responses to climate on all the scales reviewed here.

First, models of the general circulation of the atmosphere, though still incapable of accurate prediction, provide clear evidence for the likelihood of substantial changes of climate over the 21st century as CO_2 accumulates in the atmosphere. Before these changes begin to affect life in all its forms, ecologists need to know far more about the dependence of ecosystems on the relatively stable climatic regime prevailing now. Indeed, there is little point in refining prediction of future climatic change if the discussion of ecological consequences is confined to sensational articles in popular scientific magazines.

Second, although climate, representing the physical state of the atmosphere, may have been relatively stable over the past century, man has changed the chemistry of the atmosphere with ecological consequences which are not properly understood. It is the job of climatologists to describe the processes by which pollutant gases are distributed in the atmosphere. Ecologists need to work on pathways of deposition as determined by the nature of vegetation and on complex relations between exposure and damage which may depend on other environmental factors such as temperature and water supply.

Third, faced with the challenge of new scientific problems at a time when funds for research are shrinking, ecologists should be thankful that a new generation of field equipment based on microprocessor control is waiting to be developed and exploited. This type of equipment greatly facilitates the collection, reduction and analysis of records both of climatic factors and of the physiological responses which they involve. It is not expensive by the standards of modern laboratory equipment, and in any major field project the saving in labour can be enormous.

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