FORESTS, CLIMATE, AND HYDROLOGY

REGIONAL IMPACTS

Edited by Evan R.C. Reynolds and Frank B. Thompson

Forests, Climate, and Hydrology: Regional Impacts

Edited by Evan R. C. Reynolds and Frank B. Thompson

THE UNITED NATIONS UNIVERSITY

The United Nations University
Toho Seimei Building, 2-15-1 Shibuya, Shibuya-ku, Tokyo 150, Japan
Tel.: (03) 499-2811 Telex: J25442 Cable: UNATUNIV TOKYO

Printed at Kefford Press, Singapore

NRTS-30/UNUP-635
ISBN 92-808-0635-1
United Nations Sales No. E.88.III.A.1
02000 P

Foreword

The workshop Forests, Climate, and Hydrology: Regional Impacts and this book resulting from it are central to the programme area on Resource Policy and Management of the United Nations University. In the first place the subject embraces these vital world resources on which hinges the development of so many nations. Only by understanding the interactions of these resources can they be conserved and used rationally for the good of mankind. Human well being depends on, among other things, adequate supplies of wood and water, but what is the effect of man's husbandry of the earth's surface on these vital resources and even on the climate itself? Even if the answer from this workshop were a qualified "None," then this could be taken into account in the land use policies of developing countries.

UNU involvement is apt in the second place because of the international nature of the subject. Not only did the workshop consist of experts from more than 10 countries but serious consideration was given to the possibility of large-scale vegetation changes induced by man in one country producing some climatic effects in other countries of that region or even on a global scale. Ignorance of such effects, their magnitude and scale, could result in international tensions. International collaboration in these studies is vital both in collecting the relevant data and in carrying out the large-scale computer operations needed to simulate the effects of land use changes on regional and global circulation and climate.

Thirdly the workshop falls squarely within the UNU remit in being interdisciplinary. Experts on vegetation, earth surface hydrology, and microclimate need to be brought together with physicists concerned with large-scale atmosphere dynamics. So complex is the field that no single country has adequate resources to cover it all sufficiently, but the UNU was able to bring together the various specialists from all six continents.

Currently land use changes in developed countries are relatively small-scale from a climatic viewpoint; the greatest changes are occurring in the developing countries, especially those of the tropics and subtropics. Therefore the workshop paid particular attention to the relations between tropical moist forests and atmospheric circulation. These are also regions of greater emphasis in the current UNU programme on Climatic, Biotic, and Human Interactions in the Humid Tropics.

For these reasons I feel sure that this book will promote the objectives of the UNU, not only by informing the scientific community of the synthesis reached by the workshop and by injecting some timely suggestions on the ramifications of land use policies but also by stimulating investigators to bring forward critical projects that will advance our knowledge in the vital area of the effect on the climate of this planet by man's modification of its vegetation.

Soedjatmoko
Rector
United Nations University

Preface

The United Nations University has contributed notably to the subject area of the possible repercussions of land use change on climate in sponsoring the workshop (at St. John's College, Oxford, 25–30 March 1984) that has resulted in this publication. The initiative was largely that of Professor Walther Manshard (Freiburg and United Nations universities). The workshop was part of the Resource Policy and Management Programme of the UNU. It is anticipated that it will catalyse the efforts of the University to establish field research projects under the Programme as well as under the existing series of biennial Global View and other workshops. The Oxford meeting impinges on tasks of the Associated Institutions of the UNU and the Research and Training Institutes that are being initiated. The outcome of the Forests, Climate, and Hydrology Workshop should also promote the Fellowship Programme of the UNU as well as their publications programme.

Through their enthusiastic and critical contributions the participants are largely responsible for the success of the workshop. We wish to acknowledge the assistance of the Meteorological Office (Bracknell, UK) and the Institute of Hydrology (Crowmarsh, UK) in planning the workshop and especially Dr. Howard Oliver (Institute of Hydrology) for his help during the meeting.

The bulk of this book comprises the reviews prepared in advance of the workshop for selected areas of the subject. The reviewers kindly accepted many of our suggestions and the changes necessary to achieve a degree of conformity among the various chapters. The authors brought to the notice of the workshop participants the most recent investigations: the bibliographies following each contribution should prove particularly valuable. Interpretations of data were usually critical and carry suggestions of the physical processes involved. Special mention should be made of Dr. David Mabberley's lecture (chap. 2) presented to the members of the workshop and their guests at a reception given at the Commonwealth Forestry Institute, University of Oxford.

This showed the biological significance, complexity, and dynamism of the tropical rain forest as a background to the deliberations of the workshop on the regional and global climatic impact of its exploitation. Only the scale of the hydrological and climatological phenomena treated is implied by our use of "regional": we do not wish to confine our considerations to named geographical regions. However, among the local case studies that were communicated to the workshop, we have taken the opportunity of publishing that by Dr. Meher-Homji. This respresents perhaps the most refined of the challenging genre of somewhat anecdotal evidence for associating changing forest extent with changing rain climate. As with the Russian research (chap. 5), intriguing correlations in hydrology ought to generate quantitative hypotheses as to the underlying physical mechanisms, and these should be critically tested.

A number of experts from various disciplines were invited to the workshop with the reviewers to comment on the evidence and to suggest an appropriate course for future investigations. These assessments, much abbreviated and more the consensus of the workshop rather than merely the contributions of individual participants, are appended to each paper. At two points during the workshop, a résumé of the preceding papers was presented. These and the resulting discussions are reported in the first part of chapter 10. Since a major objective of the workshop was to produce from the reviews and subsequent discussions conclusions as far as agreement by the participants could be achieved, the last day of the workshop was devoted to this end. The second part of chapter 10 sets out these conclusions. It was not appropriate to direct these at specific agencies, so they can hardly be termed recommendations or guidelines. However, it is to be hoped that scientists involved in the climatic and hydrologic effects of land use changes will be stimulated by the conclusions of the workshop, that agencies supporting research will refer to this consensus, and that those who determine policies of land use will find them informative.

Oxford University
August 1984

Evan R. C. Reynolds
Frank B. Thompson

Contents

1

Introduction

E. R. C. Reynolds and F. B. Thompson

ABSTRACT

The case is made for an objective and quantitative assessment of the effects of vegetation on climate and its spatial extent. Reasons are given for focusing attention on changes in tropical vegetation. Previous studies have tended to be too restrictive in scale and sometimes unavoidably subjective. Improvements in experimental method and the collection of necessary data are discussed. In particular, computer models of atmospheric circulation appear to be the most feasible way of using the available data to simulate the climatic effects of vegetation change.

SENSATIONALISM

It is evident that there is a tendency to resort to overstatement and unbalanced reporting when presenting scientific theories and findings to the public through the media. The same can be true even of the scientist eager to impress the holders of the purse strings of research funds. The objective is to grasp the attention of the audience and make it so concerned about the matter that action is taken. Sooner or later the balance has to be restored by painstaking research and dissemination of the facts. Unfortunately, the earlier misinformation is often very difficult to dislodge.

This is the case with our subject. The informed public and the influential politician are convinced that felling or planting trees has a significant effect on the climate over a large area, if not globally. Consequently, decisions to increase or decrease forest cover are supposed to implicate continental, or even world-wide, changes of climate. Indeed, it is only a small step to suppose that afforestation can be employed to ameliorate regional climate or that extensive deforestation will reduce rainfall at places far removed from the felling axe.

Claims that the global climate can be protected by a policy of forest conservation have become wedded to legitimate cases for conservation of the forest fauna and flora and the control of erosion and flooding by maintaining forest areas. Proper conservation arguments are pertinent to the world's remaining tropical rain forests and the scene for this is presented in chapter 2. In terms of climatic effects, through evaporation or fixation of atmospheric carbon dioxide, any tall woody vegetation might serve in place of the tropical rain forest. Thus, to distinguish between the effects on climate and other aspects of forest conservation it is important at this stage to establish what constitutes deforestation. An extensive but transient interference with the tree cover can have enormous and permanent effects on such factors as the flora, fauna, and the soil. In contrast, at current rates of forest clearance, unless there is no regrowth of shrubs and trees, the actual area without forest cover at any one time can hardly be expected to cause any climatic change even on a regional scale. The aim of this book is to approach the influence on the regional climate of vegetation change as quantitatively as possible. We hope that it will contribute an awareness of the magnitude of likely regional climatic changes resulting from land use policies.

LOCALIZED AREA OF IMPACT

Not only must we know the increase or decrease of the water balance components due to a change of vegetation, we must also know how extensive these effects may be. If the water balance is only materially altered within the confines of the area of changed vegetation, then the problem is greatly reduced. If, however, there are significant global effects, then the international community needs to be concerned in local land use policies. To underline the significance of the scale of the effects, we speak of "regional impacts" of the hydrological and climatological changes caused by vegetation change. The well-known effects on the microclimate and purely local water balances are adequately treated by others. At the other end of the scale, global climatic effects are unlikely to be significant if we are unable to demonstrate an effect at the regional scale.

It is inevitable that our considerations are concentrated mainly on extensive tropical deforestation and afforestation since there is a concentration of developing countries in these regions and a great potential for land use change. The exploitation of the forests of these regions to finance development and release land for agriculture and plantation crops is an attractive proposition in many ways. The fact that, relative to other regions, larger areas of the land surface may be altered hydrologically focuses attention on the tropics as being currently the most likely area to initiate regional or even global climate changes by land use change. The food demands of the increasing populations in tropical areas result in permanent land use changes following deforestation leading to changes in the radiation balance and evaporation. Additionally, if we wish to test the possibility that land use change affects the climate of distant areas, the nature of the general atmospheric circulation of the earth makes the tropical zone one of the more likely areas for such changes to lead to significant effects elsewhere. A more local effect of land use on climate in need of further study is that due to the internal convective circulation cells of tropical regions producing rainfall only some tens of kilometres from its evaporative source.

METHODOLOGY

The subject has suffered more than most from uncontrolled observations leading to equivocal deductions. One problem is that large natural temporal variations of the rain climate (which have occurred since prehistoric times) are confounded with any climatic effects of land use changes. There is also the problem of land use itself affecting the systematic errors of rain gauges, especially in windy climates, so that corrections applied to the rain gauge catch may have to be changed with land use change (see chap. 5). Correlations of rainfall with the proportion of the area covered by forest are also suspect when there is no quantified value for land use change during the measurements since they may simply reflect the rainfall climates required by different vegetation types or land uses. Studies using critical experimental techniques have invariably been on a small scale due to the cost and the fact that large suitable sites (usually watersheds) that can be afforested or deforested for the experiment are simply not available. As a result, as we shall see (chap. 7), there is still a need for large scale studies using controlled methods to observe the effects of vegetation and land use changes to support other climatic research.

Historically it was probably due in part to the necessarily restricted scale of many hydrological and climatological investigations that two lines of thought evolved. One associated forests causally with greater regional precipitation and water yield, while the other denied this and even proposed a decrease in water yield. Over the last 20 years there has been some convergence of these conflicting points of view. There is now a wide area of agreement, in particular on the effects of forests on soil conservation, water quality, and the hydrograph. Many would agree that there are situations where a local or regional increase of rainfall and evaporation might be expected to follow afforestation. There is, however, still disagreement on both the magnitude and importance of these effects and on their likely locations; whether there would be an increase or decrease in the water yield following afforestation is even more in dispute. When the problem cannot be resolved by experiments, probably the next best approach is by using computer simulation models. These should be based on the physical systems involved, using as much real data as possible, and be tested against real catchment systems. This innovation for assessing the effect of land use change on climate has provided the thrust of this book. It is an objective way of combining our present knowledge to produce the best current predictions. Irrational outputs indicate our limitations in understanding the system and a lack of data. Sensitivity analyses show which parameters of the land surface, the atmosphere, and the radiation and water balances have insufficient precision.

Early general circulation models of the atmosphere lack relevance to our enquiry; they are intra- rather than interdisciplinary and too generalized to take into account the detailed effects brought about by vegetation changes. An interdisciplinary approach involving atmospheric physicists together with plant physiologists, hydrologists, and microclimatologists is needed to achieve the understanding and precision required to detect land use effects on regional climate. Scientists studying exchange processes at the earth's surface and those investigating general atmospheric circulation have been brought together by the workshop.

From the conclusions reached by the workshop (chap. 9), it is evident that the use of models to simulate the effect of vegetation change on regional climate is in its infancy. Very few situations have been simulated and those that have generally represent extreme changes. It is to be hoped that we are poised to assess to realistic degrees the significance to regional and local climate of man's manipulation of the earth's vegetative mantle.

Much depends on the reliability of the models and the constituent sub-models. Perhaps now is the time to test the models critically. This is the basis of the proposals for a mesoscale observatory study as discussed by Professor Dooge (chap. 7) and supported by the workshop (chap. 9).

OBJECTIVES

So far we have considered simply the broad question of whether there is an effect of vegetation change and if so to what degree and to what extent. However, there are several points about the dependence of climate on the management of the surface vegetation that need to be understood to assist in the rational development of both national and international land use policies. This entails examination of two rather distinct phenomena. The first is the direct effect of vegetation change on the evaporation input to the general atmospheric circulation (see chaps. 7 and 8). The second is the less direct effect of deforestation increasing the carbon dioxide concentration of the atmosphere and so changing the radiation balance and, in turn, the air temperature, evaporation, and rainfall.

Although we have previously questioned the objectivity of the observational evidence attempting to relate regional climatic changes with deforestation or reforestation, which has been accumulating for the best part of a century, one of the tasks set for the workshop was to review and assess this evidence. In chapter 3 observations from tropical countries have been reviewed. Specific empirical investigations from India are reported by Meher-Homji in chapter 4, while Shiklomanov and Krestovsky give details of Russian studies in chapter 5. The reviewers were further asked to postulate what mechanisms could account for the observed climatic effects. Without an explanation that includes feasible hypothesized processes, it is difficult to pursue the matter further.

The evidence thus reviewed may not be definitive but is certainly indicative that there could be significant effects of forests on rainfall if not on the volume of runoff.

At the very least it indicates that we are right in looking for a different approach to resolve the arguments.

OUTCOME

It has been possible for the workshop to agree to conclusions (chap. 9). They reflect the discussions of each of the review papers and are by nature compromises of the differing views of the participants (listed on page 212). These points of agreement have been discussed, drafted, discussed again by the workshop, redrafted and circulated to the members for comment and correction. Whilst they represent a consensus, the composition of the workshop will have been bound to produce some subjective bias.

Of the ten workshop conclusions, half related essentially to the investigative procedure. This emphasizes the need to improve our methodology before the precision is adequate to allow us to rely on the findings. The workshop presages a change in data collection away from small-scale observations to extensive methods. The scientific community is clearly on the lookout for new, more reliable tracers to use in large-scale hydrology. Throughout the field more rigorous attention to descriptions and scales is demanded; these need to be more relevant to the physical systems operating and the intended use of the information acquired.

The other conclusions incorporate as far as possible quantitative estimates of effects of changing forest cover. This is where greater precision is needed. On the larger to global scales, the workshop's conclusions are mostly qualitative, often indicating little more than whether changes will be positive or negative. However, there is optimism that improved simulation models will yield acceptable estimates of the magnitude of the effects.

It will be apparent that, although there are numerous uncertainties in the models that relate climate to vegetation via general atmospheric circulation, many of these arise from difficulties of parametrization and the quantitative values of inputs. Careful appraisal of the system and more reliable data should resolve these uncertainties. In one area the problems are rather a lack of proper understanding of the processes. These are the hydrological mechanisms occurring in the biosphere. The reason for our ignorance is the bewildering variety of ecophysiological adaptations directed towards the strategy of maintaining plant tissue moisture potentials to permit cellular metabolism and growth to proceed. The regulation of the distribution of plant roots and the resulting pattern of soil moisture extraction are as yet incompletely understood. The disposition, size, and behaviour of stomata controlling the rate of transpiration need further study. More information on the variations of albedo and the aerodynamic roughness of complete vegetation canopies is also required to provide a proper link with micrometeorology. Unless research into these biological phenomena is pursued, relationships between vegetation and climate will remain matters of empirical observation, and choices of land use to fulfil hydrological if not climatological objectives will be less certain.

2

The Living Past: Time State of the Tropical Rain Forest

D. J. Mabberley

ABSTRACT

Early European ideas on tropical vegetation were based on temperate preconceptions and on initial contact with secondary and pantropical vegetation types. Modern angiosperm forests in the context of fossil tropical forest are a recent phenomenon. They are maintained as a mosaic of regenerating gaps affected by environmental factors but also historical factors such as continental drift, vulcanism, and animal extinction and by slow rates of colonization by trees as well as the long lifespans of the latter, which may thus outlive their ecological associations and exist as "living fossils." Man's early effect was to modify the forest framework in terms of gaps and by consciously and unconsciously selecting certain trees. Modern destruction has increased this modification and also the number of anachronisms. In response, many trees have been found to be far more flexible than was previously supposed and to survive under the new regime, though the "new" forests differ markedly from those less affected by man.

HISTORICAL BACKGROUND

Exploration

The first that the Western world knew of tropical vegetation was when Alexander the Great, having defeated Darius in 331 B.C., pushed on over the Khyber Pass to the Punjab: the Indus became the eastern boundary of his extended Asiatic empire (Stearn 1977). His army saw mangrove swamps (which upset conventional views on trees), jakfruit, mangoes, bananas, cotton, and banyans — which upset everybody's views on what roots are supposed to do. These findings were incorporated in Theophrastus's *Inquiry into Plants,* which was translated into Latin by Pliny at the beginning of the Christian era: through this, it was to become part of the corpus of plant knowledge, to be copied, misconstrued, bowdlerized, and generally misrepresented until the Renaissance. Firsthand knowledge was not available again until the great voyages of the Portuguese and Spanish, the Dutch and, later, the British and French.

At first only the plants and animals of settlements (the plants largely pantropical weeds) and the seashore, a remarkably uniform vegetation throughout the tropics, were collected. Indeed, by the eighteenth century, Linnaeus, that great cataloguer of the living world, felt that the tropics had few new things to add to the 6,000 or so species of plants he had recorded in his *Species Plantarum* of 1753. Writing this great work, a superb synthesis of what came before, led to his having a nervous breakdown. It is difficult to gauge what would have happened had he realized that he had recorded only some 2 or 3 per cent of the species now known.

Of course, the early explorers rarely penetrated the forest and, when they did, they applied their temperate knowledge to what they saw: cauliflory was clearly parasitism to them and is embedded in nomenclature, in that the plant Linnaeus's pupil, Osbeck, called *Melia parastica* is the common cauliflorous *Dysoxylum parasiticum* (Meliaceae) of the Malay Archipelago (Mabberley 1983, 2). Around the settlements were the tangles of secondary forest known in India as *jangal,* to become the *jungle* of the colonists and to give the bad reputation of tropical rain forest to the layman, for whom it will always be jungle. The earliest specimens of tropical plants are preserved in the Sloane herbarium in the Department of Botany, British Museum (Natural History) and in the Sherard herbarium in the Department of Botany in the University of Oxford: the oldest snippets are some 300 years old. It is well to remember that when these scraps were being gathered some of the mature trees now being felled in Borneo and the Malay Peninsula were already well over half-way through their lives, while some living brazil-nut trees are thought to have germinated in South America within a few decades of the death of Pliny or, at least, the abandoning of Britain by the Roman legions.

Geological History

Let us go back further. The first tropical rain forests were dominated by woody ferns and club-mosses: those of the Carboniferous (c. 300 million years ago), growing in the tropical belt, are preserved in the coal measures of England. The plants were of varying constructions, some resembling modern angiosperm trees (Mabberley 1983, 15). Some had holes in their leaves, suggesting attack by herbivorous animals; they were wind dispersed spore-trees and their survivors are the tree-ferns. Such forests were followed by the first seed-forests, various kinds of seed-fern – some of which have led to the angiosperms – and the earliest gymnosperms, of which the tropical survivors include the cycads and the majestic araucarias of the west Pacific: these are still the tallest trees in the Old World tropics. We know rather little about the early seed-forests or how they worked, about the undergrowth or, indeed, the hydrological cycle. However, they were in place for a long time – from the Permian, which extinguished the spore-forests in its desiccation, until the rise of the angiosperms in the Cretaceous about 150 million years ago.

Only in the last 30 to 50 million years, a tiny postscript to geological time, has there been a flora at all characteristic of what we think of as typical tropical rain forest. However, these forests have a feature quite new. One of the great things the early angiosperms are thought to have been able to do (Ashton 1977) was to exploit the gap-phase, that is, the opportunity for colonization offered by the collapse of some aged gymnosperm and the consequent puncturing of the forest canopy. No known gymnosperm can do this so well. Indeed, the whole of modern tropical rain forest ecology hinges on gaps: their frequency in space and time and their filling.

THE MODERN FOREST

Dynamics and Diversity

Largely through the work of Aubreville, in francophone Africa, and of E. W. Jones at Oxford and A. S. Watt at Cambridge, both writing on temperate vegetation, built on by T. C. Whitmore and G. S. Hartshorn, working in Asia and the Neotropics respectively, we now have some idea of the dynamics of tropical rain forest. This, in turn, gives us some idea of how to interpret its structure. It is simplest to visualize the forest as a patchwork quilt, each patch representing a gap caused by the collapse of a tree or other local disaster, at a particular point in a secondary succession of refilling. The "climax" forest is thus an amalgam of the careers of individual trees. And so some gaps will be a chaos of fallen limbs with high insolation and great diurnal fluctuations in temperature; others will have rapid-growing, colonist or pioneer trees with stings, barbs and thorns, and living-in ants; yet later phases will have a consolidated canopy, possibly of just one enormous tree. Not that that tree will be simple at all, for as E. J. H. Corner (1964, 116) has written:

> On its canopy birds and butterflies sip nectar. On its branches orchids, aroids and parasitic mistletoes offer flowers to other birds and insects. Among them ferns creep, lichens encrust, and centipedes and scorpions lurk. In the rubble that falls among the epiphytic roots and stems, ants build nests and even earthworms and snails find homes. There is a minute munching of caterpillars and the silent sucking of plant bugs. On any of these things, plant or animal, a fungus may be growing. Through the branches spread spiders' webs. Frogs wait for insects, and a snake glides. There are nests of birds, bees and wasps. Along a limb pass wary monkeys, a halting squirrel, or a bear in search of honey; the shadow of an eagle startles them. Through dead snags fungus and beetle have attacked the wood. There are fungus brackets nibbled round the edge and bored by other beetles. A wood pecker taps. In a hole a hornbill broods. Where the main branches diverge, a strangling fig finds grip, a bushy epiphyte has temporary