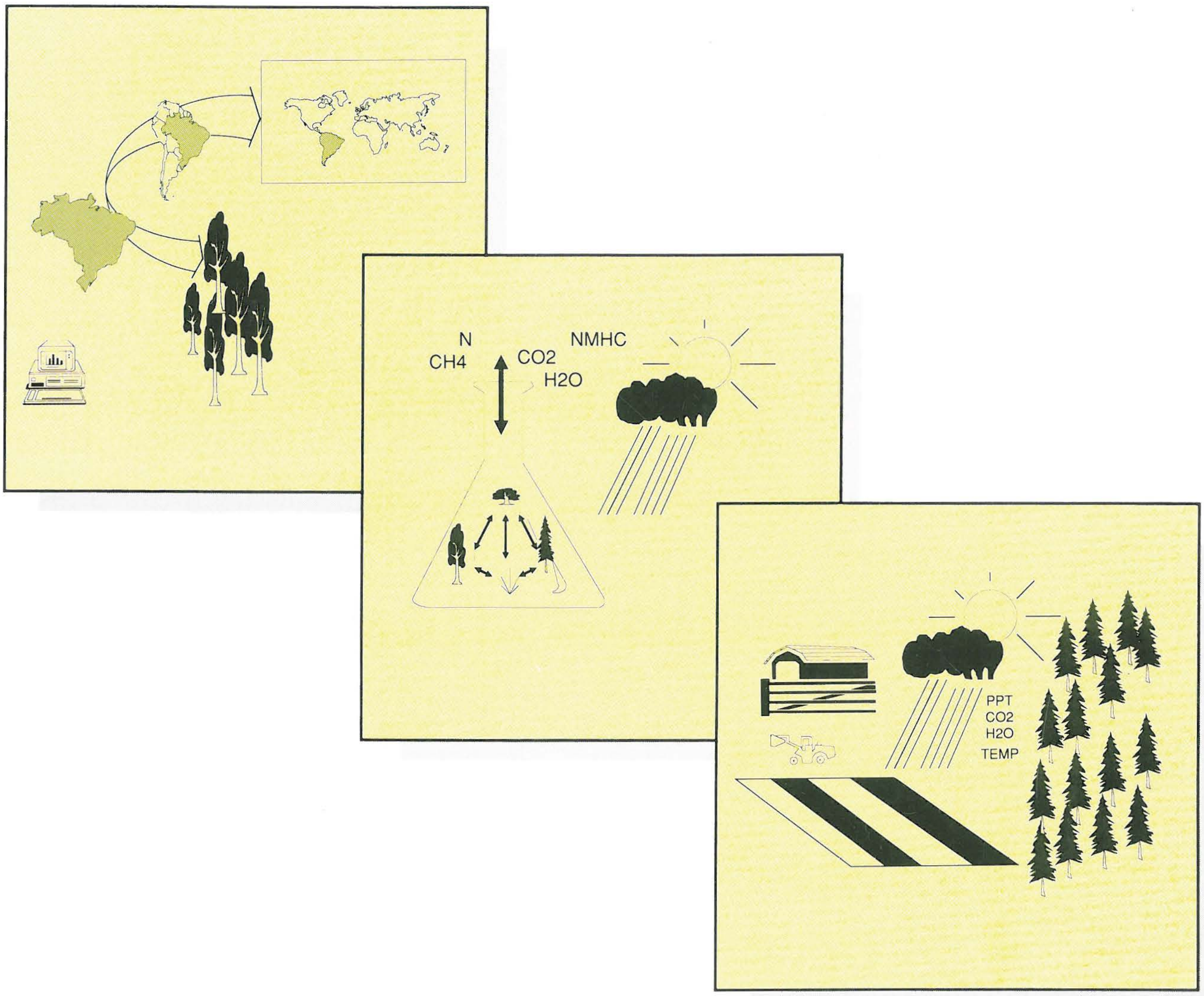
GLOBAL IGBP CHANGE

REPORT No. 11



Proceedings of the Workshops of the Coordinating Panel on Effects of Global Change on Terrestrial Ecosystems

The International Geosphere-Biosphere Programme: A Study of Global Change (IGBP)
of the International Council of Scientific Unions (ICSU)

GLOBAL IGBP CHANGE

REPORT No. 11

Proceedings of the Workshops of the Co-Ordinating Panel on Effects of Global Change on Terrestrial Ecosystems

I. A Framework for Modelling the Effects of Climate and Atmospheric Change on Terrestrial Ecosystems
Edited by B. H. Walker

II. Non-Modelling Research Requirements for Understanding, Predicting, and Monitoring Global Change
Edited by B. H. Walker and S. J. Turner

III. The Impact of Global Change on Agriculture and Forestry
Edited by S .J. Turner, R. T. Prinsley, D. M. Stafford Smith, H. A. Nix and B. H. Walker

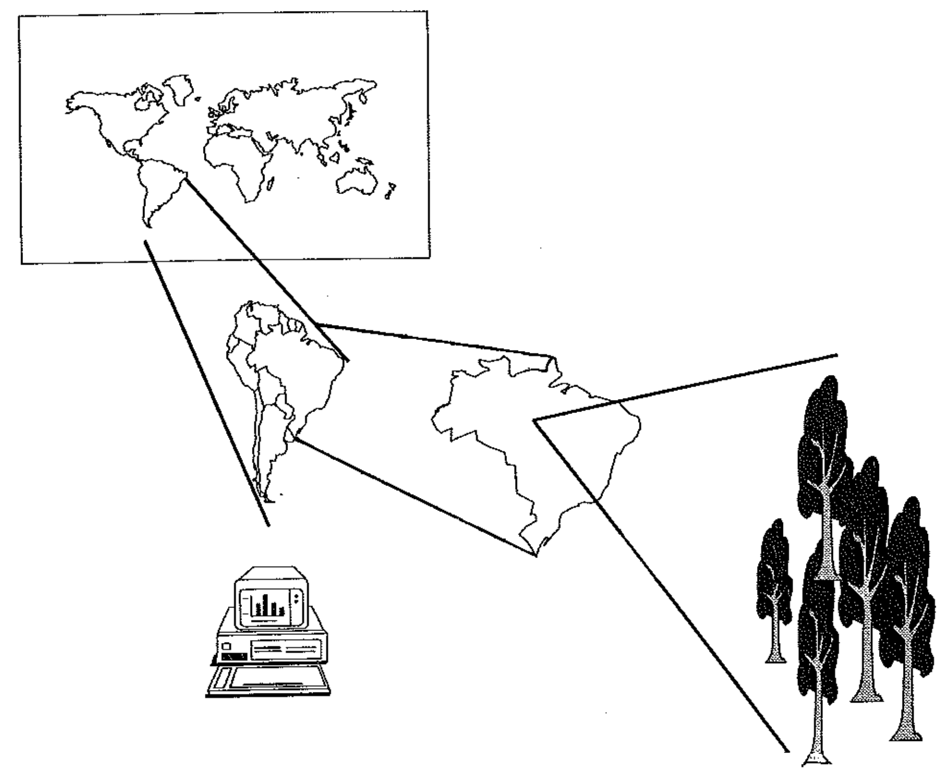
The International Geosphere-Biosphere Programme: A Study of Global Change (IGBP)
of the International Council of Scientific Unions (ICSU)
Stockholm, 1990

The international planning for the IGBP is supported from ICSU, the Andrew W. Mellon Foundation, UNEP, Unesco, CEC, Shell Netherlands, national contributions, the African Bioscience Network and the Commonwealth Science Council.

 ISSN 0284-8015

Printed by Graphic System AB, Stockholm, Sweden
Cover designed with the help of Idéoluck, Stockholm, Sweden

LIST OF CONTENTS **Page**



I.
A Framework for Modelling the Effects of Climate and Atmospheric Change on Terrestrial Ecosystems

Edited by B. H. Walker

Report of an IGBP Co-Ordinating Panel 4 Workshop
Woods Hole, Massachusetts, April 1989.

LIST OF CONTENTS

PREFACE

This document presents the proceedings of three workshops conducted by the IGBP Co-ordinating Panel on Effects of Atmospheric and Climate Change on Terrestrial Ecosystems (CP4).

The overall objective of the Panel is to develop a research programme that will generate a predictive understanding of the effects of global change on terrestrial ecosystems. Global change phenomena include changes in climate, atmospheric composition and interactions with changing land use.

This understanding is required for two reasons. The primary reason is to project the consequences of global change for ecosystem structure and function since these ecosystem attributes have direct effects on issues important to man including productivity, future land use, and biotic diversity. The secondary reason is to estimate the potential feedbacks of the changes on further atmospheric, climate and land-use change.

The three workshops were designed to cover the research needs required to meet the objectives. The first addressed the modelling requirements. It developed a suggested modelling philosophy and overall model structure, and also identified required inputs, outputs and model processes. This led to the second workshop, on non-modelling research requirements, which examined the data and experimental requirements. The third workshop addressed the needs for assessing the effects of global change on agriculture and forestry.

In addition to these three workshops, this Co-ordinating Panel was involved in two other workshops which dealt with issues related to the above objectives. The first dealt with the implications of global change for the Southern Hemisphere (published as IGBP Report No. 9). The second was a combined workshop with two other IGBP co-ordinating panels (CP3, on Biological Aspects of the Hydrological Cycle, and CP5 on Global Modelling) which examined the joint modelling needs of the three panels (IGBP Report No.10).

The results of all these workshops have been incorporated into the two Core Project proposals entitled "Global Change and Terrestrial Ecosystems" and "Global Change Effects on Agriculture and Forestry". Not all of the information contained in this publication could be included in the Core Project descriptions, and it is hoped that these individual workshop reports will prove to be of use as IGBP-related research projects are planned in detail.

B.H. Walker
Canberra, 1990

1. INTRODUCTION

The workshop was held to examine the needs for modelling within the CP4 activities of IGBP, and to establish as far as possible an agreed approach to the modelling effort. Initial discussion highlighted the need for a clearer statement on the scope and objectives of CP4. The Workshop agreed on the following:

The overall objective of the Panel is to develop a research programme that will generate a predictive understanding of the effects of global change on terrestrial ecosystems. Global change phenomena include changes in climate, atmospheric composition and interactions with changing land use.

This understanding is required for two reasons. The primary reason is to project the consequences of global change for ecosystem structure and function since these ecosystem attributes have direct effects on issues important to man including productivity, future land use, and biotic diversity. The secondary reason is to estimate the potential feedbacks of the changes on further atmospheric, climate and land-use change.

A major obstacle to achieving these objectives is the lack of adequately trained people for the task. There are too few people able to undertake the modelling developments required, even if funds were immediately available. The development of such a project therefore requires that training be undertaken, as a specific task, as soon as possible.

2. MODEL FRAMEWORK

2.1 Modelling Philosophy

2.1.1 Conceptual Framework

This section summarizes the modelling aims of CP4 and its relationships with other groups. The preferred approach is for the IGBP ecosystem modelling effort to develop and use common model structures for natural and agricultural ecosystems. This will help direct the various models produced to address the dynamics of concern to IGBP, and will ensure that their results can be integrated into larger scale syntheses.

The ecosystem, whether it be agricultural or natural, is the central component of the modelling effort. In accordance with the CP4 objectives outlined above, the ecosystem must be considered in both structural and functional terms (Fig. 1). Function and structure interact at various time scales. These interactions will be central features of the model structure.

The driving forces of interest are climate (change), atmospheric chemistry (CO_2, NOx, etc.) and land use. These three forces will lead to ecosystem responses and to changes in atmospheric chemistry and land use. Therefore, there will be feedback from these outputs to inputs. The feedback will be strong for land use, with a direct effect on ecosystem structure. The feedback of atmospheric chemistry will be less strong and spatially variable. In other words, feedback impacts of changes in atmospheric chemistry that are a result of changes in ecosystem function may occur in areas quite distant from the ecosystems concerned.

2.1.2 Linkages to GCMs

The possible linkages between ecosystem models and GCMs require special mention, since they are poorly understood by most scientists, yet lie at the heart of CP4's objectives.

Many ecosystem processes respond very slowly to changes in the environment. In modelling ecosystem change we are

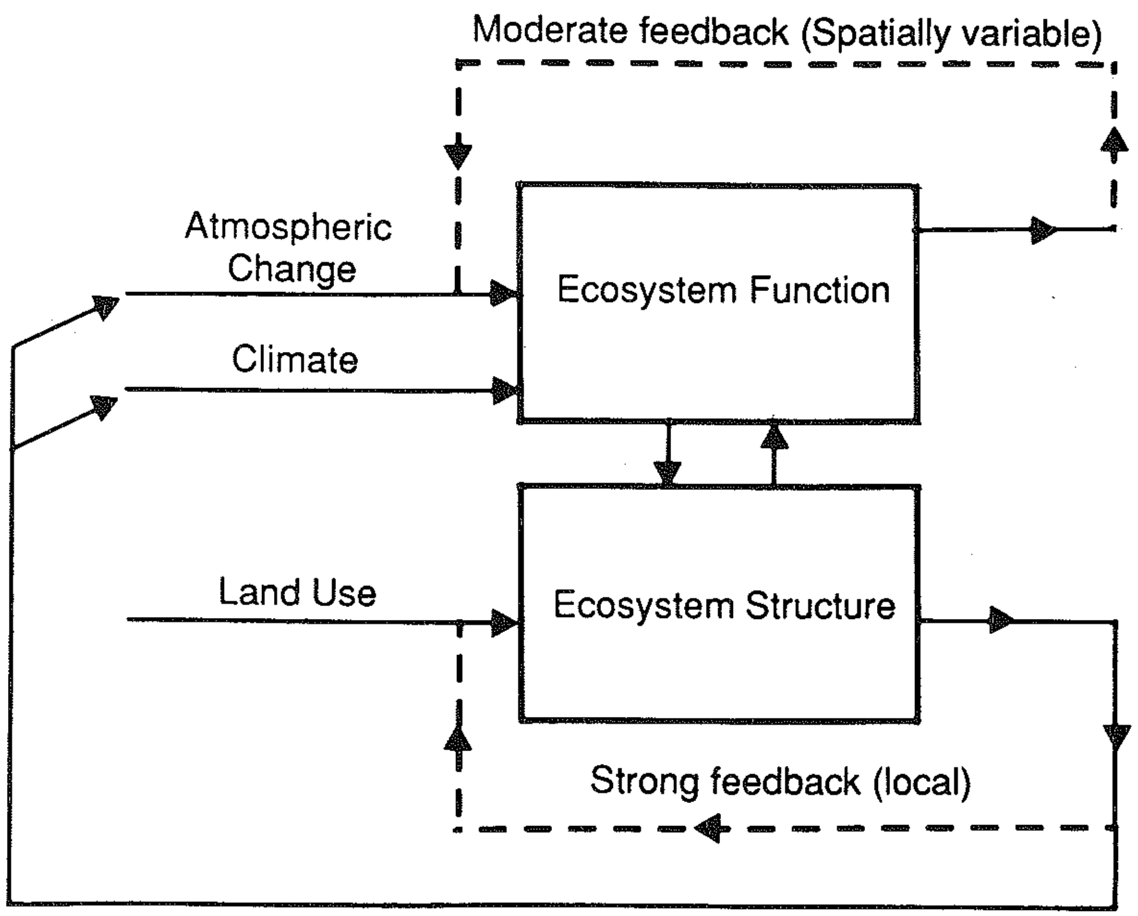


Figure I.1. Global change effects of ecosystems, considered in terms of structure and function. Structure includes spatial (vertical structure, horizontal (including patchiness)) and biological diversity (functional types and species). Functional includes material fluxes and production processes.

concerned with changes in structure and function over years to centuries. From this perspective, seasonal changes (e.g., leaf fall) and diurnal changes (e.g., stomatal opening) are lumped as part of the ecosystem state. The atmosphere has a far faster response time, so GCMs are concerned with dynamic processes over minutes to months. So for a GCM run covering, say, a few months to a year, the ecosystem state (as provided by an ecosystem model) is effectively constant, but the "scaling down" in time means that this state description must be converted into seasonal and daily dynamics of land-surface properties (e.g., evapotranspiration). SiB (Sellers) and BATS (Dickinson) are examples of schemes that perform this temporal-scale change.

There is often confusion induced by the terminology. In spatial terms, ecosystems are best defined by the boundaries of the communities which are of interest, and in this sense, ecosystems are, by almost any criteria, considerably smaller than the grid cells used as the basis for the GCMs - even if these grid cells were 1° by 1°. Ecosystem dynamics are largely controlled by processes at a much finer spatial scale than atmospheric dynamics. So the ecosystem state must be scaled up in space, taking into account vegetational and topographic variability within grid cells. This problem has not been tackled at all yet; schemes like SiB and BATS ignore the land-surface variation within grid cells.

What is needed is an atmospheric boundary-layer model that provides an adequate and appropriate interface with the global-scale circulation model. This boundary layer model should include drag coefficients which vary with topography and vegetation, turbulent-exchange coefficients that depend on the drag coefficients and on the thermal structure of the lower atmosphere, and heat and moisture balance equations (including albedo, wetness) that depend on the vegetation type and state in each cell. Note that the roughness characteristics of vegetation itself may or may not be important, depending on whether the topography in a grid cell is rough (mountains, hills), when vegetation roughness will be almost irrelevant. Given that we can improve the coupling between the terrestrial surfaces of the Earth and the atmospheric models, the next step will be to progress towards fully coupled GCM and ecosystem models, at least for the feedback of ecosystems on GCMs at the scale of GCMs.

Current models of vegetation/ecosystem response are driven by weather/climate conditions derived from weather records. GCMs properly coupled to the surface offer the possibility of by-passing such weather data and driving ecosystem models using the conditions generated by the GCMs. In one possible approach the average annual weather conditions for a starting ecosystem state would be input from GCM runs for any particular grid cell. These conditions would be used to drive the ecosystem model until there has been a significant change in the state of the system. It is then "re-coupled" to the GCM which may by that time have generated changed climates. The coupled system will update the climate and provide new driving variables for the ecosystem(s). The workshop agreed, however, that GCM outputs need to be summarized and altered to such an extent before they are relevant to ecosystem models, and that it will be more efficient to link GCMs to ecosystems via regional weather simulators. The degree to which ecosystem dynamics should be included in GCMs must obviously be determined from sensitivity analyses of GCMs to realistic scenarios of ecosystem change.

The research aimed at improving the coupling between GCMs and terrestrial grid cells must involve plant physiologists and ecologists with the ability to develop appropriate statistical descriptions of grid cells, as well as meteorologists. The research should consider techniques for defining the appropriate scale (time and space) for the appropriate process. For example, stomata and ecosystems transpire water, but the appropriate reference vapour-pressure deficit is very different for the two cases. In addition, the inclusion of geographers to help develop better (detailed) topographic descriptions of the earth to characterize the roughness in each grid cell, may be an advantage.

2.1.3 The Role of Correlative Models in Meeting Short-Term Needs

Correlative models provide the basis for extrapolation of point-based observations, measurements or estimates to wider areas at scales ranging from regional through continental to global. They include the published NPP global predictions (Leith, Esser); vegetation/climate classes (Holdridge); structural component estimates (Box) and also the more traditional geographic approaches to vegetation mapping (Kuchler; UNESCO; Matthews) as well as remote-sensing (NDVI or "greenness" index). Essentially, measurements made at points that sample a wide range of response types, are correlated with environmental or other indices (e.g., spatial reflectance values) that are available for the whole area under study. The methods used for this expansion or extrapolation vary in mathematical complexity from simple regression to very complex ordination and multidimensional scaling. At least for the immediate future such correlative model outputs will provide the necessary global cover for the study of vegetation pattern, biomass and NPP gradients.

The use of correlative models for predicting changes in the species composition of ecosystems, or in the geographic distribution of species or communities, is severely limited by assumptions relating to the direct effects of CO_2 on plant performance, lag effects in vegetation response, and the use of realized species' niches. Given access to the original point source data used in developing the correlative model based maps referred to above it should be possible to develop process-based (mechanistic) models that do not suffer from these limitations, and which could ultimately be coupled to GCMs as outlined above.

2.2 Proposed Structure for Mechanistic Modelling

With the above considerations in mind, the following model structure is presented as the best way to proceed in order to meet the CP4 objectives.

Biosphere modelling requires the representation of interacting processes at a wide range of spatial and temporal scales. Therefore, the models must be hierarchically structured both in time and space. Figure 2 illustrates this hierarchical framework. In Figure 2, increasing spatial scale (local - regional - global) is shown in the vertical; commodity in the horizontal (commodity includes inputs, outputs and state variables of models); temporal scale at right angles to the plane of the page. The principal scientific challenges are (with numbers as indicated on Figure 2):

1. Developing a set of models that treat globally important variables. These models may be developed with different fundamental assumptions. They should produce some output variables that could be intercompared but it is likely that any of these models would produce predictions of unique variables as well. One challenging problem is understanding the relationship of the underlying assumptions of the different models and the time and

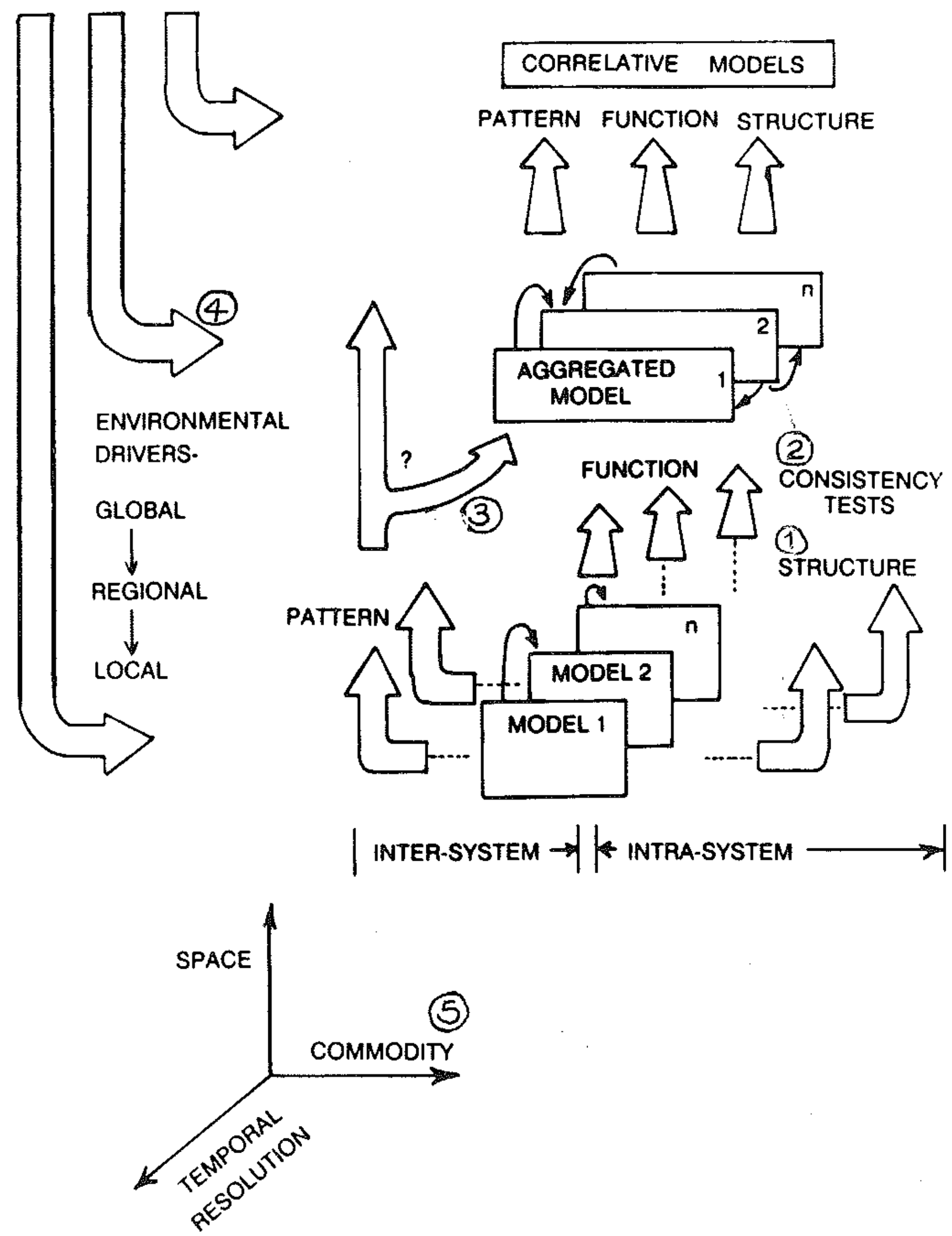


Figure I.2. Hierarchical structure for ecosystem modelling over a range of space/time scales. See text for explanation of circled numbers.

space scales to which the models apply.

2. A testing of shared output variables from these models for consistency with one another (and with reality).

3. The determination of how much the output of a given model can scale-up to global scales (limitations may be computational, data requirements, etc.) and the degree to which the model might need to be interfaced with more aggregated models for this purpose.

4. The natural levels into which the input and output variables should be structured.

5. The commodities that are treated in the models. The diagram identifies classes of commodities as pattern (proportion of different ecosystems), functions (the dynamics of important variables within an ecosystem), and structure (canopy geometry, etc.).

The structure shown in Figure 2 is abstract. Figures 3 and 4 give a more concrete example of how this frame work might be applied to model global vegetation dynamics. This particular example has been the topic of international research cooperation, sponsored by IIASA, over the past two summers.

At least three spatial scales are distinguished (Figure 3):

1. Global scale

2. Grid-cell scale (1° by 1° cells, c. 55 km by 55 km at the equator). Many global data bases are digitized at this scale. This scale also corresponds to the finest resolution that GCMs are likely to achieve in the foreseeable future.

3. "Patch" scale. Many key processes (e.g., competition for H_2O, light, nutrients) determining change in ecosystem operate on a relatively fine spatial scale (<1 ha). There is considerable environmental heterogeneity within grid cells that therefore needs to be considered in modelling ecosystems.

Although the IIASA model uses a grid size of 1° by 1°, the workshop recognized that the scale, and even shape, of the grid-scale unit should not be standard. It should be determined by the natural scale of variation in the region concerned. Depending on the complexity of the pattern and landscape dynamics it may be necessary to include two levels in the hierarchy at the lower scale (i.e., patch and landscape) as indicated by (ii) in Figure 3.

The models for vegetation-dynamics at these three scales (Figure 4) are mechanistic at the finest (patch) scale, and are projected to broader scales as statistical samples.

The primary input to the models in Fig. 4 comes from global data bases on climate and soils. These data are processed to the grid-cell scale using a geographic information system (GIS). Environmental heterogeneity due to topography is overlaid using standard GIS techniques. Topographic data are available at higher resolution, allowing estimates of roughness, elevation, slope and aspect. Semi-empirical models (e.g., lapse rates) and relations between soil properties and topography, would be used to convert this information into a statistical distribution of environmental variables within a grid cell.

A large random sample of patch environments would be drawn from this distribution. Ecosystem dynamics

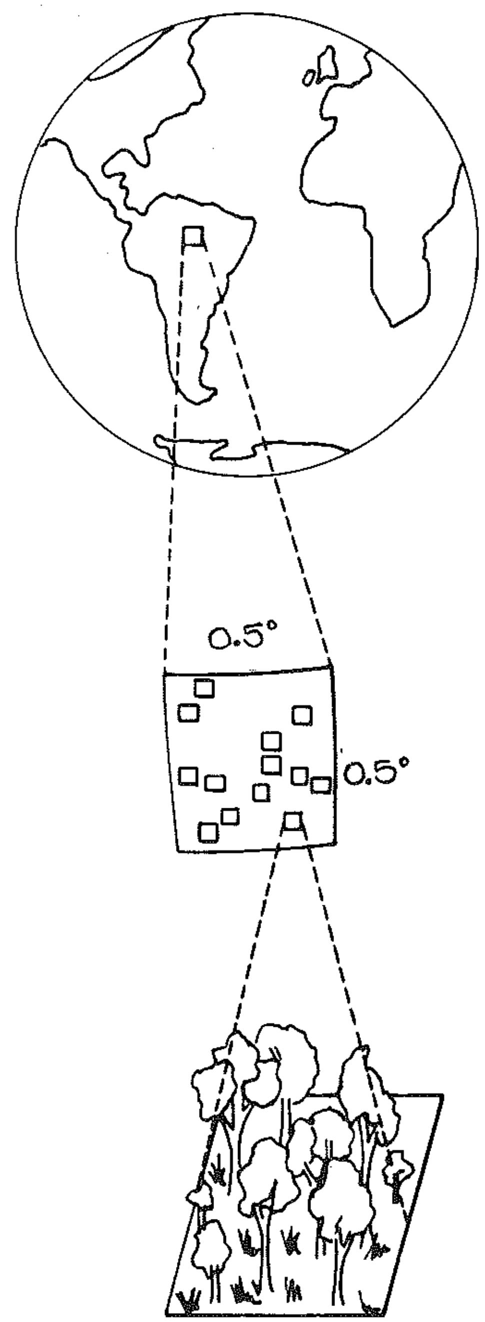


Figure I.3 Global, Grid-cell and "Patch" scales in the hierarchial structure for ecosystem models.

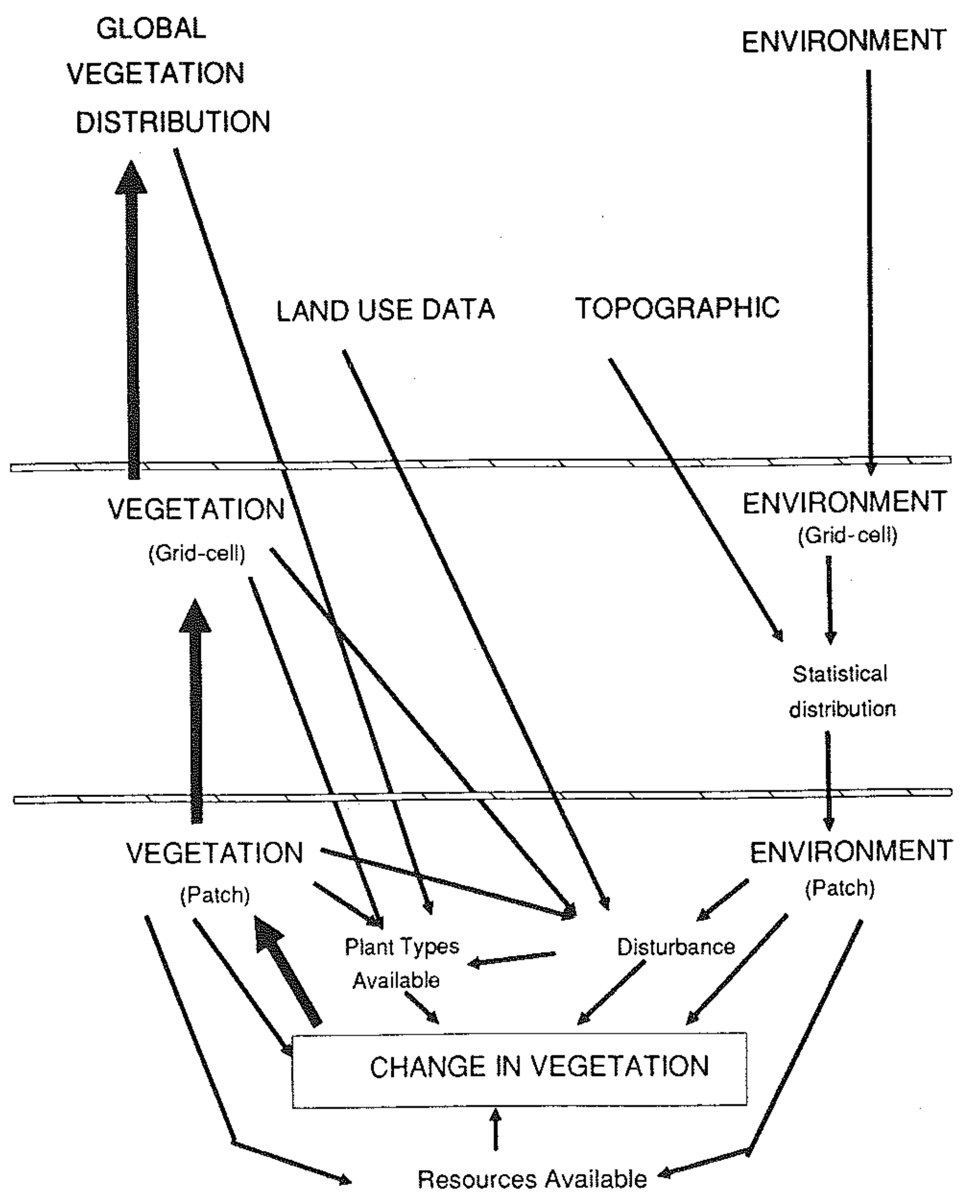


Figure I.4. Relationship between models of ecosystem change at different scales. Grid-cell size is approximately 100 by 100 km. The patch scale is considered less than 10 km and is usually much less than 100 m. Development of models to translate between these scales will be a major consideration in the IGBP core project on Global Change and Terrestrial Ecosystems (GCTE) in collaboration with other IGBP core projects.

appropriate to each patch environment could then be simulated using a generic ecosystem model. Such a model could include representations of demography, competition and other ecological processes. The resultant ecosystem states would be aggregated up to grid cell and global-scale descriptions. (Exactly how this aggregation is to be achieved needs to be spelled out.) These predicted changes would also be fed back to the patch scale to simulate mechanisms such as availability of propagules for establishment, and other contagion effects (e.g., on the probability of disturbance through wildfire spread, insects outbreaks, etc.). An important part of this modelling task will be the expression of disturbance probabilities as a joint function of the environment and the local vegetation state. Another important task will be the representation of different types of land use as disturbance regimes.

The model structure in Figure 4 could synthesize a considerable body of existing data on ecosystem dynamics. Also, many of the elements in this framework have been developed for a few cases lending some confidence to us in applying this approach globally.

Ecosystem models for use in IGBP should share a common set of inputs, and produce a minimum, common set of outputs. Furthermore, if the models are to achieve the goals of CP4 (i.e., if they are to achieve these outputs) they will need to include certain processes which are likely to be critical in projecting future changes. What follows is the preliminary proposal for these three sets of inputs, outputs and processes. A specific requirement is the initial condition of the ecosystem.

2.2.1 Inputs

Commn inputs needed for ecosystem models include parameters characterizing climatic and environmental conditions which describe the environmental drivers of the system. In the following lists, the parameter is identified, a temporal resolution is indicated, and the relevant ecological significance is noted.

The input parameters include:

1. CO_2 (Month)

   Primary relevance -- photosynthesis, respiration, transpiration
   Secondary relevance -- litter quality, decomposition.

2. Temperature (Day)

   Primary relevance -- effects of mean temperature on process rates continuous distribution function of change in threshold temperatures for key processes, forecasting means and operation (e.g., germination, flowering) extremes; annual variation in extremes relative to demographic effects of extreme events.
   Secondary relevance -- influences probability of fire.

3. Precipitation (Day)

   Primary relevance -- evaporation and transpiration; snow or rainfall timing; decomposition (under snow); intensity and duration; erosion; run-off; daily distribution function of rainfall.
   Secondary relevance -- influences fluxes of trace gases; river regimes.

4. Radiation (Day)

   Primary relevance -- solar radiation for distribution function of daily integrals of photosynthesis, growth solar radiation (allows photosynthesis)
   Secondary relevance -- U.V. damage and cloudiness estimates) (photosynthesis and DNA); U.V.-B influences transpiration.

5. Vapour pressure (Day)

Primary relevance -- influences transpiration, stomatal opening deficit.
Secondary relevance -- decomposition, infiltration (forest and savanna soils).

6. Wind (Day)

Primary relevance -- dispersal; deposition; erosion transpiration
Secondary relevance -- gap formation and consequent demographic effects.

7. Transported materials (including pollutants) -- organic and inorganic N, SO_2, 0_3 relative to deposition, and effects on production and decomposition.

8. Land and water -- demographic based predictions of land and water use for urban areas (e.g., hydroelectric and irrigation schemes and changes in agriculture extent and diversity).

2.2.2 Outputs

To assess the effects of climate change on terrestrial ecosystems, and to determine the consequences of these effects on the rest of the global system, IGBP CP4 has identified the following properties of ecosystems to be of key interest. Predictions about these properties will be made based on a suite of models at various scales (local, regional and global). All of these predictions, however, should be easily scaled to the spatial resolution of the regional scale for inter-comparison. Individual investigators may determine that higher spatial resolutions may be necessary to answer their particular questions. To reliably predict the ecosystem properties of interest, individual modellers may determine that spatial interactions are of particular importance and may therefore choose a landscape approach to the problem. Redundancy among models will be necessary for consistency cross checking of predictions. The outputs from the suite of IGBP models should include the following:

1. CO_2 flux, net primary production (NPP), decomposition, net ecosystem productivity (NEP). CO_2 is a greenhouse gas of interest to the GCM modellers, who are interested in the amount of CO_2 and where it is being produced or consumed. We are only likely to produce monthly estimates. Spatial specificity will probably be at the regional scale.

2. H_2O flux, vapor exchanges. As for 1. above. The ability to predict the partitioning of water between evaporation and runoff/drainage is also important in projecting the effects of global changes on water resources.

3. Vegetation structure, including surface roughness, leaf area index (LAI), albedo. These are important inputs to GCMs. We should be able to provide the data on a c. 1° by 1° scale. We should also be able to predict changes in these properties on a month to month basis. Spatial and seasonal patterns of LAI can be compared to satellite "greenness" data as a model test.

4. Trace gases. CH_4, NO_x, SO_2, etc. As for 1. above.

5. Carbon distribution and amounts in biomass, soil organic matter, and litter. Together with (1) above it will be of interest to those who might want to harvest biomass, as an indicator of potential production, and

as a key variable in modelling the global carbon cycle.

6. Nutrients. Expressed as nutrient availability, nutrient flux, or some index of nutrient status. It is important for prediction of 1-5. Predicting the change in nutrients will be an important and difficult part of the modelling.

7. Transported materials (sediments, windblown, organic detritus, etc.)

8. Plant functional type (PFT) changes (and/or species changes). This will be important to predictions 1 - 6 inclusive. However, depending on the scale and main purpose of the model these species variables might be taken into account by inclusion of species or PFT parameters.

9. Secondary effects such as the frequency and intensity of fire, herbivory, pest outbreaks, etc. These secondary effects can potentially feedback on other ecosystem processes and thereby influence predictions 1 - 7.

2.2.3 Processes

A generic ecosystem model should include the following processes.

1. *Net Carbon Capture by Plants*: This set of processes represents net input and/or output of carbon to an ecosystem; dependent upon the process of photosynthesis less respiration losses. Photosynthesis is a function of radiant energy, CO_2 concentration and leaf nutrient status. Respiration rates are affected by temperature and leaf nitrogen.

2. *Growth and Allocation*: Growth refers to the production of organic matter. Allocation refers to the partitioning of carbon compounds among various biochemical components including lignin, protein and cellulose and among plant parts, and of particular interest is the apportionment to above- and below-ground parts and how this will be affected by changes in the inputs (above). Allocation depends upon the balance of these input resources, particularly radiation, nitrogen and water.

3. *Birth and Death*: These processes determine the numbers and types of plants in a community. The net result of these processes determines community composition and structure, and, since much interest will be focussed on changes in composition (of either functional types or species) the factors influencing these processes will need to be explicitly addressed. 'Birth' includes both germination and the subsequent successful establishment of seedlings and 'death' will involve both age-specific and age-independent mortality. (cf. IGBP Report 5 for more detail).

4. *Dispersal and Migration*: Dispersal refers to the outflow of disseminules of plants or animals by mechanisms which include wind, water and phoresy. It is also necessary to consider seed loss (predation) as part of the process which influences seed banks. Migration refers to the large scale, active movement of animals either on a seasonal basis or in response to spatial and temporal distribution of resources.

5. *Decomposition, Nutrient Dynamics and Soil Organic-Matter Formation*: Decomposition refers to the breakdown of complex plant tissues in a process of mineralization of

carbon and other mineral species. Decomposition and mineralization are part of nutrient dynamics which include the uptake and utilization of nutrients by plants and inputs and outputs from ecosystems. Soil organic matter turnover is a function of decomposition, soil organic matter stabilization amd mineralization. These processes are primarily governed by soil temperature, moisture content and the quality of incoming plant material.

6. *Water Use and Balance*: Water use refers to the water flux through the plant. Water balance refers to the balance between rate of uptake from soil and rate of loss to the atmosphere from either the soil or plants. These processes are determined by radiant energy, temperature, humidity and windspeed interacting with leaf area and plant physiological state. Soil water balance depends on the water-holding capacity of the soil, depth of soil exploited by the roots and the balance between water use, precipitation, infiltration/runoff and bare soil evaporation.

7. *Spatial Redistribution of Materials or Resources*: This refers to the movement of matter such as soil, nutrients and detritus across landscapes, induced by water, wind, gravity or animals. Redistribution and concentration of materials may significantly affect the structure and function of ecosystems, and focusses attention in IGBP modelling on landscape-level processes. The events giving rise to the redistribution may be either episodic or continuous. These processes are typically a function of topography, land cover and the prevailing climate (rainfall and wind regimes), and will therefore be affected by changes in climate and landuse.

8. *Fire and Herbivory*: Changes due to these processes are generally regarded as secondary effects in ecosystem dynamics, though they may be very important. They are influenced by the state of the vegetation and weather.

The final two processes, both concerned with spatial dynamics, and generally omitted or poorly dealt with in ecosystem models, are worth considering in more detail, as follows.

2.3 Spatial Heterogeneity and Landscape Dynamics

Spatial heterogeneity exists in terrestrial ecosystems at all scales. This heterogeneity may significantly affect ecosystem processes such as carbon flux and it may also be important for maintenance of ecosystem integrity. By ecosystem integrity we mean persistence of species, population structure and higher level functional units such as shrub clumps, debris dams, animal mounds, etc. Spatial heterogeneity may be viewed as another form of system structure at a larger, usually landscape, scale. Inasmuch as spatial heterogeneity may be altered by global change, predictions of ecosystem response to climate change cannot be made without accounting for changes in spatial heterogeneity.

We may recognize three classes of spatial heterogeneity: topographic; disturbance-induced; biologically-induced.

Topographic heterogeneity will include topographic controls on fluvial patterns and processes (drainage patterns), catenary or hillslope processes, related patterns of geomorphology and soils and parent materials, and indirect effects of topography on climatic variables (rainfall, temperature, evapotranspiration).

Disturbance-induced heterogeneity will include processes that may be typically characterized as allogenic or exogenous (e.g., fires or wind storms); the effects of these "allogenic" disturbances may be significantly modified by autogenically, or endogenously, induced-system states. For example, fire is induced by heat, drought and lightning and spread by wind, but the occurrence of fire is also influenced by ecosystem variables that determine the probability of ignition and spread in accumulated fuel. Disturbances affect and are affected by the age or size-class distributions of dominant organisms and the spatial patterns of dominant organisms (e.g., mosaics of tree stands).

Biologically induced heterogeneity includes such phenomena as vertical redistribution of soil materials by termites or small mammals, the spatial pattern of insect outbreaks, and the spatial pattern of herbivory and dispersal. In this regard, animals may be viewed as regulators of whole-system responses to global change. Not all such phenomena will be important, in terms of practicable, IGBP goals, and the task facing IGBP ecosystem modellers will be to identify and include only those phenomena which, by virtue of the influence they exert on ecosystem function and structure, cannot be left out.

The significance of spatial heterogeneity for ecosystem function and integrity will depend on the degree to which predictions of a non-spatially heterogeneous model differ significantly from predictions of a model that includes spatial heterogeneity. In particular, if spatial heterogeneity significantly modifies predictions that a model may make of ecosystem responses to climatic change, then it is significant. An example of this would be a region where elevational effects on weather or climate result in differentiation of life zones or land-use practices with the elevational gradient. In this case, climatic change would significantly alter the distributions and relative abundances of these life zones or land uses, thereby altering the function of the region as a whole.

It is easy to imagine how ecosystem functions such as primary production might be influenced by climate-induced alterations in spatial heterogeneity. It is more difficult to imagine, and certainly more difficult to predict, how such alterations might influence the ecosystem properties we have categorized under "integrity". Spatial heterogeneity may be even more important in terms of maintenance and stabilization of species and population-level processes. We may find many ecological "surprises" resulting in the alteration of heterogeneities.

In some cases, the actual dynamics of a landscape will have to be considered. Landscape dynamics refers to an explicit consideration of the movements of landscape functional units. Functional units may include plant communities, plant-animal associations, or specific plant-soil relations. The dynamics of movements of materials or organisms over a landscape as in a shifting fire mosaic may have to be explicitly characterized to effectively represent the way a whole system is likely to respond to global/climatic change.

Research proposed for inclusion in IGBP should include spatial heterogeneity at a range of spatial scales and the potential significance of heterogeneity at various scales for ecosystem function and integrity. If significant heterogeneity is identified, then the sampling regime and modelling of that system should characterize the heterogeneity and its consequences in an effective way. However, it will not be necessary in all cases to model spatial variability explicitly. In many instances, it will be more effective to simply make the spatial effect implicit in a model formulation or parameterization. This would be more likely where spatial variance occurs at small scales, or where spatial variance can be effectively described by statistical distributions rather than by actual mapping.

2.4 Interactions with Other Groups (Fig. 5)

Interfaces are classified in three groups; data requirements, products and validation. Data requirements and products are considered later. Validation has not been considered in any detail, but is clearly crucial.

Ecosystem models will need to be developed before the various predictions from different GCM predictions become convergent. The IGBP should therefore be developing models that can be tested using standard meteorological station data, with data acquired over recent times (last decade) and also incorporating extreme events over this period.

The models will predict agricultural and natural ecosystem responses to short-term changes in climate and weather. These responses will be partly in terms of CO_2 drawdown, productivity and species composition and can be compared with data acquired from time series of observations. Similarly, the monthly records of CO_2 concentrations could prove useful for comparing observations and predictions of CO_2 drawdown by ecosystems. More terrestrial CO_2 monitoring sites need to be established, to provide information on annual drawdown by terrestrial ecosystems.

Satellite remote-sensing data now exist from about 1972 and should, therefore, incorporate both short-term (predominately) and long-term trends and changes in ecosystem phenology and distribution. These data (the seasonal changes in ecosystems, and the relative distributions of ecosystems in space) should be particularly useful for testing ecosystem predictions.

Results of the SSC (Scientific Steering Committee) on Global Changes of the Past are likely to have a circumscribed but considerable value for validation purposes. Such results will also be useful in setting boundary conditions and for considering rates of movement of vegetation over the landscape -- a crucial feature of dynamic responses of ecosystems to climate change (see final section).

2.5 Evaluation Procedures for the Model Framework:

1. Meetings (c. 30 people) including "new" people with different insights to the modelling efforts should be held. These workshops would evaluate results from current and comparable modelling efforts, and discuss priorities for new modelling efforts, with a focus on validation..

2. Cross-comparisons of models with different resolutions in space and time to determine degree of consistency. These comparisons could be directed to places with large data sets, such as the GBOs.

3. It would be useful if proposals that use the rationale of fitting the IGBP modelling effort would explicitly state how proposed research work links or compares with other efforts.

4. In interacting with atmospheric modelling groups, the ecosystem modellers should identify critical variables of interest to ecosystem dynamics.

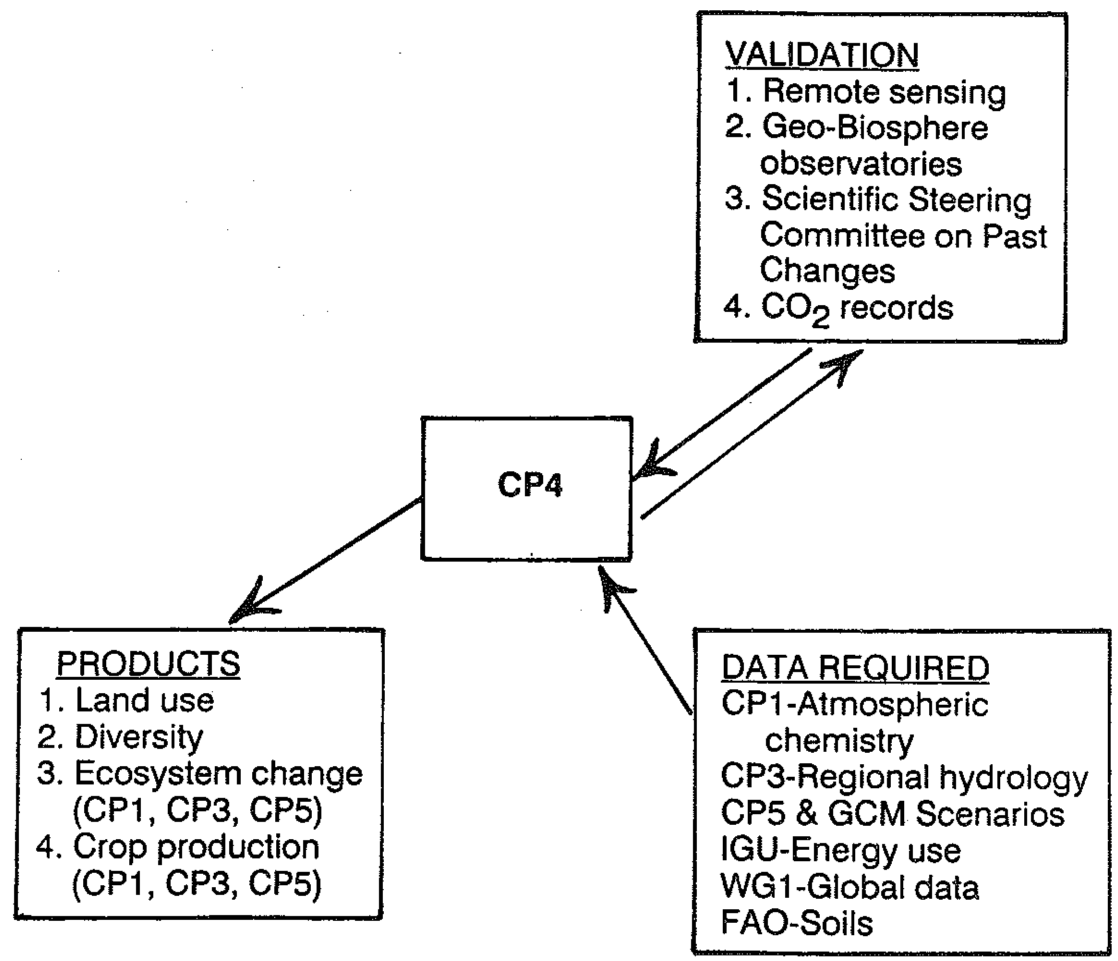


Figure I.5. Interactions of CP4 with other groups in terms of data required, validation and CP4 outputs.

3. OTHER TASKS FOR CP4 (i.e., Non-Modelling Requirements)

This workshop was called to address the modelling requirements for CP4. The overall work of CP4, however, will involve much more than just defining the modelling effort. Consideration of the modelling requirements will be of major importance in helping to define those other tasks. They will be specifically addressed at a future workshop, but are considered briefly in this section, as a basis for this further development.

3.1 Data Needs

CP4 has identified the following data needs.

1. *Data at the appropriate scale.* One of the major problems with using extant data to corroborate ecosystem models is the lack of data at the appropriate scale. Although many data have been collected at the fine scale (e.g., leaf physiology, litter-bag decomposition, etc.), integrated process data at the scale of whole ecosystems (e.g., hectare or larger estimates of CO_2 or water-vapour flux) are rare. The problem is both conceptual (lack of theory for integrating across scales) and technological. However, new technologies are being developed that could be applied to the problem (e.g., eddy correlation, satellite imagery). More effort and funds should be committed to developing these types of methodologies and actually making the measurements.

2. *A digital elevation model that will provide information on terrain.* The elevation scale of approximately 20-m height resolution and 1-minute grid. For maximum utility, these data will need to be accompanied with data on drainage lines and sinks, since these features are not likely to be captured by the 20-m contours. These data are essential to relate hydrological status of ecosystems, water transport of sediments, etc.

3. *Digital maps of parent material from geology maps.* These data in combination with climatic and terrain data would provide needed information to determine important soil properties.

4. *Better information on the types and distribution of vegetation (potential and actual).* This would include functional types of vegetation, their physiological properties, dispersal potential, structure, etc.

5. *Better information on soils including organic matter content, texture, chemical properties of the mineral soil, etc.*

3.2 Process Studies

Earlier workshops (CP4 and SCOPE) have already identified a number of processes which are inadequately understood for CP4 modelling objectives. They include such processes as:

- Stand-level allocation of C
- Effects of soil fertility on C, N mobilization and immobilization Stabilization of soil organic matter
- Factors controlling phenology and other plant vital attributes
- Determinants of whole-plant mortality
- Erosion and run-off and other effects of spatial re-distribution and dynamics in ecosystems
- Plant responses to herbivory
- Controls of nutrient uptake in relation to soil nutrient availability

- Effects of extreme events on ecosystem structure
- The effects of changes in vegetation on consumption
- Non-consumptive effects of animals, etc.

Clearly, a list such as this is of little use in guiding the IGBP, and CP4 needs to run a workshop aimed at determining the critical processes in priority order or grouping, the understanding of which most limits our ability to predict the effects of CO_2 and climate change. Putting these processes in priority order will clearly be facilitated if there is general acceptance and understanding of the required ecosystem-model structures. The Inputs, Outputs and Processes discussed in this report are of particular importance in this regard.

The workshop would then also address the questions of how best to obtain the information -- e.g., through comparative measurements in different places, controlled experiments on single variables or sub-systems, etc. In each case it should consider the scale and general methodological approach, and the precise nature of the output or results which are needed in order to meet the required products of the models.

3.3 Whole Ecosystem Experiments

The workshop strongly supported the proposal for IGBP whole-ecosystem experiments. Given the immense complexity of ecosystem interactions it is the only way we will be sure of obtaining answers to many questions concerning the net effect of the many positive and negative feedback effects involved in changes in CO_2, temperature, and precipitation regimes.

The workshop recommended that future developments await the final report of the SCOPE project on this topic. Once this is out, CP4 needs to use this report, plus the CP4 reports on modelling to run a workshop aimed at selecting and designing the few experiments that most need to be done.

The workshop strongly recommended that these whole-ecosystem experiments be intimately tied in to the GBO network, and in fact suggests that the term GBO be re-placed with the term Geosphere-Biosphere Experimental Sites. Such a development is more likely to gain the support of scientists and funding bodies. The development of large, expensive projects as an integrating mechanism in big science is a common paradigm (e.g., oceanography). The sites would each be one of the second-level GBO sites, and the original notion of the GBOs as a global network for monitoring global change would be preserved. The experiments would be a scientific resource, available to many scientists, integrating the interests of CP1, CP3, CP4 and CP5. The experiments would be designed as a combination (perhaps) of large enclosures, open plot and partially enclosed sites. For inclusion in IGBP they would need to be built according to agreed IGBP standards, and freely available to IGBP scientists. Many practical issues need to be resolved at such a workshop.

3.4 Land-Use Change and its Effects

There are three levels of concern:

- direct effects of land-use change on components of the global climate and atmospheric chemical systems;
- effects of land-use change on the mobility (migration rate and pathway constraints) of species, populations, and entire communities of organisms to move in response to land-use change in the spatial heterogeneity of the landscape.

- effects of land-use change on resource heterogeneity and redistribution dynamics.

The first of these may fall within the purview of CP1, and is discussed here to emphasize the importance of the impact of land-use change on ecosystem processes which can have global consequences and must be dealt with in some detail by IGBP. Land clearing affects a number of transfers from terrestrial ecosystems to the atmosphere including carbon fluxes (CO_2, CH_4) and storage; less well-documented fluxes of nitrogen trace gases; key processes of the hydrological cycle; and changes in land-surface characteristics such as albedo and roughness. Any effort to predict the response of terrestrial ecosystems to climate change must incorporate these processes and properties of the ecosystem which interact with the global system.

The second area of concern, the effects on the mobility of species and populations, is central to CP4. The ability of any vegetation formation to respond to climatic change is a function of the rate of climate change, the dispersal rate and regeneration of key species, and the presence of an open pathway for migration. Formally, open pathways may have been closed by land-use change. Humans are also moving species around both deliberately and inadvertently; some of these species can alter the process rates and the structure of their new community or ecosystem. We need to know the importance of migration effects now and to project these effects into the future under various scenarios of land-use change. Such efforts have been made for particular species, for which the problem is acute, but it needs to be generalized for ecosystems.

Thirdly, we need to develop a better understanding of the effects of land-use change on resource heterogeneity and its consequences. The biological functioning of natural forests and their carbon dynamics will differ depending on the patch size of the forest in a forest-grassland or forest-cropland matrix; consequently we need to know patch size as well as the overall forested area when considering the effects of land-use change. Land clearing also affects patterns and processes of resource redistribution by fluvial, aeolian, and biotic pathways. These have significant consequences for the functioning of down-stream, down-slope, down-wind, or down-range ecosystems.

Complementary activities necessary for the development of modelling land-use changes relative to climate include remote sensing of land cover, geographic data bases for soils, land use, cropping systems, and socio-political-economic parameters and inputs. The time series of land-cover characteristics (e.g., vegetation greenness, initiation of land-use change, seasonal pattern of greenness, amount of bare soil, fragmentation of land-cover distribution and distinction between row crop vs pasture, and tree vs grass dominated types of vegetation) recorded by remote-sensing techniques will provide needed global information about changes in land cover.

The determination of land use and changes in land use will also depend on inputs from additional non-remotely sensed information built into a geo-referenced ancillary data base. The information needed in this data base includes the bioclimatic parameters necessary to describe the general classes of ecosystems present (e.g., data relative to distinguishing the different ecosystems, agroecosystems, and other management systems). Basic information soil properties and climate will be essential. Geographic information on land-use practices would also be highly desirable.

Classifications of crop or vegetation functional types need to be developed to distinguish various classes of land cover in relation to C flux, C storage, water flux, trace-gas flux, albedo, and land-surface roughness. These characteristics include distinctions between C_3, C_4, annual, perennial, grass, forb, and tree types. In addition, relative management intensity needs to be indicated (e.g., high = intensive mechanical farming techniques; medium = passively-managed ecosystems, like grazing pasture and tree plantations; low = natural or very passively-managed systems). Descriptors on fire, grazing, management practices and disturbance patterns characteristic of the ecosystem would also provide useful information in tracking land use and subsequent changes to climate.

3.5 Climate Change and Agroecosystems

One of the most important concerns of the IGBP must be the effect of climate and atmospheric change on agroecosystems. How this can be best incorporated into the planning process includes the following possibilities:

- Include it under the purview of this coordinating panel as it exists now.
- Develop a new coordinating panel expressly to deal with agroecosystems, or find such an independent group to accept this role.
- Expand the purview of this panel to include agroecosystems and to expand the membership of the panel by two or three members with expertise in these areas.

The third alternative is the one most recommended. The first is not feasible because the present composition of the panel does not adequately cover the breadth for the problem and the group is skewed toward natural systems. Most importantly, the panel lacks the expertise to understand agricultural management and economics in enough detail to deal with climate-change impacts on agroecosystems.

The second alternative received more serious consideration, but it was rejected for both practical and scientific reasons. The practical reason is simply that it was felt that another coordinating panel could not be established at this stage of the IGBP, and that no other group could be identified to take the responsibility for the IGBP. Scientifically, the approach that such a group would take (if one could be constituted) would be highly overlapping to this panel. The methodological problems faced by the two panels would be the same relative to scale, techniques, experiments (e.g., generic crop models are well developed and possibly would help formulate natural analogs, issues of scale are similar, and environmental drivers are the same).

It is also proposed that in late November 1989, a workshop of approximately ten agroecosystem experts, plus the extant panel (with the additional members) meet in Cameroon to discuss the research plan to address climate change impacts on agroecosystems. Henry Nix and John Stewart (with assistance from the secretariat) will coordinate the selection of invited experts and the agenda topics. UNESCO has indicated that they are willing to handle the logistical end of things in Cameroon.

3.6 Linking Modelling Efforts with the Palaeoecological Record

Pollen and plant macrofossil records are the main sources of information on vegetation changes over time scales long enough to register impacts of natural climatic change. 14C-dated records for the past ~ 20 ka are geographically very extensive.

Ecosystem models that predict changes in vegetation composition as a function of changes in climate and atmospheric composition can potentially be tested with these palaeoecological data. Reconstructions of past climatic patterns since 20 ka come from GCM experiments in which global boundary conditions have been appropriately changed. In the COHMAP project such reconstructions have been extensively verified or modified by physical geological data (e.g., palaeohydrology). A global ecosystem model should reproduce the patterns of present natural vegetation. It should also (when run to equilibrium under a changed global environment) reproduce past patterns.

In some places, pollen analysis from annually laminated sediments has provided continuous vegetation records with exceptionally good time resolution and control. These records may give a unique opportunity to test ecosystem models' transient behaviour. This aspect of the models is crucial if they are to be applied to the effects of changes on a time scale of 100-200 years, comparable with the ecosystems' own memory.

Large-scale changes in taxon distribution and abundance patterns are documented in the vegetation records of the past 20 ka. This information will be vital in constraining those aspects of global ecosystem models concerned with plant dispersal and ecesis.

The IGBP project "Global Changes of the Past" has thus important links with the activities proposed by CP4. That project can and should produce state-of-the-art physical and biological data sets in a form that can be used for testing and improving global ecosystem models.

SUGGESTED READING

Bolin, B., Döös, B. R., Jäger, J. and Warrick, R. A. (eds) The Greenhouse Effect, Climatic Change, and Ecosystems. SCOPE 29. John Wiley & Sons, Chichester.

Box, E. O. 1981. Microclimate and plant forms: an introduction to predictive modelling in phytogeography. In: Leith, H. (ed) Tasks in Vegetation Science Vol. 1. Junk, The Hague.

Emmanuel, W. R., Shugart, H. H. and Stevenson, M. P. 1985. Climatic change and the broad-scale distribution of terrestrial ecosystem complexes. Climatic Change 7:29-43.

IBSNAT. 1989. International Benchmark Sites Network for Agrotechnology Transfer. University of Hawaii, 2500 Dole Street, Krauss 18, Honolulu, HI 96822, USA.

IGBP Report 5. IGBP Secretariat, Stockholm. IGBP 1990a. Land Atmosphere Interface. Report on a Combined Modelling Workshop of IGBP Coordinating Panels 3, 4, and 5. Turner, S. J. and Walker, B. H. (eds). IGBP Report 10. IGBP Secretariat, Stockholm.

Moore, A. D. and Noble, I. R. 1990. FATE: An individualistic model of vegetation stand dynamics. Environmental Mechanics. (In press).

Noble, I. R. and Slatyer, R. O. 1980. Use of vital attributes to predict successional changes in plant communities subject to recurrent disturbance. Vegetatio 43:5-21.

Parton, W. J., Schimel, D. S., Cole, C. V. and Ojima, D. S. 1987. Analysis of factors controlling soil organic matter levels in Great Plains grasslands. Soil Sci. Soc. Am. J. 51: 1173-1179.

Pastor, J. and Post, W. M. 1988. Response of northern forests to CO_2 induced climatic change. Nature 334:55-58.

Prentice, I. C. 1986. Vegetation response to past climatic variation. Vegetatio 67:131-141.

Prentice, I. C., Webb, R. S., Ter-Mikhaelian, M., Solomon, A. M., Smith, T. M, Pitovranov, S.E., Nikolov, N., Minin, A. A., Leemans, R., Lavorel, S., Korzukhin, M. D, Hrabovszky, J. P, Helmisaari, H. O, Harrison, S. P., Emanuel, W. R., and Bonan, G. B. 1989. Developing a Global Vegetation Dynamics Model: Results of an IIASA Summer Workshop. International Institute of Applied Systems Analysis, Laxenburg, Austria.

Rosswall, T. R., Woodmansee, R. G., and Risser, P. G. 1988. Scales and Global Change: Spatial and Temporal Variability in Biospheric and Geospheric Processes. SCOPE 35. John Wiley & Sons, Chichester.

Sellers, P. J., Mintz, Y., Sud, Y. C. and Dalcher, A. 1986. A simple biosphere (SIB) for use within general circulation models. Journal of Atmospheric Science 43:503-531.

Shugart, H. H. 1984. A Theory of Forest Dynamics. Springer-Verlag, New York. 278 pp.

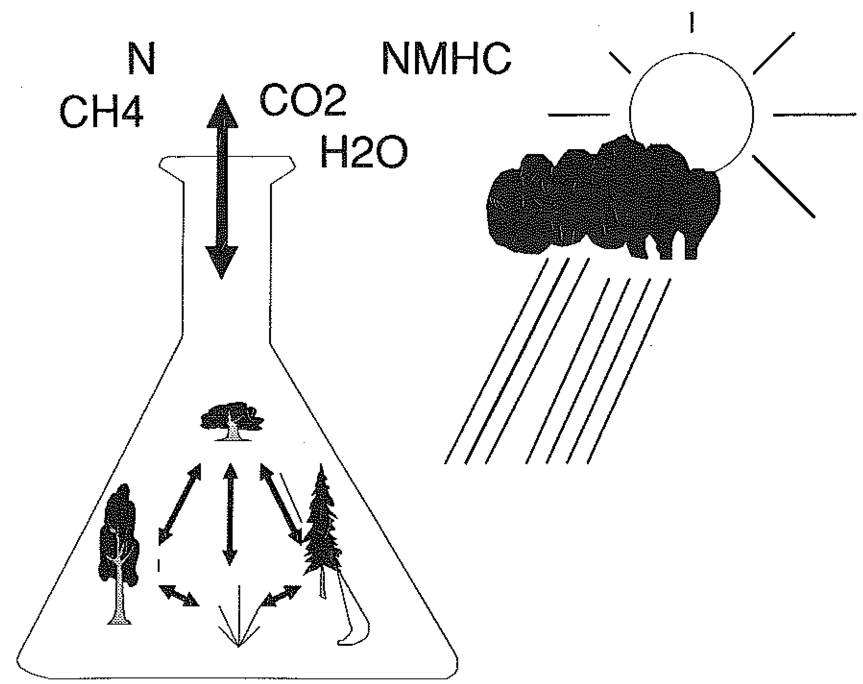
Shugart, H. H., Antonovisky, M. J., Jarvis, P. G. and Sanford, A. P. 1986. CO_2, climatic change, and forest ecosystems. In: Bolin, B., Döös, B. R., Jäger, J. and Warrick, R. A. (eds) The Greenhouse Effect, Climatic Change, and Ecosystems. SCOPE 29:475-521. John Wiley & Sons, Chichester.

Smith, T. and Huston, M. 1989. A theory of the spatial and temporal dynamics of plant communities. Vegetatio.

Stewart, J. W. B. and Cole, C. V. 1989. Influences of elemental interactions and pedogenic processes in organic matter dynamics. In: Clarholm, M. and Bergström, L. (eds) Ecology of Arable Land - Perspectives and Challenges. Developments in Plant and Soil Sciences Vol. 39. Kluwer Academic Publishers.

Walker, B. H., Young, M. D., Parslow, J. S., Cocks, K. D., Fleming, P. M., Margules, C. R. and Landsberg, J. J. 1989. Effect on renewable natural resources. In: Global Climatic Change - Issues for Australia, pp 31-76. Commonwealth of Australia.

West, D. C., Shugart, H. H. and Botkin, D. B. (eds) Forest Succession: Concepts and Application, pp. 132-153. Springer-Verlag, New York.



II.

Non-Modelling Research Requirements for Understanding, Predicting, and Monitoring Global Change

Edited by B. H. Walker and S. J. Turner

Report of an IGBP Co-Ordinating Panel 4 Workshop
Canberra, Australia 29-31 August 1989.

LIST OF CONTENTS

PREFACE

This workshop was a joint meeting of IGBP CP4 and the Australian National Committee to the IGBP (ANC-IGBP), held from 29-31 August 1989 at the CSIRO Division of Wildlife and Ecology, in Canberra. The ANC-IGBP identified the topic as being of particular importance and, in addition to this report, required specific recommendations for the Australian research programme.

Presentations on the first day of the workshop were aimed at raising the issues to do with data and understanding that are currently constraints at various levels of modelling in the context of IGBP. Discussion of the research activities identified and the empirical tools required provided the structure for the remainder of the document.

The major recommendations are those in Section 1, in which the empirical information requirements for predicting climate-change effects were considered by Working Groups. Section 2 presents further research needs, considered from a disciplinary point of view, that were not identified in the Section 1 working groups. Finally, Section 3 presents some of the remaining issues which have emerged during the two years of CP4's activities.

The 49 participants are listed in the Participant List. Funding was provided by the Special Committee of the IGBP and, for the ANC-IGBP, by the Australian Academy of Science. Much of the credit for the workshop must go to the CSIRO staff and particularly to Ms Fiona McFarlane, who gave many hours of effort to the workshop.

SUMMARY OF THE PRIORITY LIST OF EMPIRICAL RESEARCH REQUIREMENTS
(Numbers in parentheses refer to Sections in this section)

RESEARCH REQUIREMENTS FOR A PREDICTIVE UNDERSTANDING

- Incorporation of ecological (ecosystem) questions and approaches into the design and conduct of mesoscale meteorological field studies (1.1.1).

- Field-scale experiments to measure the effects of extreme events (1.1.1.).

- Integrated experiments, from single leaf through to whole ecosystem experiments, to examine the effects of elevated CO_2, in different environments over several years (1.1.2 and 2.4.1).

- Experiments of CO_2 effects on ecosystems in which climatic variability is manipulated (1.1.2, 3.4).

- Experimental determination of the effects of changes in climate and atmospheric inputs of carbon and nitrogen on pools and fluxes of carbon. Secondly, the feedback behaviour of these changes in pools and fluxes on ecosystem structure The highest priorities are experiments in the tundra/boreal transition and in tropical forests. An inventory is needed of carbon pools in vegetation and soils (1.1.3).

- Experimental manipulation of ecosystem level demographic processes, such as diaspore input rates and pathogen impact, to determine their significance in ecosystem dynamics (1.1.3).

- Development of new high resolution data bases of land use, and land-use change, in order to address the problem of how land-use change will influence the fluxes of greenhouse gases and energy. Strong support must be given for the development of medium term (~30y) social/economic/demographic models which predict land-use change in order for these effects to be coupled with biophysical models (1.1.4, 3.1).

- Development of a data base for the determination of current realized niches of species and other taxons in major regions. The data required include the distributions of selected taxa and of associated selected abiotic variables (1.2.1.).

- Studies to obtain the information needed to develop functional models (or definitions) of potential niches, so as to predict changes in species (taxon) distribution on the bases of "new" realized niches related to CO_2 and secondary effects (1.2.1. and 2.5.2).

- Development of a Sensitivity Index (or sensitivity indices) to measure the response of species and/or functional groups to environmental variation. This will require the use of existing data as well as new experiments based on hypotheses about particular life-history attributes (1.2.2).

- Determination of which guilds or functional groups with similar responses will be the appropriate test "species" for global change studies, and whether these guilds are similar to those formed for other purposes. These guilds should form the basis of controlled, manipulative experiments which examine the interactive effects of changing structure and/or metabolism (1.3 and 2.5.1).

DISCIPLINE-BASED RESEARCH NEEDS FOR GLOBAL CHANGE STUDIES

- Determine the effect of past climate change on past vegetation, to provide insights into the effects of present changes. This should include an attempt to reconstruct the frequency of past extreme events, and their effects (2.1.1 and 2.1.2).

- The highest priority soil project should involve elucidation of the dynamics of the active fraction of the soil carbon. This will require standardized methodology from sites located across ecotonal boundaries, using experimental manipulation of water and temperature (2.2).

- Most priority research areas require controlled environment studies with the species, life-forms and community types under consideration. These studies should address primarily the interactive responses of CO_2, water, temperature and nutrition. Development of integrative technology for assessing ecosystem function on scales relevant to, and by techniques compatible with, remote sensing and global modelling should be encouraged building on the experience of the above process studies (2.4.3).

- The greatest need in regard to remote sensing is the development of scene models that take coarse-scale (e.g., NOAA) data and relate them to measures of vegetation structure (including roughness at the landscape scale) and function (albedo, evapotranspiration and net CO_2 flux). The development of these models requires research using, simultaneously, high resolution RS and coarse resolution RS, together with field measures of the vegetation attributes, with the objective of eventually being able to predict these vegetation attributes using only the coarse RS data and the model (2.3).

GENERAL ISSUES

- One important requirement permeating all the recommendations is the need for an appropriate monitoring system to detect changes in terrestrial ecosystems that are related to the phenomena of global change. The planning and organization of such a scheme requires a workshop of its own (3.3).

1. RESEARCH REQUIREMENTS FOR A PREDICTIVE UNDERSTANDING

Predicting change requires a basic understanding of the mechanisms that underlie the change. Validation of prediction requires specific knowledge of the state of the system before the particular change and a knowledge of where change might first be evident, and which changes will matter most, if they happen. The workshop considered two broad categories as organizational aids in addressing the problem of empirical research needs for basic understanding of global change, and for input and validation for global change models: i) *Ecosystem function, or metabolism*; and ii) *Species dynamics*. The two are tightly coupled, in that ecosystem function is strongly determined by the kinds of species, and the dynamics of species composition is in part a consequence of ecosystem-level processes such as nutrient cycling and primary production. Atmosphere and climate have the greatest effect on function of ecosystems while land-use practices have a greater immediate effect on the structural components. Beyond the general configuration of ecosystems in relation to global change it is necessary to identify the important aspects of ecosystem production.

1.1 Ecosystem Function

Climate change creates a feed forward to new ecosystem dynamics in function and state while feedbacks from the new system drive further atmospheric changes. Feedbacks to the atmosphere in the form of surface roughness, albedo and evapotranspiration control energy flow and mass momentum (functional properties).

Exchange of energy and materials are basic to the function of ecosystems, where "function" is used in the sense of ecosystem "metabolism" or "physiology". Measurements and experiments at this level are needed for model development, validation and basic understanding. Empirical investigations must consider changes in the state and functions of ecosystems alone, changes in state and function as feedback, and changes to state and function as they influence ecosystem composition, species and all structural parameters.

Three spatial scales (patch, landscape and regional) have been distinguished as particularly important for studies of global change (see the modelling workshop report) though these should not be considered the only important scales. Within the frame work of these scales it is necessary to look at system parameters and identify the conceptual and experimental limitations.

Four particular lines of research must be accomplished.

1. Research is needed to support the coupling of ecosystem models with GCMs. This involves questions of how to scale up; how to put good terrestrial ecology into GCMs. The time scales of the two types of models must be rationalized.

2. The effects of increased concentration of CO_2 on ecosystem level change; on physiology, decomposition and nutrient availability to plants. This will require component and whole ecosystem-level experiments, and must include the interactions of CO_2 effects and climate change.

3. The effects of climate and atmospheric changes on net exchange and storage of carbon in terrestrial ecosystems and the atmosphere -- the feedback effects of change in vegetation on further atmospheric changes.

4. Land-use effects. Land use is a multiple feedback system linked to species changes. A global land-use data base is needed as input to global-level models.

Each of these research needs is dealt with in turn.

1.1.1 Ecological Measurements on Coarse Spatial Scales: Working Towards the GCM Grid Cell.

The priority need is to bring ecological questions and approaches into the design and conduct of meso-scale meteorological field studies. The ecological component of these studies will improve CO_2, water, and trace gas flux estimates, and will also address fundamental ecological questions.

Ecologists can do a reasonably good job of measuring and modelling the storage and exchange of materials over small areas (0.1 - 10 ha) on annual time steps. We need to be able to do as well over larger scales (10 x 10 km to global), so that we can contribute to understanding regional and global-scale processes. In order to do this there are fundamental ecological questions involved in scaling from local to landscape to regional to global levels. The question of whether measurements and calculations that were derived locally can be linearly summed to yield a regional scale estimate requires experimental evidence. This may require new instruments or ways of measuring ecosystems, and/or new models of ecosystem function.

Mesoscale meteorological field campaigns can now provide measurements of CO_2 and H_2O exchange on spatial scales of 10 - 100km. These could provide an independent check on estimates developed by adding up fluxes measured in small patches (or developed by any other pathway). The problem is that the micrometeorological measurements yield more or less hourly fluxes. The challenge, then, is: Can terrestrial ecosystem ecologists step estimates and predictions of flux down to shorter time scales so that they can be validated on coarser spatial scales by meteorological measurements? If we can do so we can test directly our ability to work on coarse scales which would be a substantial contribution to testing ecological theory.

At the same time there are several areas of research where biological involvement in micrometeorological field campaigns will be especially important for an understanding and predictive knowledge of global change. In particular:

i. some ecological questions can be answered in meteorological field campaigns and in no other way -- most notably scaling towards GCM spatial scales;

ii. micrometeorological campaigns need ecological input (as they recognise) in production, decomposition, hydrology, trace-gas flux, etc;

iii. there are good ecological reasons for choosing locations for field campaigns (i.e., savanna/forest transition areas); and

iv. we need an ecologically-driven meteorological field campaign mainly to look at scaling.

The incorporation of physiology with micrometeorological data on common time scales will add the necessary biological reality for modelling across single plant to landscape and GCM spatial scales. These are ecological questions which must be addressed during meteorological field campaigns. Likewise ecological input to meteorological field campaigns is necessary for understanding production, decomposition, trace-gas flux and hydrology.

Important study areas are boreal forest and wetland mosaics; tropical forest/deforestation regions; savanna/woodland interfaces. Critical information is lacking in these areas. The fluxes which should be measured would necessarily be CO_2, H_2O, NO_x and CH_4.

A preliminary test site designed to address the importance of heterogeneity and our ability to cross spatial scales is necessary to determine the baseline work which must be accomplished at all other sites if the data are to provide input for a comprehensive set of ecosystem models. A logical candidate would be an agricultural landscape in a semi-arid area; contrasts and interactions among landscape units should be maximized there. If we can predict regional fluxes from component measurements and predictions in such an environment, we should be able to do so anywhere.

Another question important to translating information and impacts between scales from physiological to global is: How can we understand and predict the influence of catastrophic events (unusual disturbance) on ecosystem -atmosphere exchanges? Catastrophic events are important to ecosystem energy budgets and trace gas exchanges because they abruptly change the state of the system. To interpret exchange, we need to account for the influence of such events themselves and the time-scale of ecosystem recovery from the event.

The research requirement is to design appropriate field-scale experiments to measure the effects of particular extreme events (e.g. extended drought) and/or to establish the appropriate set of observations of natural extreme events which will allow for the same objective.

It is being assumed that a realistic predictive understanding of these exchanges will require the development and empirical validation of appropriate models of: a) extreme events and disturbances; b) their impact on state variables and parameters; and c) the integration of these models into comprehensive ecosystem models.

1.1.2 Effects of CO_2 Change on Ecosystems

The major question is: how will elevated atmospheric concentrations of CO_2 interact with temperature, precipitation and radiation to affect key ecosystem processes? Subsidiary questions relate to the implications of these effects for interaction between vegetation structure (e.g., species composition), competition and herbivory. Ecosystem processes which respond to CO_2 changes are net primary production, carbon partitioning, decomposition, nutrient cycling, and water-use efficiency.

Priority requirements for coordinated field and controlled environment experiments are:

Development of integrated experiments with elevated CO_2, from single leaf through to whole ecosystems. An associated requirement is the development of technologies which will measure biological responses with improved sensitivity by non-destructive techniques.

Experiments incorporating manipulation of the effects of climatic variability, such as seasonality and extreme values.

The primary ecosystem processes would be measured as part of the response. They would need to run for a minimum of three to four years. The information needed could probably be achieved with an experimental time of around 10 years. This time period is probably too long in the face of rapid change so, while the experiments should run for that time span, interim information must be made available for model input.

Field research sites must be developed in three key climatic zones.

- Temperature-limited areas including the Tundra-Boreal forest transition and the temperate C3/C4 grasslands.
- Water-limited areas, such as grassland-shrubland transition zones.
- Areas with no water and temperature limitations (e.g., the wet tropics). These are important because they may respond most sensitively to concentrations of CO_2.

1.1.3 Climate and Atmosphere-Change Effects on the Storage and Flux of Carbon and Nitrogen in Terrestrial Ecosystems

Priorities in this area fall into two categories:

i. Effects of changes in temperature and precipitation patterns, and atmospheric CO_2 on pools and fluxes of carbon and nitrogen. It is also not evident how the effects will feed back to the atmosphere and hence to climate change.

ii. Effects of these changes on the distribution of structural types of vegetation, and how that will feed back to the atmosphere. Within each of these questions, specific areas for investigations are proposed as the first experiments which should be undertaken.

The highest priority for research under (i) is to characterize changes in carbon pools of tundra/boreal and tropical-forest ecosystems. An inventory is needed of carbon pools in vegetation and soils (differentiating labile and stable soil organic-matter fractions).

The tundra/boreal forest systems are in areas where anticipated climate changes, in terms of temperature, are likely to be the largest. They also contain the largest mass of stored carbon among terrestrial ecosystems after rainforests. Changes in temperature and hydrological regimes will affect ecosystem processes such as production and decomposition, which influence biogeochemical fluxes from these ecosystems. Soil carbon pools at high latitudes are more susceptible to large changes in response to smaller changes in temperature and hydrologic regime than other systems. Conversely, net mobilization of carbon from tropical systems is largely anthropogenic. In addition, experimental studies to investigate fluxes of CO_2, NO_x and CH_4 from the systems are required.

Measurements to be made should include decomposition of organic material, release of nitrogen and other mineral nutrients and changes in the production of biomass in response to the changes in resource availability. The feedbacks will be assessed through the fluxes.

Under (ii), the effects of atmospheric deposition of reactive atmospheric constituents (CO_2, NO_x) on terrestrial species and ecosystem structure should also be assessed. Dependent upon the rate and effect of deposition, these may also produce a significant feedback.

The success of this research will be strongly dependent upon the activities of CP1, dealing with the controls of biogenic trace-gas exchange from the tundra/boreal system. Research should be designed to meet the goals of both CP4 and CP1.

It is also important that work on the mass of material stored in, and being cycled through, the tropical forest and savanna systems should continue and increase. An improved data base for tropical systems is required for improved resolution of current

global carbon-cycle models. This would include inventory of standing biomass and studies on pool sizes and turnover rates.

In relation to category (ii) above, a specific type of geographic region is particularly appropriate for investigating how the distribution of structural types of vegetation will be affected by global change. The area should be less than 30 deg. latitude, where grass-dominated vegetation changes over to woody vegetation in response to a rainfall gradient. These factors are important for a number of reasons, including;
a) this kind of vegetation occupies a large area of land surface; b) the radiation load of the area is large; c) many humans live there, and their activity in clearing, burning, managing livestock and collecting firewood will interact importantly with the outcome of change; d) changes in the structure of the vegetation will bring about strong feedback to climate change because they are likely to affect albedo, carbon storage and evapotranspiration, quantity and seasonality. The effects of changes in roughness, brought about by changes in vegetation structure, are unlikely to be significant in relation to climate change unless they are relatively large, and occur over a large area. Effects that influence exchange processes at the scale of the planetary boundary layer will cause significant feedback between vegetation structure and the atmosphere; and e) changes in vegetation structure are likely to be associated with changed fire regimes, which may have climate feedback consequences.

Areas within the tropics and subtropics are also important because predominantly grassy vegetation may become increasingly dominated by woody vegetation as climate zones shift. The general question is, given a scenario involving such a climate and CO_2 shift, how quickly might vegetation respond?

It is suggested that field experiments should be aimed at complementing models by assessing whether processes which are not currently included in the better-developed modelling efforts are, in fact, important. Many models currently emphasize relative competitive ability during vegetative growth, and life-history adaptation to the disturbance regime. Among processes the importance of which we do not yet understand are diaspore input, plant pathogen and insect herbivory impact under changed climate.

Diaspore experiments should test whether increased diaspore input does in fact lead to increased establishment and change in growth-form mixture. Experiments run in parallel should consider factors affecting seedling establishment. Pathogen impact experiments should expose species currently dominating grassy vegetation to the climatic conditions and inoculum load currently found in woody vegetation, to see whether they are seriously impacted. The impact on insect herbivores, life cycle, seasonality and defoliation rates must be investigated.

1.1.4 Land Use: A Multiple Feedback System

The priority need is to assess land use at a high resolution on a global basis, and to quantify land-use changes. This information is required at a sufficiently fine resolution to assess the relationship between land use, fluxes of CO_2, and CH_4, etc. under current and future conditions.

Answers to these question will require satellite imagery, improvement of existing data bases and inclusion of data on surface albedo, vegetation structure, surface roughness, energy and water balance. It will require subdivision of vegetation into categories that clearly distinguish between types of natural and cultivated wetlands, tundra, boreal/tropical forest, etc. This will require increased effort in the development of high resolution data bases with ground truth that helps distinguish processes controlling gaseous fluxes. It will also be important to archive all available imagery now for future use. Central comprehensive data bases with easy user access become important.

The need to have fine-scale (cf. Matthews 1983), global data on land-use and land-use changes over time arises from population pressure and its interaction with the physical environment and global climate change. Examples are:

i. Land development pressures augmenting the flux of greenhouse gases by changes in tropical-forest regions, for example the burning in Amazonia.

ii. Quantification of methane fluxes requires information on the extent of various types of natural and cultivated wetlands, along with information on water dynamics in these areas.

iii. Development pressures are likely to change land use in boreal forest regions, presently too cold to develop.

Anticipation of future land use is possible using a range of possible future scenarios, probabilistically, and interactively. Short-term processes of land-use change are relatively well understood. Medium term (i.e. ~ 30 y) interactions between population, land use and markets must get research emphasis. The Woods Hole modelling workshop recommendations for this are strongly supported. That is, bio-physical models need to be coupled with social/economic/demographic models and predictions. Long-term land-use changes are too hard to predict and may not be relevant without information about the feedbacks and therefore are of low research priority.

Anticipation of future land degradation needs attention. Scenarios need to be developed for erosion, salinization, soil structure change, and soil carbon change, among others.

1.2 Species Composition

The primary focus of species considerations concerns the research required to predict the response of selected entities (from biomes to species) to climatic and atmospheric change. Two approaches to this problem were developed. The "top-down" approach addresses the question of whether a taxon is likely to be strongly affected by global climatic and atmospheric change. The corollary "bottom-up" approach focussed on the same question, but expressed it in terms of asking whether it is feasible to develop an index of species sensitivity to global climate and atmospheric change. The two approaches converge in many aspects.

1.2.1 Top-Down; Which Species are Sensitive to Change?

IGBP report 5 addressed issues of vegetation dynamics and distributions, and the maintenance of biological diversity. In response to modelling requirements needed to address those issues empirical research must answer the question about the likely effects of global change on species (taxons). The non-modelling research requirements are i) correlative studies, and ii) mechanistic studies, in that order.

Correlative Studies

Correlative studies would be used to determine the current realized environmental niches of biomes, growth forms (grasses, trees, shrubs), and individual species. The research requirements for these studies include:

- data bases of taxa distributions and selected abiotic parameters (especially climate and soils) for plants;
- field tests (verification) of current models such as those of Box (1981) and Holdridge (1947);
- development of new models of the correlation between the abiotic environment and niche space.

Specific taxa for study should be selected on the basis of their relevance to global change and its impact on society. For example taxa from the tundra biome; growth forms relevant to feedback parameters such as albedo; species important to agriculture and forestry such as livestock, cereals, pests, weeds and pathogens; and regions likely to be subject to the greatest impacts, such as mangroves.

Specific research is needed as correlative tests (statistical) of current and new models. Experimental tests of model predictions need to be conducted via transplant experiments for key taxa inside and beyond the taxa's predicted range (Woodward 1982). A review of the invasion literature is needed to establish how and why invasive taxa become successful outside their previous realized niche (SCOPE). In addition, correlative models should be used to predict feedback parameters. Albedo for instance may be predicted from expected grass and tree distributions.

Each continent or specific region would require a set of investigations designed to provide the needed input for global coverage. A protocol would be designed to test and augment current and proposed models.

Mechanistic Niche Studies

Mechanistic models for biomes, growth forms and species could be useful in developing a predictive understanding of potential distribution under changed conditions. Currently there is no generally accepted methodology for their development. Rather, each environment responding to a different suite of controlling factors requires unique methods. Further development of these methods is required for regional-level studies.

Experimental methods currently in use for determining distributions need to be tested in the context of global change scenarios. Tests which should be included are CO_2 enrichment experiments, temperature-increase experiments and theoretical models of growth-form responses in microcosms.

1.2.2 "Bottom Up"; An Index of Sensitivity to Change

The species taxonomic level is appropriate for investigations of global change if it is feasible to develop an index of sensitivity to global climate and atmospheric change. Precisely, it is necessary to determine whether it is possible to predict which species will respond most rapidly and with greatest intensity to global change. This involves predicting the response of species to abiotic (first order) effects and understanding the biotic effects (second order) such as sensitivity to competition and increased vulnerability to herbivory.

A research protocol for developing an index of sensitivity should be developed. Measures of reproductive, growth and mortality responses of a range of species must be developed. Temperature response and CO_2 response for instance will alter growth processes and should be explicitly investigated. The species-based index would also require data about life history and genetic and phenotypic variability attributes.

A series of hypotheses about which properties or response functions are indicative of sensitivity must be tested. Among them, those which treat narrow temperature range requirements for growth or reproduction or specific requirements for pollen or diaspore dispersal, or low genetic heterozygosity, may be the most indicative of high sensitivity.

Analyses of the above data must determine if there are groups of properties (syndromes) which define functional groups of species. Indirect indicators of sensitivity to global climate and atmospheric change will have to be used. These include the current distributions of species assuming that narrow ranges of distribution imply sensitivity. It also includes the temporal stability of populations (if fluctuating distributions implies sensitivity) and disturbance manipulations. The approach of examining what holds species at a boundary may be appropriate.

Analyses of data via correlative tests are necessary to see if there is a relationship between functional groups and indirect indicators of environmental sensitivity. Further tests will indicate whether the relationships identified are consistent with the assumptions about sensitivity.

To assist in focussing research efforts, one suggestion is to choose parts of the world where considerable stress or change is anticipated and, within those areas, choose species where the consequences of change would be important.

1.2.3 Top Down and Bottom-Up Experimental and Observational Approaches

These two approaches converge to basic questions and experimental and observational programmes. Both require that existing distributional data of taxa be collected and that the response of taxa to environmental variables be measured. In both cases genetic variability is considered a prime source of information about sensitivity to change.

1.3 Interactions of Investigations into Ecosystem Function and Structure

The changes in ecosystems will involve changes in their structure on the one hand (their species composition and their physical configuration), and in their function on the other (their exchanges of materials and energy -- or their "metabolism"). The interactions between the two are at the heart of ecological science, and there is a need for experimental programmes which combine the sorts of investigations outlined in 1.1 and 1.2 above. It is necessary to know how changes in the metabolism of an ecosystem will affect structure (e.g., species composition), and vice versa.

Controlled field experiments are required in which structure is manipulated (e.g., by removal of particular kinds of plants) and the effects on ecosystem metabolism is measured; with a corresponding experiment in which specific aspects of metabolism are manipulated (e.g., changing the input of energy, water, CO_2 or N) and the effects on demographic processes of the species are measured. The two kinds of experiments need to be integrated, both in their planning and in the analysis of their results, by means of interactive models. Of the various recommendations made in regard to research requirements, the workshop considered that these controlled field experiments should be considered as amongst the most important.

The design and interpretation of these interactive experiments would be greatly

facilitated if we had a valid classification of functional groups of species (or guilds), with similar responses to the sorts of environmental change, that are expected. There is therefore a research need for such a functional group analysis, leading to identification of appropriate test "species" for global change studies.

The variables which could be used to characterize species fall into four categories: (i) morphological -- growth forms, etc; (ii) to do with plant and ecosystem metabolism -- C3/C4/CAM, deciduous/evergreen, etc; (iii) geographic and climatic and soils distribution; (iv) dispersal and establishment and disturbance-regime biology.

The research problem therefore consists of testing for how consistent the between-species correlations are among these different categories of characteristics. The priorities for the IGBP suggested are:

a) Make more objective and if possibly unify the classifications that exist.

b) Identify the characters under (iii) needed to relate vegetation composition to ecosystem metabolism, and work them in with the classification.

c) Develop data bases dealing with (iv), dispersal and establishment and disturbance-regime biology to understand how consistently these characters, which will control the transients, are related to categories (i)-(iii).

A predictive understanding of global change may be gained from such experiments if current classifications, which together contain the needed information, are unified and made more objective. This priority must include identification of the characters (geographic climate and soils) that relate vegetation to ecosystem metabolism incorporated into the unified classification data bases of dispersal, establishment and disturbance-regime biology must also be incorporated to understand the relationship between these transient phenomena and the structure and function of ecosystems.

2. DISCIPLINE-BASED RESEARCH NEEDS FOR GLOBAL CHANGE STUDIES

The following topics were suggested by considering the contributions that particular disciplines could make to global change investigations.

2.1 Palaeoecological Studies

Information about past climates and events are locked in the palaeo record in the form of ice cores, sediment deposits and tree rings. Interpretation of past events from these records provides clues to the effect of natural variation and perturbed behaviour of the coupled earth atmosphere system of the present. Quantitative information on changes from the past taken from around the globe can help provide an interpretation of current changes.

Palaeoenvironmental reconstructions and interpretations can be used as analogues of future conditions provided that the boundary conditions (evolutionary stage of a taxon, sea level, ice cover, land/sea distribution, etc.) are similar between the present and chosen periods in the past. Palaeo studies provide a unique framework as a way of testing climatic or ecosystem models by assessing the models ability to simulate conditions substantially different from the present. Recent changes can be charted from either unrecorded or records pre-dating the instrumental period which will allow a more complete explanation of modern changes.

Each of these uses can be applied to a number of research projects. The following listed in priority order, are research projects which are important investigative tools for understanding and predicting global change.

2.1.1 Determine the Effect of Climate Change on Past Vegetation to Provide Insights into Future Changes.

This priority project would provide validation for ecosystem models of change as well as provide basic understanding of the link between biosphere and geosphere. Components of the project are:

i) Measure change of the δ C13 value in plant materials over the last 1000 to 2000 years (include the Medieval Warm Period) to estimate changes in water use efficiency during a period of higher temperature and one of increasing CO_2.

ii) Explore and develop use of boreal and tropical forest peats as records of vegetation changes and decomposition changes caused by temperature changes rather than CO_2 changes over the last 2000 years. Use these results to test models and evaluate predictions of carbon-storage change and vegetation change under greenhouse conditions (see Ecosystem Function 1, 2, 3 above).

iii) Explore explicitly the limits of fine-resolution pollen analysis, particularly modern pollen vs climate, lags between vegetation change, and pollen preservation.

iv) Support existing efforts to monitor the response of tree growth to CO_2 fertilisation, using tree rings grown since CO_2 has been increasing.

v) Monitoring programmes set up under IGBP should include variables that can be confidently detected in palaeo-records, e.g., leaf characteristics, decomposition indicators (organic matter extracts), pollen rain, sediment transport.

2.1.2 Reconstruct Frequency and Explain Past Climate Change and Extreme Events

Variability and frequency of extreme events in the future may change. This unknown quantity may reset the system with new dynamics and feedback complexity which daunts attempts at prediction. Understanding the outcome of extreme events of the past may serve to mitigate the scientific uncertainty that they represent in current studies. The reconstructions of past extreme events will necessitate research in several directions.

i) Reconstruct the frequency of extreme meteorologic events and ENSO over the last 2000 years. These include cyclones (investigated from; coral-debris beaches, coral cores), floods (from; coral cores, slackwater deposits, lake deposits), sediment transport (from; lake sediments, slackwater deposits), El Niño events (from; documents, flood deposits, and coral cores).

ii) Promote research into both documenting temperature change over the last 2000 years and its causes (solar radiation, and North Atlantic Bottom Water production) to provide more realistic climatic models and predictions.

2.1.3 Use Records of Past Hydrology, Erosion, Sedimentation and Fire as Analogues of Future Changes and for Testing Models

In this research, the last 2000 years are especially important. The work is given less priority than the previous research. Some such records currently exist from various environments.

2.2 Soil Science Studies

It is not possible to research every possible soil-based response to global climate change, and it is therefore necessary to identify the most important types of information.

In considering the possible effects that global climate change will have on soil, one of the first tasks is to retrieve soil data already in existence from experiments, surveys and observations and re-interpret them to suit the objectives of IGBP at a landscape level. Many of these studies will not have been originally soil-centred, but contain information about soil collected to support related studies. This exercise will enable knowledge gaps or inadequacies in various regions to be identified and corrected if necessary, and will obviate the establishment of long-term field studies where data are adequate.

These data should be summarized in a new set of maps which will also include a reinterpretation of vegetation types to reflect the objectives of IGBP (being developed by WG1). GIS technology should be used to overlay the different data sets.

In regard to new research, the key soil study should involve the elucidation of the dynamics of the active fraction of the soil carbon pool. Organic soil carbon mediates soil structural stability, erodability, porosity, nutrient supply and cation exchange capacity. The active fraction is a small proportion of total soil organic carbon at any given time, but large quantities of carbon may flow through this pool per unit time, depending on supply and conditions. The consequences of disruption to the dynamics of labile carbon, flow promptly through to other soil properties such as infiltration, water storage and gas exchange which directly affect plant productive potential.

Although there is not total agreement about precise methodologies, techniques of organic carbon fractionation are sufficiently accepted for use in IGBP studies (e.g., TSBF, UNESCO). As it is expected that these measurements will be carried out in a variety of laboratories around the world, it is vital that methods be standardized.

The data relating to labile carbon flux should be derived from studies where plant responses and hydrological inputs are an integral part of the studies system so that broad, ecosystem-scale principles are derived in a coherent fashion. It will be impractical to carry out very long-term research studies, so interpretation from relatively short studies will need to be interpreted carefully, with strategic monitoring of key sites.

Sites to be measured should be located across ecotonal boundaries because functional changes caused by global climate change will be most sensitively detected by looking at boundary shifts whether caused by climate alone or a combination of climate and population pressure (i.e., changed land use). Experimental manipulation of water and temperature as they affect the amount of carbon inputs, rates of decay and output sinks are the appropriate environmental factors to vary. CO_2 does not directly affect the soil, and the quality of organic matter input is of secondary interest because carbon transformation reactions are essentially edaphic.

The data should provide an appropriate input to presently developing organic matter decomposition models such as Century, which will need to be modified to handle a range of changing edaphic habitats and become more predictive. Soil stability models (e.g., USLE) can make use of the data directly.

Monitoring is an essential activity to institute, using inexpensively collected data, some of it perhaps observational, from a large number of stations. Monitored parameters should include changes in the functional groups of decomposers.

2.3 Remote Sensing

Ecologists have had far too little input to the development and application of remote sensing to biosphere-scale problems. Too many data have been collected by those who are not operational users. Left in the hands of technocrats, remote sensing has frequently become an end in itself. An increased input from field ecologists is required for the most critical stage in the use of remote sensing, the formulation of realistic scene models.

Remote sensing should be used to indicate the global scale of changes in ecosystems to indicate the state and change in ecosystem function and to address the problems of ecological scaling. Further development of several lines of current research is strongly recommended.

One of the major stumbling blocks to the further application of remote-sensing technology to ecological problems at all scales is the development of models for scenes, atmosphere and sensors.

A major recommendation with regard to remote sensing is therefore the development of scene models that take coarse-scale (e.g., NOAA) data and relate them to measures of vegetation structure (roughness) and function (albedo, evapotranspiration and net CO_2 flux). The development of these models requires research using, simultaneously, high resolution RS and coarse resolution RS, together with field measures of the vegetation attributes, with the objective of eventually being able to predict these vegetation attributes using only the coarse RS data and the model.

A second recommendation is for the further development of techniques evolving leaf area index, greenness, bare soil, erosion, vegetation structure and water content.

Research to develop the connection between these and ground-base data proceeds (NASA and WG1) and is required for a predictive understanding and monitoring of atmospheric change on ecosystems.

2.4 Manipulative Experimentation

Proposals involving experimental manipulations of the environment require an hierarchical suite of methods ranging from controlled-environment, short-term, small-scale studies to long-term field studies with much less experimental control over the environment. Thus, ideally, a phytotron, portable field controlled-environment "greenhouses", portable field open-topped fumigation chambers, very large-scale (>1000 m^2) fixed-position freely-ventilated greenhouses, and free-air CO_2 enrichment systems, should all be used in coupled experiments across scales.

2.4.1 Controlled Environment Research

All priority research projects require controlled environmental studies at appropriate levels. At least four levels of study are needed.

- Artificial controlled environments in phytotrons, using microcosms transferred from the field, as well as traditional synthetic media studies. Separate control of soil and atmospheric environments is needed to monitor small-scale processes in the soil-plant-atmosphere continuum. Few such facilities are available and they require renovation to serve the needs of IGBP research

- Open-top chamber studies enclosing 5-10 m^2 communities with accurate control of atmospheric composition (CO_2, other trace gases). These are most suited to uniform low stature communities.

- Mesocosm studies, enclosing of the order of 1000 m^2 communities, capable of handling complex, tall vegetation types. These enclosures can be trenched and are especially suited to studies embracing normal rooting systems and below-ground process observation.

- Open systems designed to release CO_2 and trace gases throughout unenclosed plant communities. The level of control attainable is lower, and the technology more expensive than for the above methods.

2.4.2 Field Transplant and Manipulative Experiments

Based on selected species of interest and a range of landscapes which differ in key abiotic variables, communities should be established and maintained so as to assess biotic and abiotic interactions

The experiments should include mesocosm-level manipulations of CO_2 (control vs. elevated CO_2 levels), water (+ and -) and soil temperature (soil heating).

Effects would be assessed in terms of population parameters of survival, growth, reproductive output and recruitment. Wherever possible, provision should be made for evaluation of controlled, second-order effects such as herbivory and fire. Experimental design will address a priori hypothesis about interactions, and individual experiments should not attempt to address all the interactions.

2.4.3 Development of Integrative Measurement Technologies.

Large sectors of experimental research for climatic change are technology limited. There is a need for technology for assessing ecosystem function above and below ground, on scales relevant to, and by techniques compatible with, remote sensing and global modelling.

Examples include microwave back-scattering for estimates of vegetation water status and vegetation structure (Harbinson and Woodward, 1987) and IR or fluorescence scanning methods for evaluation of canopy photosynthetic activity, stable isotope techniques (Ehleringer and Osmond, 1989) for evaluation of large scale CO_2, H_2O and trace-gas fluxes (Figure II.1), biomass partitioning and food-web flux. In addition, novel approaches to environmental control itself, at appropriate scales are needed.

Each of the priority experimental programmes have a suite of common problems which need to be addressed.

- Phytotron and field research must be coordinated with monitoring programmes in selected field sites.

- Ecosystem, population, and organism perspectives must be maintained in design and measurement.

- Adequacy of replication, which always becomes a consideration in biological research with expensive facilities must be accommodated.

- Experiments need to be scaled according to species composition, size and objective, and duration.

2.5 Non-Manipulative Research for Predicting Biotic Change

Non-manipulative research has an important role in investigating vegetation dynamics and distribution for global change research. The Workshop focused on three topics: Classification of Plant Functional Types; Statistical Models to predict the current environmental niches of biomes, growth forms and species; and correlative and mechanistic models of the potential environmental niche of the same spectrum of functional types.

2.5.1 Classification of Plant Functional Types

Correlative statistical models of the environmental niche provide a prediction of "taxa" likely to occupy a region with a changed climate. Vegetation types at three levels of organisation will probably be required; biomes, formations and communities. Functional types will need similar levels, e.g., life forms which may influence climatic feedback variables such as surface roughness, albedo, functional types based on physiological responses to nutrients, CO_2 and climate variables and species. These "taxa" will provide the biological level of resolution for modelling activity.

Research on functional categories of plants should adopt a continent-based approach and should focus specifically on key "taxa" (biomes; tundra, boreal forest, savanna), life-forms (grasses, shrubs, trees), functional types (C3, C4, and CAM plants) species. In addition, it should involve development of data bases for climatic change and predictive modelling studies with a common minimum data set of attributes and location-specific plot data. Finally, it should establish international collaboration for testing the continent-based classifications for modelling climate change.

2.5.2 Statistical Models

Predictive models based on statistical correlations have three advantages: i) they provide a first approximation to predicting possible vegetation changes. ii) they provide an initial test for any process model; iii) they provide a measure of the relative importance of different environmental variables in predicting distributions and their likely importance in process models.

Global Change Report No. 5 discusses their disadvantages, in particular their assumption of equilibrium and failure to define the fundamental (potential) environmental niche. There is a need to test existing correlative models of vegetation distribution, particularly those for biomes; e.g., those of Holdridge (1947) (Leith, 1974; Box, 1981), and determine if they can be improved with newer, statistical methods (Bartlein et al 1986; Austin et al. 1984; Margules et al. 1987)

Recommendations for a research project are:

1. Test existing models of vegetation distribution at biome level, e.g., Box (1981) with the database developed from classification of plant types.

2. Test similar models for life-forms, ecosystems processes and species depending on the "taxa" selected for importance to climate change studies.

3. On the basis of (1) and (2) develop new models incorporating improved statistical techniques, better data and improved independent (environmental) variable estimation, including indices that reflect processes (e.g., evapotranspiration) rather than mean annual rainfall, etc.

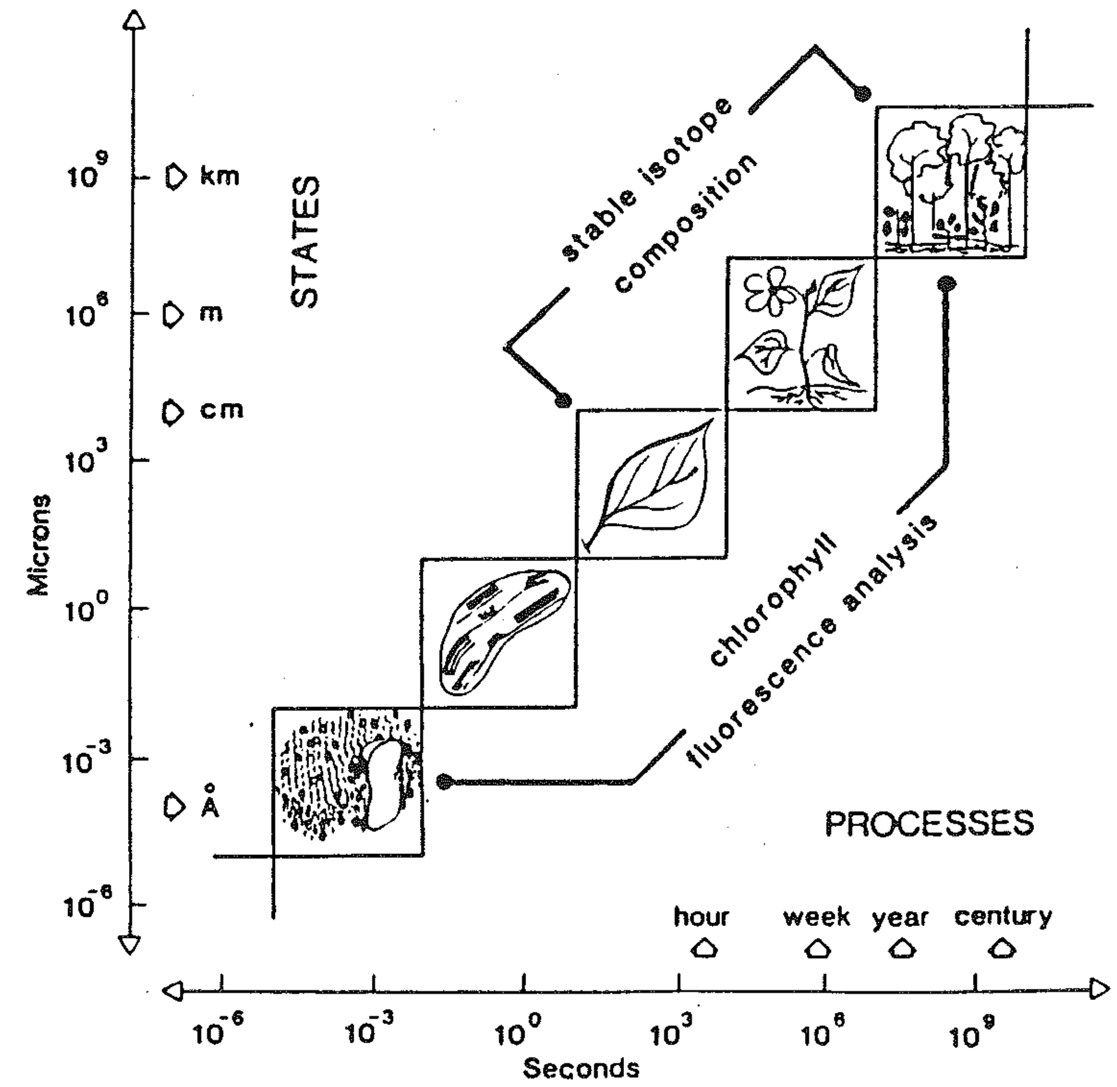


Figure II.1. The scaling of plant states and processes and illustration of the way small scale methods may be used to evaluate large scale processes.

4. These projects should be developed on a continent basis with selection of key biomes and species, reflecting relevant variables for that continent.

5. Establish international collaboration for testing predictive models developed for single continents in a global context.

2.5.3 Mechanistic/Correlative Models of the Potential Environmental Niche.

The projects outlined above provide a context for developing research on the mechanistic base of the "potential niche". Defining the potential niche of a biotic "taxon" is a fundamental issue in ecology and no generally accepted methodology exists (see discussion in Global Change Report No. 5 on the minimum sufficient model and the need for keeping complexity to a minimum).

This workshop identified the need for an integrated project using a mechanistic modelling approach. Non-modelling research in this area is closely related to theoretical studies in plant community ecology, where attempts are being made to define the potential niche and how this is modified to produce the realized niche of species; e.g., Grime, 1979; Tilman, 1988; Gaudet and Keddy, 1988; Austin, 1987.

Recommendation: In order to increase the value of vegetation dynamic models to GCMs and the effects of global change on terrestrial ecosystems, there is a need for:

1. Development of physiologically-based models which can be tested by means of statistical correlative models of present vegetation structure and function (e.g., E/T) (Section 1).

2. Experimental tests of the predictions, hypotheses and models.

3. OTHER ISSUES IMPORTANT TO IGBP EMPIRICAL RESEARCH EFFORTS

During the course of the CP4 workshops a number of issues were raised which did not get specifically nominated as research requirements. In order to ensure that these issues are not overlooked they were reintroduced by the CP4 members during this workshop. The following topics span the range of concerns.

3.1 A Better Map of the World

A map of cover of the world is needed as base-line data. The Map must link to IGBP work on Land Cover and Land Use. Map parameters must be determined in cooperation with scientists across disciplines.

3.2 Mass Transport Across a Changing Planet

Changes in removal, transport and deposition of substances across the earth 's surface are guaranteed by changes in climate, land use and atmospheric composition, as noted in earlier IGBP documents (Report No. 5), the Woods Hole Report and the IGBP Report 10). The critical question for IGBP planning concerns which of these aspects are worth attention as a serious change in biogeochemical cycles, and would require attention as a critical global issue.

Many aspects of mass transport are intrinsically involved in a number of IGBP projects and these will certainly be addressed in some manner, e.g., air and water vapour in climate modelling, water vapour, liquid and solid water in hydrology projects, trace-gas efflux and deposition, etc.

However, other aspects of transport may be overlooked because they do not fit into particular modelling programmes. For

example, the CP4 Woods Hole Report has a significant section devoted to landscape-scale research, much of which involves influence of one portion of the landscape on the other through the transport of material. Examples are the runoff-runon relationships found in many landscapes, and the influences of landscape patterning on animal activities and the dispersal and migration of species across landscapes.

Other aspects of mass transport (discussed in the IGBP Report 10) include the movement of critical resources through commercial means. Particular examples were the movement of chemical wastes, radionuclides and agrotoxins by combinations of commercial and natural transport systems to concentrated zones where they might be of critical environmental importance. Another was the extensive transfer of foodstuffs from large land areas such as South America and Africa to small areas such as northwestern Europe where they are used as feed to produce animal proteins. Not only does this represent a significant loss of limiting nutrients from the original source areas of the foodstuffs, but a serious pollution problem in the areas of conversion. These examples are relatively easily documented from economic data and could conceivably be incorporated in a research programme involving the social sciences.

In summary, it appears likely that mass transport of gases and water in the atmosphere will probably be taken care of by combined programmes resulting from joint CP1, CP3 and CP4 interests. Less clear is whether or how mass transport at the landscape level will be incorporated. A research programme on erosion and deposition at continental scales seems eminently appropriate for an international, global-scale effort.

3.3 Monitoring

A strategy for the development of an integrated monitoring system must be developed, which will incorporate the ability to observe changes to properties associated with energy and water fluxes from the earth surface, changes in biotic characteristics, and changes in the biogeochemical fluxes in gaseous, aquatic and soil-related forms. The documentation of changes in these parameters will provide the necessary framework for measuring the scope of global changes which are occurring in various regions of the globe and to aid in the development of the necessary understanding of how the earth system functions.

The information gathered through an integrated monitoring system will allow scientists to document global changes, serve as test sites for remote-sensing interpretation, test hypotheses relative to the basic understanding of interactive processes of the earth system, and to provide a data base for implementation into models developed for global change studies.

Criteria for such a monitoring system include that the system is practical, results be intercomparable, and a long-term commitment to the upkeep of the system be in place. Selection of monitoring sites and measurement parameters will depend upon the nature of questions being asked. Global change monitoring includes observations of areas where change in ecosystem structure may be particularly sensitive to changes in the environment. Equally important is the monitoring of ecosystems for changes in rates of critical ecosystem processes.

Although it is not strictly a research problem, the workshop considers that monitoring is a very high priority indeed. Two strong recommendations about how monitoring programmes should be instituted:

1. A monitoring network must have broad spatial coverage, e.g., for land areas the size of Australia or USA, several hundred locations. Correspondingly, it will be necessary to limit monitoring to a few simple measurements, not necessarily taken every year. For example, for vegetation change, a simple photo-point, at a location which could be registered on remote-sensed evidence with confidence, backed by a visit by a site validation, species list and seedlings count every 5-10 yr. Remotely sensed data would be taken frequently and used for numerous purposes.

2. The use of stable soil organic matter or other slow decay standards is recommended to provide a means of monitoring microbial responses to changes in soil microclimate, both for model validation and as a sensitive means of measuring the impact of climate change on soils, which may not be detectable in ecosystem studies because of high spatial variation.

It is recommended that monitoring programmes should start from existing bases. They should be designed to monitor change in relation to some initial state and they must include new data requirements such as CO_2 concentration.

3.4 Research on Variance and Seasonality

Change in the seasonality of climatic variables may be expected to have a controlling effect on many ecosystem processes, for instance in changing distributions of C3/C4 plants. Seasonality observations on indicator species would provide information which is important for a basic understanding and prediction of global change, and may provide input for monitoring.

Identification of dynamically changing areas and species in relation to climate change is a first priority. Monitoring and research in these areas will necessitate monthly records (collected simultaneously with meteorological data). In regard to plants, a number of growth characteristics are important, including shoot growth, inflorescence growth (together with fruit and seed production), stem expansion, rootlet growth, litter fall and decomposition rate, and germination rates.

Seasonality observations on indicator vertebrate species would include comparable types of information. Monthly records must be collected simultaneously with meteorological data, and would include aspects of reproductive phenology (breeding season, mating, etc.), adult phenology (energy storage, moulting, hibernation/aestivation, migration), and food/shelter (which for vertebrates is plant related).

LITERATURE CITED

Ackerman, S.A. 1989. Using the radiative temperature difference at 3.7 and 11 um to track dust outbreaks. Remote Sens. Environ. 27:129-133.

Austin, M.P., Cunningham, R.B. and Fleming, P.M. 1984. New approaches to direct gradient analysis using environmental scalors and statistical curve-fitting procedures. Vegetatio 55: 11-27.

Austin, M.P. 1987. Models for analysis of species' response to environmental gradients. Vegetatio 69: 35-45.

Bartlein, P.J., Prentice, I.C. and Webb III,.T. 1986. Climatic response surfaces from pollen data for some eastern North American taxa. J. Biogeog. 13: 35-37.

Box, E.O. 1981. Macroclimate and plant forms: an introduction to predictive modelling in phytogeography. Tasks in Vegetation Science 1 ed. by H. Lieth, (The Hague, Junk).

Drake, B.G., Rogers, H.M. and Allen, L.H. 1985. Methods of exposing plants to elevated CO_2. In Strain, B.R., Cure, J.D. Direct effects of increasing CO_2 on vegetation. pp 11-31. DOE/ERO238, Washington DC.

Ehleringer, J.R. and Osmond, C.B. 1989. Stable isotopes. In R.W. Pearey, J. Ehleringer, H.A. Mooney and P.W. Rundel (eds). Physiological Plant Ecology: Field methods and instrumentation. pp 281-300, Chapman and Hall, London.

Gaudet, C.L. and Keddy, P.A. 1988. A comparative approach to predicting competitive ability from plant traits. Nature 334, No 6179, pp 242-243.

Grime, J.P. 1979. Plant strategies and vegetation processes. J. Wiley & Sons. Chichester.

Harbinson, J. and Woodward, F.I. 1987. The use of microwaves to monitor the freezing and thawing of water in plants. J. Expt. Bot. 38: 1325-1335.

Holdridge, L.R. 1947. Determination of world plant formations from simple climatic data. Science. N.Y. 105: 367.

Leith, H. 1974. Phenology and seasonality modelling. Sprinter-Verlag, 444 pp.

Margules, C.R., Nicholls, A.O. and Austin, M.P. 1987. Diversity of Eucalyptus species predicted by a multi-variable environmental gradient. Oecologia 71: 229-232.

Matthews, E. 1983. Global vegetation and land-use: New high resolution data bases for climate studies. J. Climate and Applied Meteorology 22: 474-487.

Morales, C. (ed.). 1979. Saharan dust. Wiley & Sons, Chichester. 297 p. Pewe, T.L. (ed.). 1981. Desert dust: origin, characteristics, and effect on man. Geological Society of America Special Paper 186.

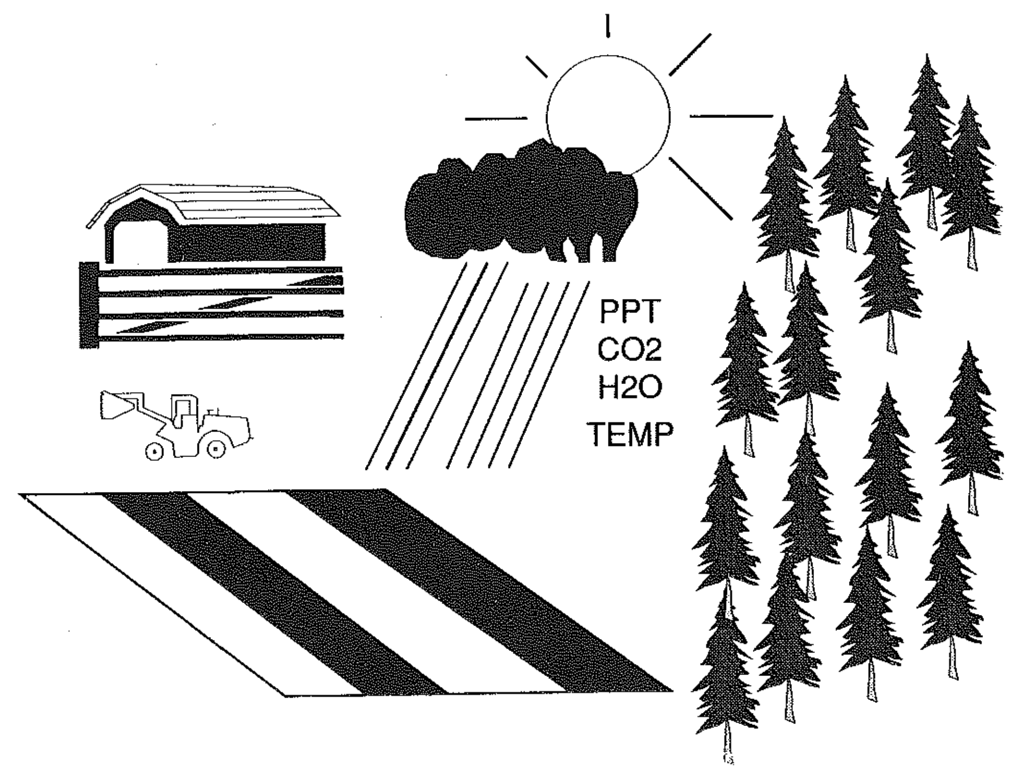
Reiners, W. A. 1983. Transport processes in the biogeochemical cycles of carbon, nitrogen, phosphorus, and sulphur, pp. 143 176. In B. Bolin and R. B. Cook (eds.) The major biogeochemical cycles and their interactions. Wiley & Sons, Chichester.

Tilman, D. 1988. Plant strategies and the structure and dynamics of plant communities. Princeton Univ. Press, Princeton.

Walker, B.H. and R.D. Graetz (compilers). 1989. Effects of atmospheric and climate change on terrestrial ecosystems. Global Change Report No. 5. International-Geosphere- Biosphere Programme, Stockholm, Sweden. 61 p.

Wasson, R.J., P.M. Fleming and R. Srikanthan. 1988. Sediment delivery and stream behaviour, with a note on wind erosion, pp. 231-237. In G. I. Pearman (ed.) Greenhouse. Planning for climate change. CSIRO. Division of Atmospheric Research. Melbourne, Australia

Woodward, F.I. 1982. Climate and Plant Distribution



III.
The Impact of Climate Change on Agriculture and Forestry

Edited by: S. J. Turner, R. T. Prinsley,
D.M. Stafford Smith, H.A. Nix, and B.H. Walker

Report of an IGBP Co-Ordinating Panel 4 Workshop
Yaoundé, Cameroon 27 November - 1 December, 1989

* Co-sponsored by the African Bioscience Network and the
Commonwealth Scientific Council

LIST OF CONTENTS

1. INTRODUCTION

1.1 Global Change Issues

Most long term agricultural and forestry land use decisions rely upon relationships derived from recent climatic data. These relationsips, however, may no longer be an appropriate guide. Many global-scale factors are changing and will probably alter regional climates over the coming decades. The effects of these changes on agroecosystems will be both direct and indirect. Despite great uncertainties in the extent and nature of regional climatic change it is highly likely that many agroecosystems will need to be managed differently. We need to know how agro-ecosystems will respond to a range of possible climate and land use changes and their interactions in order to maintain sustainable production. General Circulation Models (GCMs) need to be refined to give reliable predictions at appropriate spatial scales for agroecosystems. Meanwhile there are valuable lessons to be learned by studying the effect of recent climatic fluctuations on cropping systems and by examining the sensitivity of existing agroecosystem models to change of climate input variables. Although we can not predict exactly how climate will change, it is possible and necessary to estimate the potential consequences of various scenarios.

In addition to the physical and biological effects of climate change it is essential also to understand concurrent global changes such as those related to population growth and shifts, economics, technology development and socio-political changes. Political, economic, and social systems exert strong controls on agroecosystems. For instance, the impact of drought cannot be understood solely in the context of the effects of meteorological events on agriculture. Political, social and economic events affect the susceptibility of a region to drought-related hardship. They also result in feedbacks on biology through the inertia and preferred directions of social change. Interpretation of an agroecosystem model needs to be extended to its social implications. Sustainability, maintenance of the quality of the land and its ability to produce food and fibre, is an important goal in the management and use of agroecosystems. To achieve this it is necessary to consider the system over longer time scales than the traditional seasonal or annual time frame. Management for sustainability will require present activity to be based on future scenarios rather than on the past. Fifty years is a suitable timescale for management planning. Because technology and information flow strongly influence the potential for change in agroecosystems new developments must be explicitly considered in scenarios of the changing future and access to them by the agriculture community must be insured.

1.2 Scope

Agroecosystems of the world constitute a continuum from high-technology, intensive, commercial production to extensive, nomadic pastoral systems. For convenience in developing a research approach to investigate the impacts of global change, they have been broadly classified into four main groups - agricultural cropping, forestry, pastoral, mixed farming systems. This report is presented in several sections, first by subsystems (crop, forestry and pastoral) followed by a section on issues general to all systems including mixed farming, soils, generic model development and data sets. The final section brings together recommendations from the whole workshop.

1.3 Objectives

The overall aim of this workshop was to set the framework for developing the capacity to predict the effects of global change on agroecosystems, in terms of i) production of food and fibre, ii) their sustainability, and iii) changes in their distribution. Although it was not a primary aim, the workshop also considered, where relevant, the assessment of the feed- back effects of agroecosystem changes on further atmospheric and climate change (e.g. changes in albedo, methane production, etc.).

1.4 Uncertainty of prediction.

It is unlikely that detailed regional climate predictions will be available for some time to come, and in any case climate change is likely to be an on going, continuous process. Policy makers need predictions which indicate what ranges of outcomes are possible or likely. Thus research should not be aimed at developing precise predictions of response to particular changes at specific sites, but should rather aim at examining responses to a range of possible changes, thereby, developing an appreciation of the sensitivity of agro-ecosystems to various kinds of changes. All modelling efforts should deliberately aim to provide sensitivity analyses of their important outputs with respect to significant climatic variables. Of particular importance in this regard is consideration of changes in the nature, frequencies and sequences (or combinations) of extreme events. They are a recurring theme in all the systems being examined, and are likely to pose special problems in extrapolation into the future of models based on current conditions.

2. CULTIVATED CROPS

2.1 Introduction, Scope and Objectives

A relatively small number of crop species provide the staple food for the global human population. Disruption in production of any one of these will have serious implications for significant numbers of people. Twelve of the most important food crop species have thus far been targeted by the International Benchmark Sites Network for Agrotechnology Transfer, (IBSNAT 1989), for development of generic models of crop growth, development and yield. The minimum data sets (site, soil, weather, genotype, management) needed for development and validation of models of aroids, barley, cassava, dry bean, maize, peanut, potato, rice, sorghum, soybean, and wheat have been identified. Manuals for field data collection have been printed and are being distributed. Model development and validation must be extended to include additional food crops. These should build upon the modelling framework for crop species already

established within the IBSNAT (1989) project. The additional species include: bananas/plantains; sugar-cane; grain-legumes such as cowpea, pigeon-pea, chick-pea, pea, lentil, lupin; oil seeds such as sunflower, safflower, rapeseed, mustard seed, sesame, coconut, olive; other root crops such as sweet potatoes and yams; vegetable and fruit crops (onions, tomatoes, citrus, mangoes); as well as stimulant crops (coffee, tea, cocoa); fibre crops (cotton, kenaf, sisal) and industrial crops (rubber, oil-palm). While the IBSNAT project provides a framework for the systematic improvement of understanding of key processes and biological responses and a more quantitative basis for prediction of crop response to varying site, season, genotype and management variables, much further development is necessary. At their current stage of development, the IBSNAT models do not incorporate or do not adequately represent key processes that are important for global change studies. In particular, the models must be expanded to include plant development and competition, nutrient, soil and water dynamics, and the impact of extreme events. Most importantly there is a need to incorporate modules for pest and pathogen attack, modules that simulate long-term processes in the soil that play a vital role in sustainability, and last, experimental field-scale testing and model validation of the direct effects of enhanced CO_2 on growth, development and yield. The workshop also concluded that there is a need to include with the targeted species, the culture of aquatic organisms (molluscs, crustaceans, fish) which are a significant source of protein in some Asian Pacific countries. Land-based, inshore and near-shore facilities depend on water quality for efficient production. An aquaculture module at the single management parcel/farm level and at catchment scale should be developed for agroecosystems models. Some of the outputs from the terrestrial agroecosystem modules would be input to the aquaculture modules.

2.2 Key Issues

The major issues that require research can be grouped into:

i. Direct effects of individual climate variables and their interactions on plant response. This includes the effects of changes in temperature, humidity, CO_2 concentration, solar radiation and soil moisture regimes on growth and yield of crops. Predicting this will require an understanding of the effects on carbon allocation in plants and on plant development and flowering.

ii. Sustainability of the land; changes in soil erosion and degradation and in environmental quality. This includes short and long term nutrient and organic matter cycling, soil erosion and leaching and the build up of chemicals in soils (see also 5.2). These changes may be the direct result of changes in climate or indirectly due to the changes in management performed in response to changes in climate and population pressures, (e.g., area of arable land). Changes in climate could also lead to changes in the production and transport of agricultural residuals into natural systems, streams, ground water, and the atmosphere.

iii. Pests and pathogens. Small changes in temperature or other climate variables may dramatically change the timing, severity and types of diseases on crops. Such changes could drastically change the management requirements for producing, harvesting, and storing agricultural commodities. See also section 5.3.

iv. Management responses. Shifts in agricultural production regions, changes in management practices in a given region, and changes in agricultural infrastructures are all likely consequences of successful adaption to climate changes. Developing these responses will require a knowledge of how changes in climate would create changes in the distribution, availability and demand for water, nutrients, energy, and other resources, both in space and time.

v. Data and modelling. Development of a minimum data set for the major crops and cropping regions of the world, in order to develop and apply the sorts of models described in Section 1, (IGBP Report 11), is a major limitation. See section 5.5.

2.3 Core Activities

Global change in agriculture will have diverse effects in many different farming systems and environmental situations. The number of possible scenarios, dynamic effects and management responses will vary accordingly. To best accommodate the diverse nature of impacts and responses, generic models that can incorporate these alternatives should be used (see also 5.4). The nature, intensity and location of these changes should be monitored (Section 5.6) so that actions can be taken and appropriate adjustment of the generic models can be made. Actions recommended by this workshop, directly related to the impact of global change on crops are:

1. *Develop an understanding of the environmental and genetic control of plant development.*

It is necessary to understand the environmental and genetic controls of autogenic development in order to determine the primary impact of climate change. The impact of climatic conditions on a crop depends upon the life stage of the plant under consideration. The required research will include controlled environment experiments under growth chamber conditions, as well as manipulative field experiments. The research needs to be closely integrated with a model of plant development.

2. *Develop an understanding of the direct effects of elevated CO_2 on crop yield and water use efficiency, and of the interactive effect of CO_2 with climate change.*

Change in the atmospheric concentration of CO_2 may have consequences on the partitioning biomass to or away from harvestable products. It is critical that this process be understood for each of the targeted crops. Equally important is an understanding of the interaction of CO_2, water use efficiency and the response of plants to stress.

3. *Develop an understanding of the effects of climate change on crop species.*

The effects of climate change include the single and combined effects of changes in temperature, precipitation, soil moisture regimes and solar radiation on the critical crop species (2.1). A survey of species production at their biophysical limits for each of these abiotic parameters must be conducted to provide information about which changes might be expected and to provide input for models of the system and management options.

4. *Development and validation of a generic, modular agroecosystem model for cultivated crops.*

As a top priority, the working group on agricultural systems recommends the development and validation of a generic, modular agroecosystem model. See section 5.4 for a complete discussion. The crop system modules would include models such as those describing the dynamic behaviour of soil water, nutrients, soil properties, and soil biota. These must have the capacity to predict the behaviour of those processes which affect immediate performance of the crop as well as those which will affect the system as a whole. Those factors which affect the processes vary through space as well as time and so the truly generic models must have the capacity to capture spatial variation.

The plant growth modules must include the capability to predict development, biomass, growth and partitioning of photosynthate to harvestable products in response to soil variables, climate and biological environment. Climate modules will provide descriptions of the thermal, moisture, radiation and chemical components of the environment, over time and space, which affect processes in the soil-plant-atmosphere continuum. The specific IBSNAT model described as an example in section 5 provides a framework for further model development and research.

Since this core activity involves the development of new tools and technology, a substantial requirement exists for the training of a new cadre of scientists. This training will include concepts for data generation, the systems approach, and interpretation of model simulation and data over time and space. See also section 5.4.

5. *Development of methods for characterising the effects of global change on systems for harvest, post-harvest, handling and storage of agricultural products.*

Global change is likely to impact strongly on the harvest, post-harvest, handling and storage components of agroecosystems. Post-harvest losses are currently large and may increase further under many global change scenarios. In addition, practices such as storage may assume greater importance where global change imposes additional pressure or variability on agroecosystems.

The issues are complex and many interactions are likely between post-harvest activities and other components of agroecosystems. Hence, model development and systems analysis will also be a major feature of this project. The models needed will have many inputs in common with the agroecosystem models described in 5.4, with climate being the most obvious and relevant to global change. The outputs of those models will also be inputs to the post harvest models. Development of models of post harvest losses to pests and pathogens and their management will be a major activity and many gaps in the knowledge base are likely to be identified.

This activity should interface with the activity described in 6 (below), in the identification of appropriate post-harvest management and policy strategies to mitigate the effects of global change.

6. *Development of minimum data sets.*

Vital to crop studies is the development of data sets. Detailed data sets are necessary for process studies and understanding and validation of models of the effects of global change on crops. Because this topic is common to all agroecosystems it will be discussed in section 5.5.

7. *Identify Appropriate Responses to Global Change*

There is need to consider the potential responses to global change. Already, examples are available that can serve as models of what to consider within the temporal frame work of the core activities. Such appropriate responses include the following;

- Breeding/selection of suitable varieties, cultivars or animals for the changed environmental conditions
- Management strategies
- Policy changes
- Infrastructure adjustments

2.4 Implementation

The information and activities identified by this workshop as important for understanding the effects of global change will require a variety of research approaches including observation, experimentation, modelling and monitoring. Significant research on autogenic development and the simple and interactive effects of elevated CO_2 on crop yield is necessary to develop basic understanding. Without these process studies the further development and validation of crop models specifically for climate change studies is not possible.

From an examination of a list of crops (2.1), it is clear that crop model efforts, particularly IBSNAT, have covered less than half the important crop products. The other crops have received relatively less attention from modellers. Identification of the additional crops to be modelled must be agreed upon and the necessary information for modelling must be obtained. A workshop should bring together scientists with capabilities for developing a generic model of specific crops that have not yet been modelled.

Development of methods for characterisation and prediction of global change effects on systems for harvest and post harvest handling, storage and processing of agricultural products is necessary. The agricultural community must increase its awareness of global change effects on post-harvest technologies. This could include diffusion of information to the concerned institutions through simple, informative leaflets and publications that illustrate global change consequences. Scientists working in the area of post-harvest technologies should be encouraged to collaborate in generic model development (5.4).

Identification of appropriate management responses to global change must be part of the goals of an IGBP Project on agriculture. The implementation of the above core activities will result in the production of valuable information that could carry important implication for breeding/selection of species, management, policy decisions, planning and the development of infrastructures to cope with the consequences of global change. Dissemination of this information to the appropriate national, regional and international agencies should be carried out through simple, informative leaflets, articles and reports. This information should also be included in system models (Section 5.4).

3. FORESTRY

3.1 Introduction, Objectives and Approach

The effects of global change on forestry and the actions that can be made in response to (or in anticipation of) these effects vary geographically and according to the particular forest system. In the case of sustained plantation/rotation systems, the stand yield tables that are the core of the projections used to manage forest harvests will probably not be valid in an altered climate. The northern boreal forests (which contain much of the world's reserve of softwood) are in a zone predicted by GCM's to sustain a major warming. The temperate forests, which include most of the present timber industry, are also likely to undergo marked changes. This could cause the supply of softwood on world markets to vary widely. Mills and paper factories may be non-optimally located with respect to climatically displaced forest production areas (increasing the transportation costs). New genotypes, or in some instances, species may be needed to continue forestry in many regions and the methods that will be used to assess the planting and harvest strategies that attend these new trees must be developed rapidly.

The following section identifies key issues in relation to climate change across a variety of forest types. The impact of those changes and the management response will differ between forest types, management philosophies and geographic location. Thus it is necessary to observe, conduct experiments, model processes and landscape dynamics, and monitor a number of forest types around the world. An approach is proposed which focuses on the forest systems which are particularly important economically and which may be particularly susceptible to change resulting from climate shifts. Similar investigations would take place in each of these forest systems. Consistancy in the research and modelling approach must be assured.

The proposed systems are:

- Temperate and boreal forest systems (which contain much of the world's softwood supply, in both native forests and plantations);

- Sub-humid forests and marginal timber producing regions; and

- Tropical forests

The research area that is outlined below is focused strongly on the application of computer models to predict the response of production forests to global change. The diverse nature of forests and the long rotation periods that attend tree crops (when compared to other crop systems) makes a modelling approach a logical tool in predicting forest response while the basic data on forest response are being developed. In this sense, the basic research we outline is intended to augment, not replace, traditional forestry research practice regarding the determination of growth and yield. This approach also mitigates one of the major restrictions of field plot studies. Models allow the development of a predictive understanding of the impact of climate change. The requisite data sets for this project have a considerable common overlap with the crop models discussed above.

3.2 Key Issues

There are five key issues addressed in this section which relate to forestry and global change. Each incorporates many details which both explain individual issues and integrate the issues together. In addition the issue of data needs is implicit in all other issues and will be discussed with individual activities and in section 5.5.

i. The variable response of different forests to CO_2 and climate change

Incorporated into the concept of world forestry as a production system are a large number of different types of forests each of which will respond in a unique manner to climate change. This implies, for instance, that a response to CO_2 enrichment or temperature increase will be different in a Pinus forest plantation than in a Robinia plantation. This variability of response will be an important consideration in discussion of all other issues.

We must determine how a forest will change in situ, how forest boundaries will move, what shifts in pattern and process may occur, and what will be the changes in life form? These problems are discussed below, but the issue of differential impact on these parameters in different forests may not be easily generalized. For instance simulation model experiments with doubled CO_2 concentration show an increase of 20 - 30% for pine forests in Montana, but, Florida pine forests decrease 5 - 10% with the same treatment (S. Running personal communication).

ii. Transition in forest land use systems and land degradation

Current scenarios of a greenhouse gas enriched atmosphere imply that a major change in forest land use systems may be necessary (Bolin et al 1986), either because the land will no longer be suitable for the traditional crop or because other effects of climate change alter man's need

for the land. These transitions may result in deforestation, a shift in cultivation practices, and degradation of the land surface. Impacts include erosion, soil fertility degradation and hydrologic instability caused for instance, by compaction and laterization, or Fe and Al toxicity.

iii. Disruption of forest system biology

Disruption of the forest system biology will result from any significant climate change. Forest pests and diseases and their controls may change such that areas previously unaffected by pests may be seriously impacted by outbreaks because of the effect of climate change on their life cycles (See also 5.3). The life cycles of bird, bat and insect pollinators are likely to be affected. These components are completely missing from current models but will have a major impact.

Regeneration processes of trees are often most climate sensitive. In commercial forests this could increase the cost of site preparation and regeneration techniques. In other regions an amelioration of these costs may occur.

In addition we know from observation of forest ecosystems responding to climate that all biologically mediated components of the carbon and nutrient cycles will be changed. Primary production will be altered. Competition among forest species may be different. Species habitat ranges may be altered so that their ecological or economic boundaries may shift. These are the focus of current models which must be adapted to climate change studies (See 5.4).

iv. Extreme Events

The frequencies, sequences and distribution in time and space of extreme events such as large storms and fires are likely to change, and may become increasingly unpredictable, with climate change (Wigley 1985, Warrick, Gifford and Parry 1986). Given the long cycle times of forest ecosystems extreme events are of particular importance. Understanding of the systems response to this variation is critical to management in a changing environment.

v. Air Pollution

Air pollution is a global change which is having a direct effect upon forest systems by alteration of stomatal function and soil chemistry. In addition air pollution may interact with climate change in ways which are currently not understood.

3.3 Core Activities

The problems outlined above may be understood through investigations at 3 levels within the forest system. Activities at a physiological/species level are necessary building blocks to understanding the impact at the landscape and global scale forest systems. All three are necessary for management.

1. *Develop a predictive understanding of the functioning of forest stands.*

Understand the primary effects of climate change on forest stands is undoubtedly an important requirement. They are, however, not the only important effects. In some forest ecosystems competition effects may override more direct effects of climate change on forest productivity. Where this is so, inter-plant competition for available water, nutrients and radiation will be important considerations. Predicting the consequences of climate change (including effects on nutrient availability) for leaf area production and retention is particularly important because of feedbacks on both water balance and carbon accumulation. Factors controlling assimilate allocation and litter fall (of leaf and root especially) in relation to nutrition and water status are poorly understood for forests, largely because of difficulties in acquiring long-term, quality biomass data necessary for sub-model development and validation. Experimentation is required specifically geared to develop and test mechanistic models of these processes.

The first priority identified for managed forests was the development of generic ecosystem models of the functioning of forest stands. The role of these models is to improve our predictive understanding of the impacts of climate change. The models will describe responses to forest management practices such as thinning, fertilisation and irrigation. These models will need to be flexible tools, readily transferable to new sites or species and able to predict productivity in terms of a variety of wood products (e.g., fibre, sawn timber, wood fuel, etc.) derived from either plantations or managed native forests/woodlands. A variety of models will be required to answer questions about the effects of climate change on forest composition and function at various temporal and spatial scales. Existing models of carbon balance and of nutrient-water-carbon interactions will need further development. See also 5.4 where the model requirements and integration among various models are described.

Models will need to realistically represent linkages between key processes and climate change (including respiration, photosynthesis, canopy conductance, water use efficiency, phenology, whole-tree mortality, net mineralisation, stabilization of soil organic matter). Formulation of models should be consistent with state-of-the-art theory on these linkages (5.4).

Although the initial focus will be on the development of generic stand growth models, impacts of climate change related to pests (and their controls), disease, (5.3) pollinators, interference from biological invaders, consequences of extreme events (fire, storm, frost, erosion, others?) and air pollutants will be incorporated at a later stage. Retaining the generic nature of models when such non-generic features as attack by pests with complicated life-cycle is one of the more challenging aspects of applying these models. Integration with the crop investigations is necessary.

Particular Experiments:

There has been much speculation about which forests will benefit from the so-called "CO_2 fertilisation effect". There is considerable uncertainty about the likely magnitude of changes in photosynthetic rates and crop conductance, especially for canopies of mature trees, whether changes will endure as plants acclimate to increased CO_2 and the extent to which

increases will be moderated by nutrient limitations (Shugart et al. 1986). (Little is known about the long-term response of mature trees to elevated CO_2). One or more CO_2 manipulation experiments should be conducted for mature forest stands, under conditions limited by water and nutrients, and neither.

The interpretation of these experiments will be more straightforward for carefully controlled field experiments than for natural ecosystems. These experiments should be conducted in regions with reliable infra-structure and local scientific expertise.

Validation of canopy CO_2 and water exchange sub-models should be conducted using eddy correlation or alternative technologies. This would provide a direct test of instantaneous model performance, which is more powerful than less direct methods testing simulations of annual, for instance, biomass development.

Data Requirements

The models will be used to define standardised minimum data sets required for characterising sites (e.g., meteorology, topography, soil). These minimum data sets are necessary for extrapolation of results from experimentation on plantations or managed native forests. See also 5.5.

2. *Gain an understanding of landscape/regional level processes*

Forest systems theory relies excessively on equilibrium concepts that suggest a landscape with fixed spatial arrangement of potential uses. Global change will severely test our abilities to predict the shifting mix of land use potentials. For this purpose a core activity developing landscape level principles is proposed.

Although the mechanistic physiological models (Core Activity 1) provide the best predictive capacity for future forest responses to global change, they are effectively 1-dimensional, and require more information than is possible in land management. Consequently, landscape models are required that simplify the 1-D models, and most importantly provides explicit spatial representation of the land (3-D). If time is added as a variable, four dimensions can be considered. This scale is most useful for land management decision making. It is imperative for the study of mixed agroecosystems (section 5.1).

Specifications for Landscape Models

Landscape models must be developed that are sufficiently generic to be applicable in various environmental, forestry and agroforestry systems. They must:

i. Have explicit representation of key variables and spatial resource flows.

ii. Be applicable or adaptable to agroforestry mosaic of land use. To do this we need to improve the basic understanding of patch dynamics and improve our basic understanding of the importance of variability in the system, as well as the interactions between system components.

iii. Have outputs which:

a) provide a predictive understanding of how landscape structure will change. This will necessitate input from the physiological models as drivers

b) provide information about maximum achievable production and optimization of land use; and

c) are consistent with stand models.

Primary to all of this is making a translation from biophysical models to landscape and production models. Input from biophysical model must be in units which are compatible with landscape models. Outputs must be expressed in units which are meaningful to global models and to production forest managers. See also 5.4

Data Requirements

At the landscape level, the required data include the output information from the stand level models. In addition empirical data are required. Land cover information will be needed to set initial conditions for the models and for validation. Soil data, meteorologic data, and the distributions of key variables such as LAI will also be model input. In addition an automated inventory of techniques for measuring forest production must be developed. Currently labour intensive techniques are used exclusively and as a result few areas of the world are measured adequately. See also section 5.5.

3. *Global Scale Activities*

Although forest management decisions are made at the scale of land ownership, i.e., 10ha to 100,000ha, some forestry issues must be confronted at continental to global scales. A first priority must be to develop an accurate, repeatable inventory of the extent and productivity rates of global forests. This may be accomplished by:

i. Standardizing a field inventory data format and organizing a system to generate a global digital forest database.

ii. Use the global database in conjunction with global satellite coverage to identify the commercially productive forests of the world.

iii. The satellite data could then be used to implement a regular global monitoring of forest land. This becomes particularly valuable for direct monitoring of forest land losses to land cover conversion by human activity, i.e., tropical deforestation.

Such a satellite inventory would allow direct monitoring (section 5.6) of shifts in forest boundaries as global climatic changes progress. It will be very important to follow the encroachment of the boreal forest into the arctic tundra, the retreat of the dry tropical savannah forest into grasslands and other major shifts in global coverage of forests. Satellites can provide a routine repeatable method to do this, but must be "calibrated" by ground data.

3.4 Implementation

The implementation of forest system activities must proceed at several levels simultaneously. The workshop suggests a timetable for stand level activities.

i. IGBP should ask each National Committee to advise on their nation's critical forest resources (plantation and managed natural forests) and major foreseen local issues relating to climate change (e.g., for Australia, concern may be whether existing Pinus radiata plantations will no longer be within the species' temperature niche). IGBP should then identify its global priorities for experimentation and model development in relation to national/regional priorities and availability of scientific resources and expertise. See also section 5.

ii. Good communication is essential between groups developing process-models of forest growth. Various relevant programs are underway:

- SCOPE Project on Impact of Climate Change on Production and Decomposition of Coniferous Forests

- Proposed Workshop on Carbon Balance Modelling of Pine Ecosystems, Florida June 1990

- Proposed workshop on Closed carbon-nutrient-water models for forests (Fort Collins, June 1990)

- European co-operation on modelling of impact of climate change on forests - Uppsala/Edinburgh/Wageningen/ Finland (commencing mid-1990)

- IUFRO Solar energy conversion of forests project has identified 20 or 30 relevant existing intensively monitored experiments from all parts of globe (co-ordinated by Bob Luxmoore, Oak Ridge)

- Commonwealth Science Council (CSC) programme on Amelioration of Soil by Trees, looking at the effects of trees on soil processes in agroforestry and reclamation forestry in developing countries of Africa and the South Pacific

- Recommendations from the SCOPE workshop (above) will be especially pertanent to this core activity.

In late 1990/early 1991 IGBP should conduct a workshop where individual forests modellers are asked to describe their progress towards generic ecosystem models, with working sessions on comparison of model behaviour. Where models disagree, it may be appropriate to focus research effort. Comparison of simulations of various models might clarify the relative strengths of key assumptions and linkages between processes. At this meeting, an experimental program should be defined to develop better allocation/litter fall models and to prescribe other priority experimentation.

Minimum data sets should be established. Contributors should be encouraged to converge on similar (modular) model structures, and perhaps exchange sub-models.

iii. Communication with modellers of other terrestrial ecosystems (crop, rangelands and natural ecosystems) is invaluable. Mid-1990: conduct workshop bringing together authors of key generic models for various ecosystem types.

iv. Late 1991: Once we have converged on minimum data sets, standard formats for experimentation should be prepared for distribution. IGBP should then encourage particular National Committees to take on specific priority experiments.

v. 1992: Start experiments.

Implementation of landscape level activities (activity 2) depends upon information from the stand level activities and other data bases. Landscape level investigations will require a global forest inventory database, and satellite coverage. Coordinated data bases of key variables (species mix, soils, nutrition climate, LAI) will be needed. This might be accomplished in coordination with the International Union of Forest Research Organizations (IUFRO). Development of the required list of key variables must proceed in conjunction with the stand level key variable list, above. Soil data sets are a goal of a natural systems core project (CP3) and this project should work with that group in developing the data set. Feed backs from the landscape level to stand level processes require explicit cooperation between investigations at the two levels at all stages of model development.

Implementation of global scale activities (activity 3) requires development of satellite based observation and data from both smaller scale activities (1 and 2). By the late- 1990s, capabilities of both the sensors and data system of the US NASA Earth Observing System should allow a satellite driven simulation of forest productivity at continental scales. As currently envisioned, daily overpasses of the satellite will be composited weekly to produce continental maps of forestation. This is similar to the current AVHRR Normalized Difference Vegetation Index, but future sensors will be at 500m spatial resolution and have greater spectral detail. By incorporating surface temperature data from other channels of the satellite sensor, periods of freezing or water stresses can be removed from the time integral, dramatically improving the generality and accuracy of the simulation.

4. RANGELANDS AND LIVESTOCK

4.1 Introduction, Scope and Approach

Rangelands are a highly climate-sensitive land use system, located mostly in semi-arid to arid regions which are agriculturally marginal. Associated with

the use of rangelands are cultural systems of intrinsic value. In order to assess the impact of climatic change on these systems, it is necessary to understand both the biological and socio-economic processes controlling their sustainability.

Rangelands, for this study, are all systems in which the primary source of production is livestock, recognising that many such systems have other products, and may combine to include mixed or multiple land uses with cropping and forestry (section 5). This definition includes a wide range of systems (Fig. 1). The systems vary with respect to climate, management intensity and social structure:

- climate: rangelands occur in cold to hot, and dry to seasonally wet climates

- management: all systems involve a considerable degree of animal management, but direct pasture management varies from slight in the case of extensive ranching to substantial in the case of improved pastures

- social structure: may be subsistence or market-oriented, and the former may be nomadic or sedentary and may have communal or exclusive access to land

All these factors affect which aspects of production from the system are most critical. The effort to determine the implications of climatic change on the rangelands must eventually be able to make useful predictions across all of these gradients.

At one extreme, intensive livestock systems on improved pastures are analagous to intensive cropping systems. However, rangeland livestock areas in general are characterised by relatively variable climates, low per unit area productivity which leads to large management units (whether fenced, paddocks, or nomadic ranges), and complex and usually semi-natural multi-species vegetation. As in forestry ecosystems, these characteristics raise problems of ecological complexity, variability in time, and large spatial scales. However, rangelands have received relatively low levels of research effort in the past so that their ecology is often poorly known.

The following sections identify key issues in relation to climatic change across the variety of rangeland types. Some of these are reasonably well understood already but require a re-assessment in the specific context of climatic change. Some key processes are poorly understood and these are identified as activities requiring further investigation.

Other issues lack the database to permit the extension of local results to larger areas; these are identified as activities requiring data collection. Even if the ecological factors were fully understood, social and economic systems will constrain the way in which information can be applied. Any model of rangeland response to climate change must take these interactions into account.

Tools must be developed which can be used to examine the implications of change to real management systems.

These will include models of various system processes which can be integrated as necessary to describe whole systems. Some processes, such as soil organic matter dynamics, may be reasonably universal in their critical components. However, rangelands are complex, and other processes, such as the spatial implications of animal and herders movements, will require conceptually different models for different systems. Databases must provide data both to validate predictions locally and to extend them over larger areas.

An approach is therefore proposed which focuses on six different rangeland systems which span the variety described above, with the intention of developing an adequate understanding of how climatic change will affect each. There must be interaction between groups working on each type of system to ensure a consistent approach, with the goal of developing a generic modelling tool.

The proposed key systems could be drawn from:

- Cold climate nomadic systems (e.g., reindeer in Scandinavia: dry cold climate, nomadic without pasture management)

- Hill pastures (e.g., Scotland, New Zealand, Himalayas, the Andes: mild wet climate, sedentary, free-ranging with low-input pasture management)

- Commercial livestock production systems (e.g., US, Australia, C. and S. America, southern and East Africa etc: temperate and tropical semi-arid climates, sedentary)

  a) Intensive (high inputs to range management)
  b) Extensive (low inputs to range management)

- Subsistence semi-arid grazing systems (e.g., communal grazing systems mostly with mixed farming in southern Africa, India, China, C. and S. America, sometimes with shifting cultivation: temperate and tropical semi-arid climates, mostly sedentary, subsistence)

- Nomadic grazing systems in semi-arid and arid regions (e.g., goats and cattle in Sahel, camels in Central Asia: continental climates, nomadic without pasture management, subsistence)

- Seasonally flooded grazing systems (e.g., Llanos and pantanal in S.America, riparian plains: hot climates, seasonally wet lands)

A review of relevant existing studies should identify which systems and which specific localities within each of these systems can be most efficiently and appropriately studied.

4.2 Key Issues

Six key issues need to be considered:

- plant production and plant population composition
- animal responses
- management and cultural implications
- environmental factors
- disturbance regimes
- water resources.

These main issues must be considered with respect to the scale in both time and space relative to biological and cultural response. Changes in the temporal and spatial characteristics of climate will have direct and secondary effects. For example, changes in water resources will affect the balance of woody to herbaceous components of the system. This influences availability of forage thereby changing the browser/grazer balance. Under a changed climate, a combination of fire, grazing and water management will help to mitigate changes in environmental conditions. Finally, the role of extreme events must be explicitly considered. The frequency and nature of extreme events such as droughts, wind storms, heavy rain events, and pest outbreaks are likely to alter, and pastoral systems are influenced more by changes in extreme events than by changes in mean conditions.

i. Plant production and species composition

Climate and atmospheric changes will have direct and secondary effects on productivity and community composition. The impacts of changes in environment on production are better understood than those controlling plant community responses. These include temperature effects on the balance between C3 and C4 plants, and water and temperature effects on the balance between woody and herbaceous components of rangeland. The interaction of temperature and moisture is critical in this context. In the northern hemisphere high latitude grasslands, a shift from C3 to C4 grasses would be expected due to a temperature increase but this may be offset by early rainfall that favours cold season C3 grasses. Changes in vegetation patterns will be further modified by human activity related to grazing intensity, fire management, etc. The spatial patterning of the vegetation existing in the landscape will also modify the response of the system to these general environmental changes.

ii. Animal responses

Direct effects on the physiology of animals will include temperature effects on net production, on fecundity and on milk production (Walker et al 1989). Indirect effects will include changes in the frequency of pest outbreaks and disease, and their distribution.

iii. Management implications

Management response to climatic change will depend partly on the plant and animal responses. Pastoral management activities include the manipulation of vegetation and the distribution and numbers of animals, water resource availability, fire, and pests and diseases. These management options need to be understood to evaluate the socio-economic reactions to environmental change. The ability of management systems to accommodate change is dependent on the mixture of land-use, cultural factors affecting attitudes to change in management practices, and the ability to mobilize resources to counteract changes in the system. Susceptibility will depend on the spatial heterogeneity of the mixture of land-use and the nature of multiple uses of a single parcel of land. Impacts of climatic change on potential uses will differ in relation to the specific character of land use.

iv. Environmental Impacts

Major global changes will have effects on local climate and to landscape and soil processes. In terms of local climate, the changes in rangeland cover and composition will influence evapotranspiration and albedo. The significance of these changes to further changes in local climate (e.g., the suggested positive feed-back on reduced rainfall) needs investigation. Changes in rainfall patterns and landcover will lead to changes in landscape level redistribution of water and soil. These will alter both the spatial pattern and amount of plant production.

The intensity of environmental degradation is contingent upon the climatic impacts on various ecosystem and landscape characteristics. These include wind and water erosion, soil degradation (e.g., salinity changes, soil organic matter quality, soil nutrient status), and changes in water resources (quality and quantity). Forage and animal production will be severely affected by changes in the environmental properties as well as direct impacts of climate change on the production systems.

v. Disturbance regimes

As climate changes, so will the characteristic patterns of fire, erosion, flooding, pest and disease events. Changes in the intensity and frequency of these events will affect the dynamics of pastoral and livestock systems. These changes will dramatically affect the system if they occur at critical periods in the production system and are asynchronous with historical patterns of these events, particularly in marginal areas which are especially vulnerable to change (Parry 1985).

vi. Water resources

The hydrological cycle describes the natural transition of the water resource through the atmospheric, surface and groundwater stages. Global and regional climatic changes directly disrupt the various stages of the hydrological cycle resulting in modifications of water availability and quality which in turn affect range and livestock production.

Solar radiation is central to the various rates of processes in the hydrological cycle with precipitation as a measurable direct output from the cycle. A warming trend in the overall climate will affect precipitation quantity, intensity, duration and frequencies. These precipitation changes will result in a ripple effect through the other hydrologic stages so that the surface and ground water storage could increase or decrease. Runoff processes could also be greatly affected by global or regional changes in precipitation.

A direct impact resulting from climatic change in the range/livestock system would occur in the evapotranspiration regimes. Groundwater resources would be affected changing the overall availability of water. Indirect impacts of climatic change on the hydrologic cycle would include the rates and direction of wind speeds resulting in new convergence zones, hence changing both temporal and spatial precipitation distributions. Water resources are directly linked to global climatic patterns and persistent changes would result in altered range/livestock characteristics in relation to new surface and ground water patterns.

4.3 Core Activities

Core activities involve the evaluation of existing data as well as collection of new data in process studies. Initial responses by rangeland and mixed farming/grazing systems to climatic change will be greatly modified by social adaptations. This will require integration of ecological with socio-economic research. In order to develop predictive capabilities, ecosystem models are required at a range of scales from local to regional.

1. *Changes in rangeland vegetation composition and production.*

Rangeland composition is important since species composition influences biomass production and forage quality. Plant cover and composition influence evapotranspiration and albedo, which have implications for local climate. Vegetation composition also determines nutrient and organic matter dynamics through residue returns and root production. Organic matter levels control water holding capacities and nutrient storage and turnover.

This first core activity is the collection of data and analysis of existing data on rangeland composition, fertility and soil organic matter along climatic gradients. In particular the influence of extreme events on composition needs to be evaluated.

An initial requirement and an activity which needs early attention is the development of an appropriate classification of plant functional types (PFTs) for rangelands. These are divided in terms of potential response to climate change and their role in livestock grazing systems. Composition change would be expressed in terms of these functional types. Palaeo data may provide a tool for evaluating the relationships between climatic change and rangeland composition.

To evaluate the feedback of rangeland composition on local climate, measurements of evapotranspiration, albedo and depth to water table with different plant cover compositions are required.

2. *Direct response of livestock to climate change*

Climate change may have a direct effect on animal net production, mortality, fecundity and milk production. Higher temperatures could reduce fertility in sheep in some areas while an increase in summer rainfall would promote the incidence of fleece rot (Walker et al. 1989). Those species which are likely to be affected by climate change must be identified and the information made available for management.

3. *Spatial redistribution of water and soil*

Redistribution of rainfall through runoff and interflow limits plant growth on top slopes and enhances production on lower positions. In many regions only areas receiving water supply through runoff or interflow maintain a plant cover. The third activity in this core project is the characterisation of hydrological units in the landscape and their associated vegetation patterns within each rangeland type. Water balances and spatial dynamics, and their sensitivity to climate change need to be quantified. This should lead to the development of a generic model for water redistribution and associated plant cover in rangeland. Effects of water redistribution and supply on impoundments, wells and water tables as influenced by climatic variability need to be investigated. Redistribution of soil and associated nutrients with runoff is an important component of the above processes. (See Core activity on soils in 5.2).

Land classification with respect to susceptibility to wind erosion is required for rangelands. Data collection and models relating land cover, topography and wind regimes are required at both local and regional scales. See also section 5.5.

4. *Fire*

The effects of management, and climatic events and gradients on fire regimes, as a function of dry season lengths and fuel loads need to be evaluated. Remote sensing will be used to characterise existing fire regimes. This needs to be supplemented with field experimentation on fuel loads, burn intensities and its effects on vegetation composition and nutrient dynamics. An important component of nutrient dynamics is soil organic matter as controlled by residue returns and root dynamics.

5. *Diseases and pests*

An analysis of pests affecting all aspects of range plants and animals is necessary for development of integrated change scenarios and a predictive understanding. This issue is discussed further in section 5.3.

6. *Management and Social Linkages*

Climatic impacts on rangeland and crop/grazing systems will invariably elicit social and management responses that interact with the function of physical system. Information exchange and joint research with social and economic sciences is essential for a complete evaluation of the system response to climatic change.

7. *Generic Models*

The central goal of this activity is the development of a generic model, based on a number of clearly defined, easily transportable modules, which integrate the issues discussed above and allow for prediction of secondary productivity and changes in the composition in terms of plant functional types (PFT's), and functional properties of the rangelands

concerned. This will include predicting the potential changes in the large scale dynamics of nomadic systems, which are characterized by the interdependence of different regions. The model will need to be structured such that it allows for easy inclusion of management options. See also section 5.4.

4.4 Implementation

The implementation of rangeland activities will proceed in a stepwise fashion with many activities contemporaneous.

i. Rangeland Composition

The first requirement is for the development of the functional classification of rangeland plants. An appropriate procedure would be for IGBP to initiate a working session on the topic at the next International Rangelands Congress in 1991. Having developed a classification, the second step is to locate appropriate groups to conduct field work. Conduct a synthesis workshop in 1995.

ii. Animal Response.

Analysis of existing information on livestock distribution in relation to climate to identify which animals will be significantly affected by climate change, and which areas will be most affected. Incorporation of this information in order to develop an appropriate mechanistic models based on 1.

iii. Spatial Dynamics of Water and Soil (see also 5.2).

It is essential to collaborate closely with the CP3 and GEWEX activities research groups or individuals within each selected rangeland type need to be identified. Working groups for the development of a generic "module" for these processes will be established.

iv. Fire

The first step will be a workshop to define the scope and requirements for IGBP related fire research in rangelands. This will be most appropriately held in conjunction with already proposed workshops (c.f., RSSD, Freiburg group).

A contract to an individual or a group to collate the existing information on fire research and fire models with the aim of developing an initial model for predicting changes in fire regimes, and in the consequences of these changes needs to be issued.

v. Management Regimes

Formation of a working group on changes in management regimes needs to be done. The working group should commission one ecologist and one rangeland manager/economist to jointly develop a background document on management scenarios. This document would form the basis for further work by the working group in developing directions and rates of change in management regimes in response to given climate change scenarios.

vi. Modelling

Models of rangeland ecosystems are being developed for several areas of the world. Current models must be adapted to climate change studies. A workshop to begin the integration of these models and to set a structure for various modules of the generic models is necessary. Activities related to assessment of existing studies are required to accomplish the modelling activities. These models must become modules within the generic agroecosystem model (5.4).

vii. Review of existing rangeland studies

Existing studies on rangeland systems should be reviewed and a workshop planned to identify which systems and specific localities within each of these systems can be most efficiently and appropriately studied.

5. COMMON ISSUES OF THE INTEGRATED AGROECOSYSTEM

This section deals with various issues that transcend the boundaries of the systems discussed in Sections 2, 3, and 4. Some of these do so because, like mixed farming and agroforestry systems, they specifically involve combinations of and interactions between the other systems. Others, like soils, pests and diseases and data sets, are issues which occur in all systems and can be tackled with a common approach. The need to develop a "generic" model of agroecosystems is common to crop, forestry pastoral and mixed systems and must include all common issues. Discussion of generic models is likewise, included in this section.

5.1 Mixed Agroecosystems

In many areas of the world, trees - either in woodlots, rangelands, woodlands, natural forests or in fields - are integrated with other production systems such as crops and livestock. Little is known or understood about these mixed systems but changes in climate will affect them. On the other hand their multi-component nature may make them more flexible than monocrops in response to climate change.

Mixed farming systems occur with all combinations of the agroecosystems mentioned in previous sections. Combined crop-grazing-forest or agroforestry systems, represent the most predominant form of land "management" in developing countries and is also prominent in developed countries. Such land-use systems can provide a variety of useful products, conserve and restore natural resources, build self reliance rather than dependence on industrial inputs, and contribute to risk aversion. The mixes depend upon environmental factors such as climate and soil type but also on availability of labour and needs of rural households. How this mix of products must change as the global climate changes, in conjunction with increasing populations is an important question.

Agroforestry produces a mosaic of cropland in a forested matrix. Widely practised agroforestry systems include trees dispersed in cropland, planted on field boundaries, or arranged in multi-storey or close spacing intercropped plantings with annual plants, planted in fallows, planted in woodlots, or selectively protected in rangelands for animal fodder, fruit and wood products including firewood. Trees may be planted with grasses for erosion control across gully channels or on stream banks. Agroforestry does not require trees to be present in cropland. In many cases, tree leaves and twigs may be removed from the forest to provide mulch for cropland. Agroforestry may also be represented by planting crops in natural forest. Where practised by populations at low density in its traditional culturally integrated form, shifting cultivation produced a quasi-steady state mosaic of vegetation. Climate change, and other dimensions of global change, pressures of growing populations and resulting environmental degradation are changing these agroforestry systems. It is important to consider mixed systems in addition to the 'pure' systems because:

- in general they are more common than the 'pure' systems, especially in subsistence agriculture;
- understanding them involves more than understanding the components since an important element of mixed systems is that there are resource flows between the components of the mix, and these resource flows can be affected by climatic change independently of effects on the components themselves;
- modelling their change involves additional techniques which aim to optimise the mix in some way, as well as understanding the components of the mix.

5.1.1 Key Issues

Although the initial emphasis has been on single species cropping, the need to consider crop rotation, intercropping, alley cropping and agroforestry alternatives is recognised and needs further attention. It is necessary also to include pasture/livestock and tree components in a total land-use system. In mixed farming systems, croplands are linked to range lands through rotational practices, transfers of nutrients and organic materials, transfer or browsing of fodder, and the dependence of arable fields on draught animals. Major changes may occur in these systems and loss of productive areas may result if the problems are not anticipated. Lands traditionally used for mixed farming practices may require a different mix of products to remain productive. Lands currently dedicated to a single or few species may under the impact of a changing climate, be more productively utilized with mixed production.

5.1.2 Core activities

1. *Develop understanding of linkages between components of a mixed system*

This core activity involves identification and quantification of those linkages which are critical to the functioning of the mixed system. Particular attention needs to be paid to nutrient and organic matter transformations and transfers, as they affect productivity and environmental resilience (sustainability) of grazing, forest and cropping systems. The susceptibility of these linkages to climatic change needs to be evaluated with the occurrence of extreme events such as flooding, droughts, freezing or fire, and along climatic gradients. It is expected that social adaptation will play an overriding role in this context.

2. *Develop linkages between other models and landscape models.*

Interfacing resource flows in mixed systems in such a way that they can be used predictively to assess the impact on the overall system of the flows being upset by climatic change must be developed. See also section 5.4. Landscape models will allow exploration of the dynamics of multiple systems. This activity must be developed in the context of the generic models of each subdiscipline and maintain coherence between the various systems.

5.2 The soil resource and its ability to produce food and fibre

The interactions of all important biological and physical components of crop, forest and livestock systems need to be integrated if we are to meet the challenge of development while maintaining the quality of land resources (Paul and Robertson 1989). Soils reflect the properties of the original parent material, past climate and vegetation, topography and time, but more accurately within the time frame of global change concerns, soil development is the result of shorter term processes of additions, removals, transformations and translocation (Anderson 1989). These short-term processes are particularly important in agricultural systems where management is the controling factor. For instance, the soluble salts in the soil change over a season and are capable of approaching equilibrium in a few years. In this respect soils must be considered as being highly dynamic.

5.2.1 Key Issues

Consequences of climatic and land use changes on the quality of land through soil processes and properties include changes in:

i. Soil erosion, which includes accelerated wind and water erosion of uncultivated and managed areas. Managed areas are particularly susceptible because changes in land use cause changes in canopy cover and surface soil protection, and in carbon inputs and distribution. These changes make soils more vulnerable to erosion. In many shallow soils depth may be reduced sufficiently to restrict or curtail plant growth.

ii. Carbon accumulation and distribution in the soil. Most of the changes associated with a change in atmospheric CO_2 concentration and climate will impact on soils through the amount, distribution and composition of plant biomass above and below ground. These changes will alter the rates of plant decomposition and in combination with any observed moisture effects will alter the distribution of organic C,N P and S in soils. It also can alter the availability of organically held nutrients that are normally

released by nutrient cycling processes.

iii. Soil water supply and the ability of the soil to sustain the growth of land plants. These will involve changes in organic matter content, water holding capacity, and changes in soil surface characteristics such as compaction which will affect permeability and water infiltration.

iv. The distribution of salts, other soluble components and nutrients. These will result mainly from changes in the hydrological cycle (e.g., accumulation of salts on soil surfaces, leaching of nutrients, leaching of soluble organic components, clay migration and other pedogenic processes).

v. Ground water table impacts. The most obvious effect on the hydrological cycle from changing water tables would be in the extent and distribution of cultivated and natural wetlands. Equally important would be a lowering of water tables in areas where plant growth depends on ground water, either by use of this resource for irrigation or by direct root exploration. Raised water tables, particularly in alluvial areas could easily eliminate agricultural use through water logging and flooding.

vi. Changes in the biogeochemical cycles, such as gaseous loss caused by anaerobic conditions (N_2, N_2O, NO_x, and CH_4 fluxes), or the sequestration of anionic nutrients (P, Mo) in Fe and Al oxides upon drying and oxidation of soils.

5.2.2 Core Activities

In order to determine the effects of Global Change on soil and water resources, the following objectives are established.

- determine the current states of natural and agroecosystems' soil and water resources
- determine how this current state was reached
- develop a predictive understanding of the short- and long-term effects of changing weather patterns and impending climate change, existing and new management practices, on soil quality, water availability and quality, and agricultural productivity.

5.2.3 Implementation

Information is needed on soil processes with priority given to those that operate over a time scale of a month to centuries. These may be listed in terms of order of priority (reordered from UNEP/ISSS 1990) as changes in:

- The amount and quality of organic C,N,P and S in soils.
- Susceptibility to erosion.
- Soil salinity and alkalinity.
- Structural stability and moisture characteristics.
- Inorganic nutrient status, acidity and redox regime.
- Soil meso and macro fauna important for bioturbation and homogenization of soil A and B

horizons.

- Iron and aluminium amorphous minerals in soil horizons.

Two main approaches are available for this purpose:

a) Analogue studies using soil chronosequences or using situations where (e.g.due to deforestation), local soil climate has changed.

b) Manipulation studies (e.g., elevated CO_2) in the field (small chamber, small watershed), greenhouse, or laboratory.

Monitoring (5.6) and data bases (5.5) are sources of information and important tools for integration. It is important to develop data bases of soils (soil inventories at 1:250,000 scale or better) and vegetation at similar resolution at global scales and to link these data together. Current data bases have gaps in information that must be addressed (e.g., large parts of Asia and Africa are not mapped accurately at appropriate scales).

Base line data should be organised and made available through the development of a Land Information System (LIS). Where this is possible ongoing, long-term studies of cropping management systems or biological reserves make it feasible to integrate and synthesize considerable information on long-term dynamics of agroecosystems without having to wait many years for research sites to mature.

The work on processes needs to be developed in conjunction with soil process models. These models can be used to simulate the effects of a range of climatic conditions on crop productivity and soil quality. Generic agroecosystem models (5.4) can be used to integrate information on driving variables, processes and properties (e.g., Parton et al. 1989).

5.3 Pests and Diseases

Pests and diseases will change in all agroecosystems in response to climatic change. Because many pests and diseases already have substantial economic or social significance, some have been well-studied and modelled. A re-orientation of this information to the specific question of climatic change is needed, followed by the identification of organisms which have predisposing life history features for future problems but which have not yet been studied properly.

5.3.1 Key issues

The general issue of pests and diseases is common to all agroecosystems, but a few examples are far better studied than others (e.g., plague locusts, rusts, Scot's Pine beetles, sawflies, tetse fly, cattle tick, etc.). It is widely expected that problems caused by disease vectors and pests may become worse with climatic change due to a dislocation of their natural predators and competitors. For example, cold-susceptible pests or diseases, particularly insect vectors which do not have a diapause state, may become more prevalent as temperature increases and the frequency of frost is lowered. In addition, altered climate can shift the forage availability due to increases in wild grazer or plant pest populations. As environmental conditions change and affect

population dynamics, the mix of domestic animals that can be utilised will be altered.

5.3.2 Core activities

1. *Analyses of pest and disease dynamics*

Analysis of the dynamics of pests and disease affecting vegetation and animals in relation to existing climatic gradients in different biogeographic regions of the world must be initiated. The triggers and controls of outbreaks need to be identified.

2. *Development of models of the current distribution of pests and diseases*

Model development of pest and diseases affecting important plant and animals species and the projected changes in these distributions in response to climate change must be initiated. In particular, the relationship of disease vectors to climatic events need to be assessed.

These activities should begin with the existing well-studied organisms. An effort should be made to identify the pre-disposing functional characters for outbreak under climatic change for each category of pest or disease vector. These functional characters should be applied to other less-studied organisms in each category to determine what organisms need highest priority for research.

5.3.3 Implementation

1. A workshop or workshops to be held in collaboration with research groups/organizations which are expert in pests and diseases of agroecosystems, such as ILRAD, Desert Locust Control, the International Centre for Insect Pest Ecology (ICIPE), World Health Organization (WHO).

This activity may, in the initial phase, be specific to a region since the effects might be more similar regionally across agroecosystem types than within agroecosystem types across the world. It is absolutely necessary that these workshops have as their product an integrative functional study of the problem as noted in the previous section.

2. Dependent on the outcome of this workshop, there probably will be a series of commissioned projects aimed at particular groups of pests/diseases.

5.4 Generic Models

Generic models provide a key research tool for crop, forestry, pastoral and agroforestry/mixed systems. The functional and structural attributes of the generic models outlined in this section are common to all but will have specific and different attributes when applied within the agroecosystem sub- discipline.

5.4.1 Modelling philosophy

Crop, forestry and pastoral groups each separately identify the need for a "generic model". In each case the generic model provided a framework for subsystem research and linkage with the total system. The structure of these proposed models was common across systems. The generic model is a suite of dynamic models which can capture the impacts of the physical, biological, chemical and management components of agroecological systems, developed in such a way as to predict system performance independent of an individual site's specifications. They would have a modular structure with separate modules for each of the major physical, chemical and biological processes in the soil-plant-atmosphere system. With modular structure the functional components of the system can be altered and various processes can be "plugged in" as necessary to model a new example of the system. The following specific characteristics are essential:

- Modularity - models should be constructed in small units each of which performs a specific task which may be region- or process-specific (or both). The sub-modules must be validated, sensitivity analyzed and used independently of any other unit, and can be plugged in to a larger model when needed. For example, different areas might need different levels of detail in a model of soil moisture balance. Several versions of the soil moisture module might therefore, exist, all requiring rainfall as input and providing the detail of soil property description needed according to the purpose to which they are to be put in the overall model.

- Transferability - modules should be developed which are as far as possible, data independent. That is given suitable input variables for a new region or a new crop, the modules can be transferred easily to the new system. Transferability may necessitate considerable process understanding.

- Open architecture - a programming architecture should be developed which does not constrain modellers to a specific modelling language, but which does allow modules developed in different places and in different computer languages to communicate readily with one another. Standards must be specified and agreed upon early in the research program.

In all systems there are important biotic elements which interact with these other modules. Truly generic models must include components that predict the dynamics of these organisms and their impact on crop growth and yield and their components. The generic models will provide the capability to predict the effects of short- and long-term perturbations in the climate on agroecosystem performance and sustainability. It will also enhance our ability to predict the feedback effects of the agroecosystem changes on climate.

Existing models of crops and soils provide a basis for further development of the generic models. Over the last ten years considerable progress has been made in the development of component modules of soils, crops, pests and their interaction. One example is the International

Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) project. Models of maize, soybean, wheat, rice, groundnut, dry beans, millet, sorghum and barley have been integrated in the IBSNAT project. These early efforts demonstrate the feasibility of developing generic models that can be transferred to new locations to predict soil and crop behaviour at the new site.

The IBSNAT models are modular. The components from one crop model have been used in modelling other crops. All IBSNAT models use the same generic soil module which predicts the dynamics of soil water and nitrogen, as well as using the same soil characteristics as inputs. They are all responsive to solar radiation, temperature, rainfall and day length, predicting changes in crop development and growth as the season progresses. They are all responsive to management factors such as planting date, row spacing, plant populations, nitrogen fertilization, irrigation and cultivar selection. The IBSNAT project has defined a minimum data set for testing the transferability of the models, as well as developing a set of standard model inputs and outputs. This facilitates use of both model and data by others. Although the IBSNAT models have their limitations, a list of areas for improvement is given in Section 2.1, the project framework and the experience gained provides a valuable source for refinement in taking on the activities described in this document.

These models provide a conceptual framework for the crop modelling efforts and may prove useful in the further development of forestry and pastoral models. At the same time it is important to recognize that there are many experienced agricultural system modellers and experimentalists who have worked with models around the world who will be able to contribute directly to the proposed activities.

5.4.2 Model Standards

Standards for all modules of the generic models must be maintained. A workshop of modellers from all systems should define some broad guidelines on modelling structures. This does not mean prescribing particular obscure modelling languages, rather agreeing that all models should be able to communicate via ASCII files, and their own command languages, so that model superstructures can be written which have the expertise to know how to extract a particular piece of information from a particular program module. Generalised standards on graphics, 'user interfaces', reports, standard inclusion of modelling techniques like sensitivity analysis, etc, will be important. As a task, this workshop could be held once or twice and completed in a year or two.

5.4.3 Implementation strategies: workshops that integrate the work in agroecosystems.

A proposal is made to conduct a workshop that brings together scientists knowledgeable in the development, validation and application of present models, in order to develop a framework for preparing a generic model for agroecosystems. The major objective will be to develop a common modular structure for different components and identify the minimum data sets necessary to run the model.

5.5 Minimum Data Sets

There are at least four different levels of data sets that are needed for each system.

- Understanding and model development: the most detailed data sets are needed where process studies are being carried out to understand how the various systems function. They are also necessary in order to devise the models. These data need only be collected in relatively few sites, carefully chosen to span the range of possible responses.

- Understanding and model validation: These are less detailed data sets. They include the necessary basic inputs and all important outputs needed to validate the understanding produced above. These should be collected in relatively few sites, but spanning a wider range of intra-annual variability than above.

- Predictions: in order to make predictions using models, the basic input variables for the models are needed over suitably large areas. Some of these are static, such as landform; others are dynamic, such as climate. This data set will be the least detailed but most geographically widespread. It will form the basis of a global geographic information system.

- Monitoring: on a reasonably wide spread scale, it will also be necessary to monitor the key factors predicted by models, as on going validation and confirmation.

For each level a minimum necessary data set can be defined (and largely has been for the IBSNAT models, for example). This data set will differ for different systems. System specifications are discussed in the appropriate sections.

5.5.1 Key issues

There are various levels of data needed to develop understanding, test models, make predictions of changes, and monitor the actual changes in the different agroecosystems in relation to climate change. To manage this data collection realistically and efficiently, it is vital to define the smallest possible necessary but sufficient data set. These minimum data sets are likely to have many similarities for different systems, so that it is sensible to try to define an overall minimum data set that is needed at each of the different levels; there will be more similarities at some levels than others. At the same time, it will not be efficient to inflexibly insist that the minimum data set must fit all purposes: clearly cropping systems will often need greater detail in soils information, for example, than other systems, while spatial variability may be a more important factor in rangelands systems than for crops.

Consequently there is a need to coordinate the common definition of minimum data sets, recognising the need for different priorities in different systems, but placing

these necessary adjustments within the same framework. This framework is not only philosophical: a common data storage and transfer approach must also be developed worldwide, with the ability to operate at different spatial and temporal scales as necessary.

5.5.2 Core Activity and Implementation: definition of minimum data sets

Implementation of all activities across ecosystems requires the measurement or estimate of a specified minimum data sets at required levels of spatial and temporal resolution. This in turn requires an effort in research and development for estimation and interpolation of terrain, soil, climate and weather data.

This much needed research and development activity should be a part of IGBP, but database development is more properly a function of existing international and national agencies. Access to primary attribute data (terrain, geology, climate, weather) is a critical requirement for development of generic models. The minimum data sets needed for model development and validation tend to be more comprehensive than those needed for model implementation.

For concepts of minimum data sets and generic models to be accepted and applied it is essential that effort be devoted to education and training of agriculturalists, foresters and rangeland scientists at all levels of the relevant national institutions.

Formats for preparation of minimum data sets are to be devised and distributed to interested experimenters. The models need not be designed with model development and testing specifically in mind. Provision of the necessary minimum data sets would permit model application as an adjunct to any experiment.

5.6 Monitoring Systems for Agroecosystem Change

An important aspect in the development of the generic agroecosystem model is the need to monitor changes in the system in both space and time. This calls for the development of appropriate methods of monitoring, using available information and research tools, as well as the development of early signals of system change. Definition and initiation of the recording network will require international cooperation. Training of scientists associated with this activity is crucial to achieve the desired results. Equally important is the dissemination of research/modelling results, particularly to the world's decision makers. This information would help in the development of coping strategies, see 2.3.5, for instance.

5.6.1 Implementation

Monitoring change in space and time An international network of monitoring stations is required. The panel recognizes that a number of methodologies amenable to agroecosystem monitoring that include remote sensing, GIS, statistical models, and case studies have been developed at national, regional and international levels. Adoption of all those methodologies that could focus on global change monitoring and on development of new criteria and indicators for improving early warning of change could be the focus of another workshop. Immediate diffusion of such methodologies for use by national and regional agencies is considered an essential contribution of IGBP in the monitoring of agroecosystem changes.

6. RECOMMENDATIONS

The need for an appropriate, strategic response to climate change underlies all research recommendations from this workshop. Management must achieve this goal if food and fibre production is to continue without disruption. Such a timely response will be achieved through the development of integrative research tools and scientifically and internationally broad collaboration. The research which has been outlined requires this approach. Thus a prime recommendation is the early identification of the means of achieving the necessary cooperation.

Six categories of activities should be initiated. These are based on the activities in sections 2-5.

1. *A need for a basic knowledge of the processes of global change always underlies all predictive understanding, modelling and monitoring.*

Experiments and field work which must be initiated include:

- research to identify and understand the direct effect of climate change on plant and animal species;
- CO_2 fertilization experimentation on forests, crops, rangeland types, physiology of plant development as a function of environmental factors;
- soil research on the direct effects of climate change and on soil plant interactions;
- pest and disease research;
- understanding of rangeland species composition dynamics, where species need to be defined in terms of functional types. This involves collection of existing data, including palaeo data;
- identify global priorities based upon critical regional resources. This involves assessment by IGBP National Committees of resources in their own region;
- field work on Rangeland and forestry for inventories after variables are set;
- research and field work for validation of models.

2. *Development of "generic" models and sub-modules*

Development of generic agroecosystem models is necessary for forest, pastoral, crop and mixed systems. They must have common parameter specifications and common links between processes. Workshops and collaborative research are proposed:

- model workshops for evaluation and preparation of the framework for generic models within each discipline;
- workshop for integrating generic models;
- development of harvest and post-harvest models;

- comparison workshops for assumptions and linkages between processes;
- coordinate and interact with CP3 and GEWEX and include agroecosystem modules in other model research;
- commission one ecologist and one rangeland manager/economist to develop a background document on management scenarios as input to model development.

3. *Data sets for monitoring and input to models*

Minimum data sets must be developed for those key processes important to all agroecosystems. The data sets must be developed in coordination with the core project on terrestrial effects (GCTE) and the Hydrologic core project (BAHC).

- develop criteria for monitoring data sets
- global forest inventory coordinated with satellite coverage
- global soils data set
- data on the distribution of pests and disease
- defuse data methodologies to all countries
- develop Minimum data sets and similar modular model structures (preferably exchangeable) for model development and validation.
- develop key variables lists coordinated with crops, forestry, pastoral, and natural ecosystems
- workshop on fire research to identify research requirements
- collate existing information on fire research

4. Methodology development

- characterization and prediction on harvest and post-harvest handling
- develop methodology for global forest inventory
- develop functional classification of rangeland plants

5. Monitoring

- evaluate amenable monitoring technologies

6 Dissemination of information

- leaflets and regional workshops for scientists, policy makers and planning agencies
- International Rangelands Congress (1991) working session

6.1 Combined Activities of Agroecosystem Change Studies

1. An intensive coordinated effort for developing generic agricultural, forestry, rangeland, and agriculture models should be undertaken. Included in this effort is the development of generic soil physical and chemical models that simulate both short and long term changes in soil water, nutrient and organic matter.

2. Develop minimum data sets for development and testing of the generic models and for their application over regional (spatial) scales. This includes the research and development of methodology for

estimating and interpolating data required applying the models over large areas where point data are sparse. Development of standard formats will be essential for all these data to facilitate their rise by all cooperating institutions.

3. Identify specific areas for experiments to develop and test the generic models over a wide range of soil and climate conditions, including extremes and including some testing of direct CO_2 effects at several selected sites. Monitor and analyze data to characterize changes that occur year to year and over a long time frame.

6.2 Interactions with Other Groups and Organizations

This IGBP Core Project must interact with other organizations to ensure that its findings are made relevant to policy makers and that the models incorporate the most up to date GCM predictions. In particular, there is a need for collaboration with socio-economists to derive future scenarios of changes in land-use patterns in response to global change, economics, technology, etc.

6.3 Priority Five-year Goals:

The five year goals outlined below require the integration of many activities outlined in sections 2-5.

1. Increased coordination between modelling efforts around the world. This could be an IBSNAT type program leading to (a) defined general guidelines for modelling approaches and the concepts of 'generic models' and (b) a defined priority study areas across the spectrum of agroecosystems. This priority status would be maintained for a defined and brief period, e.g., 5 years, after which they are to give way to broader scale generalising studies and predictions. Note that this is the structure proposed for the Rangelands/Livestock section.

2. Under the direct auspices of the IGBP, preliminary studies of the sensitivity of outcomes to various climatic variables will be advanced. These will use whatever models already exist to (a) start giving an indication of magnitude of change, (b) identify critical areas needing more work and, (c) begin development of a predictive understanding of change.

3. Certain key experiments should be underway in five years. For instance the field CO_2 experiment Section 2.3, the soil experiments Section 5.2 and the definition of a functional classification for rangeland plants (4.3) should be progressing.

4. All required minimum data sets should be defined and collection systems should be established in a consistent way across the globe; the two limiting factors here are likely to be the broad scale mapping of input data needed for predictions, and the effective collection of monitoring data (the detailed model development and validation data

does not require such a dispersed data collection network).

5. Several social scientist/ecologist teams should evaluate and report general findings which integrate the socio-biological system. Understanding of the social implementation phase is the most intractable problem in global change studies. If we don't initiate possible approaches this will be by far the most limiting factor in our understanding of the practical implications of our (by then) modelled ecological changes.

Literature Cited

Anderson, D.W. 1989. Long-term ecological research - a pedological perspective p. 394-417 in Final Rep. of Int. Workshop, Berchtesgaden on "Long-Term Ecological Research - a Global Perspective" Published by the German Nat. Comm. for UNESCO/MAB Bonn, FRG.

Bolin, B., B.R. Döös, J. Jager and R.A. Warrick. 1986. The Greenhouse Effect, Climatic Change and Ecosystems. SCOPE 29. John Wiley & Sons, Chichester.

IBSNAT, 1989: DSSAT Users Guide. International Benchmark Sites Network for Agrotechnology Transfer, University of Hawaii, 2500 Dole Street, Krauss 18, Honolulu, WT 96822, USA.

ISSS Report. Effects of Expected Climate Change on Soil Processes in the Tropics and Sub-tropics. Proceedings of an International Workshop. Nairobi, Kenya, Feb. 1990. (In prep).

Parry, M.L. 1985. The impact of Climatic Variations on Agricultural Margins. IN: R.W. Kates, J.H. Ausubel and M. Berberian. Climate Impact Assessment. SCOPE 27. pp. 351- 367. John Wiley & Sons Ltd, Chichester.

Parton, W.J., C.V. Cole, J.W.B. Stewart, D.S. Schimel and D. Ojima. 1989. Simulating the long-term dynamics of C, N and P in soils. IN Clarholm, M. and L. Bergstrom (eds.) Ecology of Arable Land - Perspectives and Challenges Developments in Plant and Soil Sciences Vol. 39. Kluwer Academic Publishers.

Shugart, H.H., M. Ja, Antonovisky, P.G. Jarvis and A.P. Sanford. 1986. CO_2, Climatic Change and Forest Ecosystems. IN: Bolin, B., B.R. Döös, J. Jager and R.A. Warrick 1986. The Greenhouse Effect, Climatic Change and Ecosystems. SCOPE 29. pp. 475-521. John Wiley & Sons, Chichester. UNDP/ISS 1990.

Walker, B.H., M. D. Young, J.S. Parslow, K.D. Cocks, P.M. Fleming, C.R. Margules and J.J. Landsberg. 1989. Effect on renewable natural resources. IN: Global Climate Change - Issues for Australia. pp. 31-76. Commonwealth of Australia.

Warrick, R.A., R.M. Gifford with M.L. Parry. 1986. CO_2, Climate Change and Agriculture. IN: Bolin, B., B.R. Döös, J. Jager, and R.A. Warrick 1986. The Greenhouse Effect, Climatic Change and Ecosystems. SCOPE 29. pp. 393-473. John Wiley & Sons, Chichester.

Wigley, T.M.L. 1985. Impact of extreme events, Nature, 316, pp. 106-107.

APPENDIX 1
LIST OF PARTICIPANTS

Woods Hole, Massachussetts, April 1989

Dr. J.M. Anderson
Department of Biological Sciences
Hatherly Laboratories
University of Exeter
Prince of Wales Road
Exeter EX4 4PS
UK

Prof. Alicja Breymeyer
Polish Academy of Sciences
Institute of Geography and Spatial Organization
Krakowskie Przedmiescie 30
00-927 Warszawa
POLAND

Dr. F. Stuart Chapin
Institute of Arctic Biology
University of Alaska
Fairbanks, Alaska 99775
USA

Dr. M. Coughenhour
Natural Resource Ecology Laboratory
Colorado State University
Fort Collins, Colorado 80523
USA

Prof. Congbin Fu
Institute of Atmospheric Physics
Academia Sinica
Beijing 100011
CHINA

Dr. J.J. Landsberg
CSIRO
Division of Wildlife & Ecology
PO Box 84
Lyneham ACT 2602
AUSTRALIA

Dr. James MacMahon
Department of Biology
Utah State University
Logan, UT 84322-5305
U.S.A.

Prof. Ernesto Medina
Centro de Ecologia y Ciencias Ambientales
IVIC
Apartado 21827
San Martin, Caracas 1020 A
VENEZUELA

Prof. Jerry M. Melillo
Marine Biological Laboratory
Woods Hole, MA 02543
U.S.A.

Dr. J.C. Menaut
Ecole Normale Supérieure
Lab. décologie (UA CNRS 258)
46 rue d'Ulm
F-75230 Paris Cedex 05
FRANCE

Prof. Henry Nix
Centre for Resource & Environmental Studies
A.N.U.
P.O. Box 4
Canberra, ACT 2601
AUSTRALIA

Dr. Dennis Ojima
IGBP Secretariat
KVA
Box 50005
S-104 05 Stockholm
SWEDEN

Dr. Colin Prentice
Department of Ecological Botany
Uppsala University
Box 559
S-751 22 Uppsala
SWEDEN

Dr. Ed Radstetter
The Ecology Center
Marine Biological Laboratory
Woods Hole, MA 02543
USA

Prof. William A. Reiners
Aven Nelson Building
Department of Botany
University of Wyoming
Laramie, Wyoming 82071
USA

Dr. David Schimel
NREL
Colorado State University
Ft. Collins, CO 80523
USA

Prof. H. H. Shugart
Department of Environmental Sciences
University of Virginia
Clark Hall
Charlottesville, VA 22903
U.S.A.

Prof. John W.B. Stewart
Institute of Pedology
University of Saskatchewan
John Mitchell Building
Saskatoon, Saskatchewan S7N OWO
CANADA

Prof. Peter M. Vitousek
Department of Biological Sciences
Stanford University
Stanford, CA 94305
U.S.A.

Dr. Brian H. Walker
Division of Wildlife and Ecology
CSIRO
P.O. Box 84
Lyneham, ACT 2602
AUSTRALIA

Dr. Richard Waring
College of Forestry
Oregon State University
Corvallis, Oregon 97331
USA

Dr. Ian Woodward
University of Cambridge
Department of Botany
Botany School
Downing Street
Cambridge CB2 3EA
UNITED KINGDOM

LIST OF PARTICIPANTS

Canberra, August 29-31 29-31 1989

Dr. J.M. Anderson
Department of Biological Sciences
Hatherly Laboratories
University of Exeter
Prince of Wales Road
Exeter EX4 4PS
UK

Dr. Mike Austin
CSIRO
Division of Wildlife and Ecology
PO Box 84
Lyneham ACT 2602
AUSTRALIA

Dr. Marilyn Ball
The Australian National University
R.S.B.S.
PO Box 475
Canberra ACT 2601
AUSTRALIA

Dr. Michele Barson
Bureau of Rural Resources
GPO Box 858
Canberra ACT 2601
AUSTRALIA

Dr. Greg Bowman
CSIRO
Division of Soils
GPO Box 639
Canberra ACT 2601
AUSTRALIA

Dr. Gordon Burch
Bureau of Rural Resources
GPO Box 858
Canberra ACT 2601
AUSTRALIA

Dr. Graeme Caughley
CSIRO
Division of Wildlife & Ecology
PO Box 84
Lyneham ACT 2602
AUSTRALIA

Dr. Bruce Clarkson
Botany Division DSIR
C/- Forest Research Institute
Private Bag
Rotorua
NEW ZEALAND

Dr. Frank Crome
CSIRO
Division of Wildlife and Ecology
PO Box 780
Atherton QLD 4883
AUSTRALIA

Mr. David de Pury
R.S.B.S.
The Australian National University
PO Box 475
Canberra ACT 2601
AUSTRALIA

Dr. James Detling
Natural Resource Ecology Laboratory
Colorado State University
Fort Collins
Colorado 80523
USA

Dr. Daniel P. Faith
CSIRO
Division of Wildlife & Ecology
PO Box 84
Lyneham ACT 2602
AUSTRALIA

Prof. Graham Farquhar
R.S.B.S.
The Australian National University
PO Box 475
Canberra ACT 2601
AUSTRALIA

Prof. Congbin Fu
Institute of Atmospheric Phycics
Academia Sinica
Beijing 100011
CHINA

Dr. Roger Gifford
CSIRO
Division of Plant Industry
GPO Box 1600
Canberra ACT 2601
AUSTRALIA

Dr. Malcolm Gill
CSIRO
Divisin of Plant Industry
GPO Box 1600
Canberra ACT 2601
AUSTRALIA

Dr. Dean Graetz
CSIRO
Divsion of Wildlife and Ecology
PO Box 84
Lyneham ACT 2602
AUSTRALIA

Dr. Graham Harris
CSIRO
Office of Space Science and Applications
PO Box 225 Dickson
Canberra ACT 2602
AUSTRALIA

Dr. Tony Jakeman
C.R.E.S.
The Australian National University
GPO Box 4
Canberra ACT 2601
AUSTRALIA

Dr. Joe Landsberg
CSIRO
Division of Wildlife & Ecology
PO Box 84
Lyneham ACT 2602
AUSTRALIA

Ms. Michelle Leishman
School of Biological Sciences
Macquarie University
Sydney, NSW 2109
AUSTRALIA

Dr. James MacMahon
Department of Biology
Utah State University
Logan, Utah 84322-5305
USA

Ms. Fiona McFarlane
CSIRO
Division of Wildlife & Ecology
PO Box 84
Lyneham ACT 2602
AUSTRALIA

Dr. Chris Margules
CSIRO
Division of Wildlife & Ecology
PO Box 84
Lyneham ACT 2602
AUSTRALIA

Dr. Jean-Claude Menaut
Ecole Normale Supérieure
Laboratoire d'Ecologie
(UA CNRS 258)
46 Rue D'Ulm
F-75230 Paris Cedex 05
FRANCE

Dr. Ian Noble
R.S.B.S.
The Australian National University
PO Box 475
Canberra ACT 2601
AUSTRALIA

Dr. Dennis Ojima
Royal Swedish Academy of Sciences
POB 50005
S-104 05 Stockholm
SWEDEN

Dr. Barry Osmond
Botany Department
Duke University
Durham, NC 27706
USA

Dr. Carlos Prado
Ecole Normale Supérieure
Laboratoire d'Ecologie
(UA CNRS 258)
46 Rue D'Ulm
F-75230 Paris Cedex 05
FRANCE

Dr. Mike Raupach
CSIRO
Centre for Environmental Mechanics
GPO Box 821
Canberra ACT 2601
AUSTRALIA

Dr. William Reiners
Department of Botany
University of Wyomong
Aven Nelson Building
Laramie, Wyoming 82071
USA

Prof. Ralph Slayter
Office of Chief Scientist
Dept. of Prime Minister and Cabinet
Canberra, ACT 2600
AUSTRALIA

Prof. Ray Specht
Botany Department
University of Queensland
St. Lucia, QLD 4067
AUSTRALIA

Dr. John Stewart
Department of Soil Sciences
University of Saskatchewan
Saskatoon, S7N OWO
CANADA

Prof. Mike Swift
International Institute of Tropical
Agriculture
Ibadan
NIGERIA

Dr. Bruce Thom
University of Sydney
Department of Geography
Sydney, NSW 2710
AUSTRALIA

Dr. David Tongway
CSIRO
Division of Wildlife and Ecology
PO Box 84
Lyneham, ACT 2607
AUSTRALIA

Dr. Sandra Turner
CSIRO
Division of Wildlife & Ecology
PO Box 84
Lyneham, ACT 2602
AUSTRALIA

Dr. Zenbei Uchijima
Faculty of Science
Ochanomizu University
Otsuka 2-1-1 , Bunkyo-ku
Tokyo 112
JAPAN

Dr. Peter Vitousek
Department of Biological Sciences
Stanford University
Stanford, CA 94305
USA

Dr. Brian Walker
CSIRO
Division of Wildlife & Ecology
PO Box 84
Lyneham ACT 2602
AUSTRALIA

Dr. Bon Wasson
CSIRO
Division of Water Resources
GPO Box 1666
Canberra ACT 2601
AUSTRALIA

Dr. Patricia Werner
CSIRO
Division of Wildlife & Ecology
PM Box 44
Winnellie NT 0821
AUSTRALIA

Dr. Mark Westoby
School of Biological Sciences
Macquarie University
Sydney NSW 2109
AUSTRALIA

Dr. George Wilson
Animal Resources Branch
Bureau of Rural Resources
GPO Box 858
Canberra, ACT 2601
AUSTRALIA

Dr. Ian Woodward
Department of Botany
University of Cambridge
Downing Street
Cambridge, CB2 3EA
UNITED KINGDOM

Dr. Richard Wright
Norwegian Institute for Water Research
Brekkeveien 19
Box 69 Korsvoll
N-0808 Oslo 8
NORWAY

Mr. Zong Liang Yang
School of Earth Sciences
Macquarie University
Sydney NSW 2109
AUSTRALIA

Dr. Roman Zlotin
Institute of Geography of the USSR
Academy of Sciences
Staromonetny per 29
Moscow 109017
USSR

LIST OF PARTICIPANTS

Yaoundé, Cameroon 27 November - 1 December 1989

Dr. Amougou Akoa
Université de Yaoundé
Faculté des Sciences
BP 812
Yaoundé
CAMEROON

Dr. Joseph B. Besong
Forestry Department
Ministry of Agriculture
Yaoundé
CAMEROON

Dr. Juan A. Comerma
CENIAP-FONIAP
Apdo Postal 4653
Maracay 2101
VENEZUELA

Dr. Imo J. Ekpo
Atmospheric Impacts Research Group
Department of Geography
University of Birmingham
Birmingham B15 2TT
UK

Dr. Graham Farmer
FEWS Project
1611 N. Kent St., Suite 201
Arlington, VA 22209
USA

Dr. Gnoumou Faustin
AGRHYMET
BP 11011
Niamey
NIGER

Dr. Eldon Franz
ICRAF
PO Box 30677
Nairobi
KENYA

Dr. Doug Godwin
IFDC
PO Box 2040
Muscle Shoals
Alabama 35662
USA

Dr. Shrikant Jagtap
C/- L.W. Lambourn & Co.
Carolyn House
26 Dingwall Road
Croydon CR9 3EE
UNITED KINGDOM

Prof. Jim Jones
Agricultural Engineering Department
University of Florida
Gainnesville, FL 32611
USA

Dr. Zachery Kasomakera
Soil and Water Engineering
Bunda College of Agriculture
University of Malawi
Box 219, Lilongwe
MALAWI

Dr. Brian Keating
CSIRO Cunningham Lab.
306 Carmody Road
St. Lucia 4067
Brisbane, QLD
AUSTRALIA

Dr. Nsangou Mama
Center for Forest Research
MESIRES
PO Box 2102
Yaoundé
CAMEROON

Dr. Ross McMurtrie
CSIRO
Division of Forestry and Forest
Products
PO Box 4008
Queen Victoria Terrace
Canberra ACT 2600
AUSTRALIA

Dr. David Mungai
Department of Geography
University of Nairobi
PO Box 30197
Nairobi
KENYA

Prof. Henry Nix
Centre for Resource and Environment
A.N.U.
PO box 4
Canberra, ACT 2601
AUSTRALIA

Mr. Constance Ntamark
Ministry of Higher Education
Computer Services and Scientific
Research
Yaoundé
CAMEROON

Dr. L.J. Ogallo
Department of Meteorology
University of Nairobi
PO Box 30197
Nairobi
KENYA

Dr. Dennis Ojima
IGBP Secretariat
Royal Swedish Academy of Sciences
Box 50005
S-104 05 Stockholm
SWEDEN

Dr. William J. Parton
NREL
Colorado State University
Ft. Collins, CO 80523
USA

Dr. Roslyn Prinsley
Commonwealth Science Council
Commonwealth Secretariat
Marlborough House
Pall Mall
London SW1Y 5HX
UK

Prof. Thomas Rosswall
IGBP Secretariat
Royal Swedish Academy of Sciences
Box 50005
S-104 05 Stockholm
SWEDEN

Dr. Steve Running
School of Forestry
University of Montana
Missoula, MT 59812
USA

Prof. H.H. Shugart
Department of Environmental Sciences
University of Virginia
Charlottesville, Virginia 22903
USA

Dr. M.V.K. Sivakumar
ICRISAT Sahelian Center
PO Box 12404
Niamey
NIGER

Dr. Mark Stafford Smith
CSIRO
Division of Wildlife and Ecology
PO Box 2111
Alice Springs, NT 0871
AUSTRALIA

Dr. Holm Tiessen
Department of Soil Sciences
University of Saskatchewan
Saskatoon, S7N OWO
CANADA

Dr. Sandra Turner
CSIRO
Division of Wildlife & Ecology
PO Box 84
Lyneham, ACT 2602
AUSTRALIA

Dr. Brian Walker
Division of Wildlife and Ecology
CSIRO
P.O. Box 84
Lyneham, ACT 2602
AUSTRALIA

APPENDIX 2

GLOSSARY OF ACRONYMS

ANC-IGBP	Australian National Committee to the IGBP
AVHRR	Advanced Very High Resolution Radiometer
BAHC	Biological Aspects of the Hydrological Cycle (IGBP)
BATS	Biospheric Atmospheric Transfer
COHMAP	Cooperative Holocene Mapping Project
CSC	Commonwealth Science Council
CSIRO	Commonwealth Scientific and Industrial Research Organization (Australia)
ENSO	El Niño - Southern Oscillation
GBO	Geo-Biosphere Observatories (IGBP)
GCM	General Circulation Model
GEWEX	Global Energy and Water Cycle Experiment (WCRP)
GIS	Geographic Information System
IBSNAT	International Benchmark Sites Network for Technology Transfer
ICIPE	International Centre for Insect Pest Ecology
IGBP	International Geosphere-Biosphere Programme: A Study of Global Change
IIASA	International Institute of Applied Systems Analysis
ILRAD	International Laboratory Research Animal Diseases
ISSS	International Society of Soil Science
IUFRO	International Union of Forest Research Organizations
LAI	Leaf-Area Index
LIS	Land Information System
NASA	National Aeronautics and Space Administration (USA)
NDVI	Normalized Difference Vegetatin Index
NEP	Net Ecosystem Productivity
NOAA	National Oceanic and Atmospheric Administration
NPP	Net Primary Production
PFT	Plant Functional Type
RS	Remote Sensing
RSSD	Responses of Savannas to Stress and Disturbance (IUBS-MAB)
SCOPE	Scientific Committee on Problems of the Environment (ICSU)
SiB	Simple Biosphere
SSC	Scientific Steering Committee (IGBP)
TSBF	Tropical Soil Biology and Fertility
UNEP	United Nations Environment Programme
Unesco	United Nations Educational, Scientific and Cultural Organization
USLE	Universal Soil Loss Equation
WHO	World Health Organization

IGBP Reports

No. 1. The International Geosphere-Biosphere Programme: A Study of Global Change. Final Report of the Ad Hoc Planning Group, ICSU 21st General Assembly, Berne, Switzerland 14-19 September, 1986 (1986)

No. 2. A Document Prepared by the First Meeting of the Special Committee, ICSU Secretariat, Paris 16-19 July, 1987 (1987)

No. 3. A Report from the Second Meeting of the Special Committee, Harvard University, Cambridge, MA, USA 8-11 February, 1988 (1988)

No. 4. The International Geosphere-Biosphere Programme. A Study of Global Change (IGBP). A Plan for Action. A Report Prepared by the Special Committee for the IGBP for Discussion at the First Meeting of the Scientific Advisory Council for the IGBP, Stockholm, Sweden 24-28 October, 1988 (1988)

No. 5. Effects of Atmospheric and Climate Change on Terrestrial Ecosystems. Report of a Workshop Organized by the IGBP Coordinating Panel on Effects of Climate Change on Terrestrial Ecosystems at CSIRO, Division of Wildlife and Ecology, Canberra, Australia 29 February - 2 March, 1988. Compiled by B. H. Walker and R. D. Graetz (1989)

No. 6. Global Changes of the Past. Report of a Meeting of the IGBP Working Group on Techniques for Extracting Environmental Data of the Past held at the University of Berne, Switzerland 6-8 July, 1988. Compiled by H. Oeschger and J. A. Eddy (1989)

No. 7. A Report from the First Meeting of the Scientific Advisory Council for the IGBP. Volumes I and II. (1989)

No. 8. Pilot Studies for Remote Sensing and Data Management. Report from Working Group Workshop held in Geneva, Switzerland 11-13 January 1989. Edited by S. I. Rasool and D. S. Ojima (1989)

No. 9. Southern Hemisphere Perspectives of Global Change. Scientific Issues, Research Needs and Proposed Activities. Report from a Workshop held in Mbabane, Swaziland 11-16 December, 1988. Edited by B. H. Walker and R. G. Dickson (1989)

No. 10. The Land-Atmosphere Interface. Report on a Combined Modelling Workshop of IGBP Coordinating Panels 3, 4, and 5. Brussels, Belgium, 8-11 June, 1989. Edited by S. J. Turner and B. H. Walker (1990)

No. 11. Proceedings of the Workshops of the Coordinating Panel on Effects of Global Change on Terrestrial Ecosystems. I. A Framework for Modelling the Effects of Climate and Atmospheric Change on Terrestrial Ecosystems, Woods Hole, USA, 15-17 April, 1989. II. Non-Modelling Research Requirements for Understanding, Predicting, and Monitoring Global Change, Canberra, 29-31 August 1989. III. The Impact of Global Change on Agriculture and Forestry, Yaoundé, 27 November-1 December, 1989. Edited by B. H. Walker, S. J. Turner, R. T. Prinsley, D. M. Stafford Smith, H. A. Nix and B. H. Walker. (1990)

No. 12. The International Geosphere-Biosphere Programme: A Study of Global Change (IGBP). The Initial Core Projects. (1990)