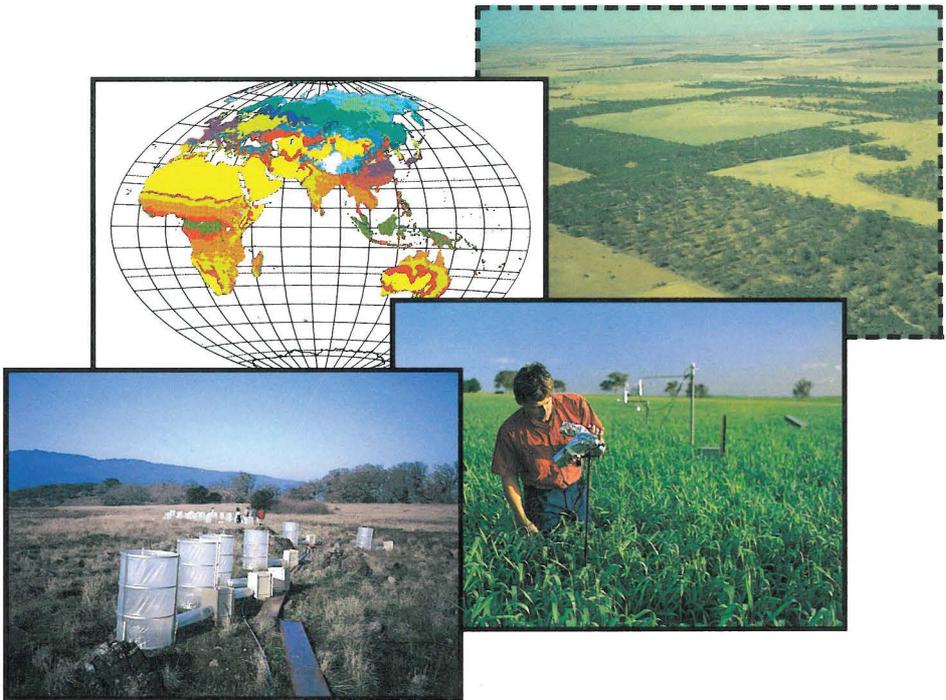


GLOBAL I G B P CHANGE

REPORT No. 21



Global Change and Terrestrial Ecosystems **The Operational Plan**

The International Geosphere-Biosphere Programme: A Study of Global Change (IGBP)
of the International Council of Scientific Unions (ICSU)
Stockholm, 1992

GLOBAL I G B P CHANGE

REPORT No. 21

Global Change and Terrestrial Ecosystems The Operational Plan



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Introduction

Global change presents a formidable and unique research challenge. The world's terrestrial ecosystems are being subjected to changing **environmental conditions of an unprecedented scale**, both in their rate and in their geographical extent. The ability of human societies to ameliorate, adapt to, and benefit from these rapid changes requires fundamental knowledge of the responses of terrestrial ecosystems to the forces of global change. To answer this major research challenge, the International Geosphere-Biosphere Programme (IGBP) has established a core project on Global Change and Terrestrial Ecosystems (GCTE).

The **rationale for this project, and the details of the strategic research plan, are laid out in Chapter 6 of IGBP Report No. 12 "The International Geosphere-Biosphere Programme: A Study of Global Change. The Initial Core Projects"** (IGBP 1990), which followed two years of preliminary planning. This present document takes the strategic plan and develops it into an operational plan. It represents a synthesis of four international workshops held during 1991. The detailed reports of these workshops are available as working papers of the GCTE Core Project (GCTE 1991a-d).

The objectives of GCTE are:

- To predict the effects of changes in climate, atmospheric composition, and land use on terrestrial ecosystems, including agricultural and production forest systems
- To determine how these effects lead to feedbacks to the atmosphere and the physical climate system.

GCTE's operational definition of "global change" encompasses far more than just predicted climate change alone. It includes changes in atmospheric composition, such as the concentration of CO₂ and other greenhouse gases, which have increased and will continue to increase and which have direct impacts on vegetation with or without climate change. It also includes change in land use, as driven by demographic, economic, technological, and social pressures. Over the next few decades this human dimension of global change will have a more profound influence on the fate of terrestrial ecosystems than will climate change in most regions of the world, particularly the tropics.

The most challenging feature of global change, however, is that these driving forces are not independent but are strongly interactive. For example, population and economic

pressures are leading to large-scale clearing of forests in the humid tropics, which is clearly an important contributor to change in atmospheric composition. This change, in turn, will likely lead to global warming, which could then allow the expansion of intensive agriculture toward higher latitudes. This, again, would likely cause further emissions of greenhouse gases to the atmosphere.

This interaction of driving forces, impacts, and feedbacks is the essence of global change. The response of humans to rapidly changing conditions in moving and adapting their agricultural and forestry production systems and the response of more natural systems through migration, altered competition, and resilience to extreme events will lead to a changing mosaic of ecosystems across the earth's land surfaces. GCTE's goal is to develop a predictive understanding of these changes, robust enough to incorporate projections of direct, human-driven changes in land cover and soil conditions, interacting with rapidly changing atmospheric composition and climate.

The role of GCTE in the overall global change effort is, quite clearly, scientific research. However, given that the results of its research will have important implications for decisions about how to cope with global change, the project will be increasingly drawn into policy issues. GCTE's contribution to these complex policy debates will be in the role of honest broker. It will attempt to objectively prepare and interpret information for international and national bodies with policy responsibilities, in an attempt to clarify the potential effects of global change on terrestrial ecosystems, including agricultural systems.

Structure of the Project

The GCTE plan to meet the research challenge is based on a strategy that is global in scope and is comprised of a well integrated set of focussed scientific questions. The structure of the programme is designed to ensure cohesiveness by facilitating the flow of people, ideas, expertise, and information among the component parts.

The Operational Plan is organised into a hierarchy of Foci, Activities, and Tasks (see Appendix 1 for a summary), for consistency with the other IGBP core projects and for clarity of presentation. The four Foci are:

Ecosystem Physiology

Change in Ecosystem Structure

Global Change Impact on Agriculture and Forestry

Global Change and Ecological Complexity (proposed)

The first two Foci are designed to provide a fundamental understanding of the impacts of global change on ecosystem function, composition and structure, and their feedback effects. The third Focus, on agriculture and forestry, and the proposed fourth Focus on ecological complexity, are designed to examine the more specific impacts of global change on systems of great importance to humans – for the production of food and fibre, and for the maintenance of the Earth's biological diversity and ecosystem complexity.

The research programmes of the four Foci are closely interrelated, and the boundaries between the Foci, Activities, and Tasks are often blurred. There is much interaction among them. To ensure that the cohesive nature of the overall GCTE programme is maintained and enhanced, each Focus includes an integrating Activity which draws together the work of that Focus and links it to the other Foci. Figure 1 depicts the overall GCTE structure, emphasizing the linkages between Foci and to outside groups.

Integrating Facilities

Underpinning the formal research structure are four project-level facilities that also integrate the GCTE research effort:

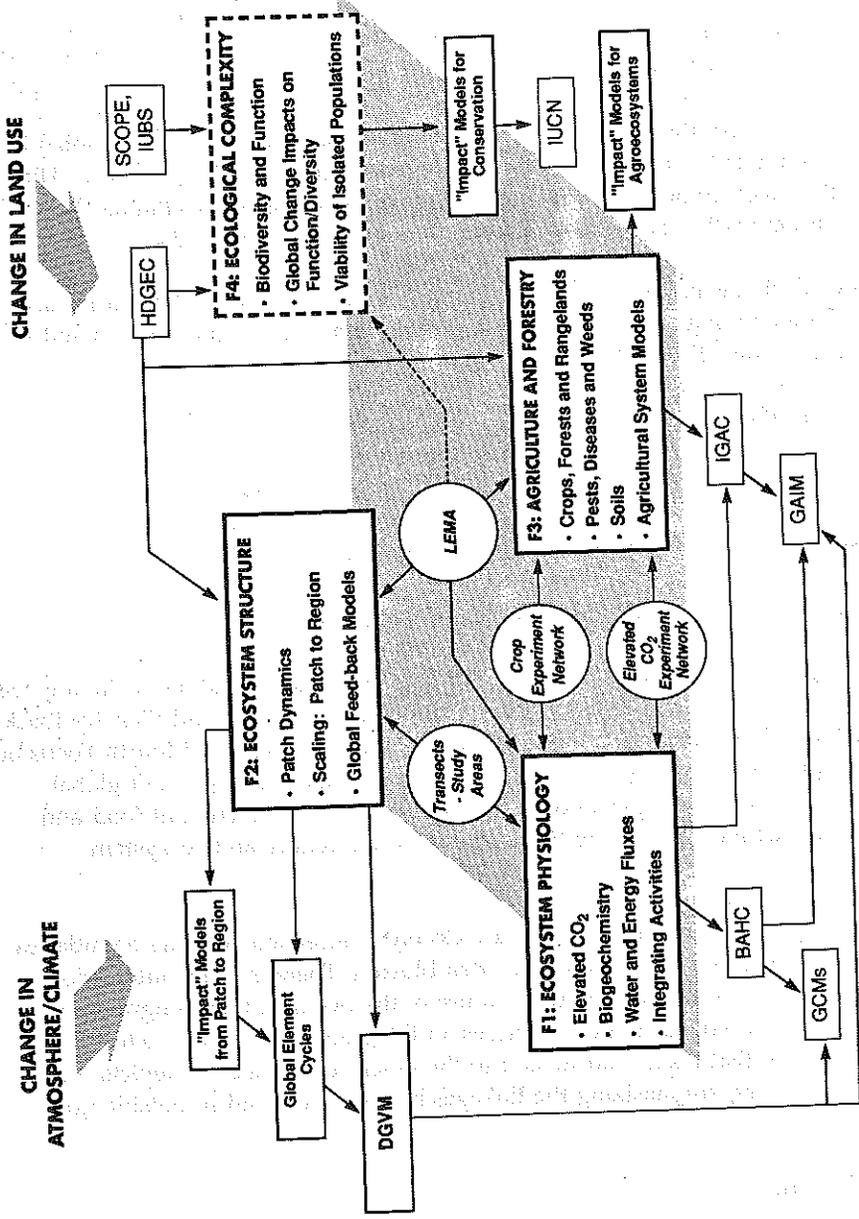


Fig.1 The structure of GCTE. Large boxes represent the four Foci. They are strongly linked through shared modelling efforts, common experimental sites, and several cross-cutting issues. Specific integrating facilities (shown by circles in the figure) further bring the overall GCTE research effort together. Small, bold boxes identify the products of GCTE, and the others are some of the major groups with which GCTE interacts.

- (i) The Long-Term Ecosystem Modelling Activity (LEMA) network of modelling centres. Although placed formally within Focus 2, the LEMA network will serve all four GCTE Foci by linking modelling activities from each. For example, the groups that develop the integrated models of ecosystem physiology in Focus 1 and the crop, forest and agricultural system modelling centre(s) of Focus 3, in addition to the Focus 2 modelling groups, will be part of LEMA.
- (ii) A set of major transects along environmental gradients, such as temperature or precipitation. These GCTE transects will be used for a variety of purposes, including biogeochemical experiments, comparisons of natural and agricultural ecosystems, and intensive study areas for development of ecosystem dynamics models.
- (iii) An international network of intensive crop experimental sites. The network will be used for studies of crop performance at various points in their environmental range, for studies of pest and disease dynamics, and for experiments on soil organic matter dynamics. Experimental results from network sites will underpin the development of integrated models of agricultural production systems.
- (iv) A set of experimental sites examining the impact of elevated CO₂ on ecosystem function using FACE (Free-Air CO₂ Enrichment) technology. Implemented under Focus 1, these systems are of particular interest to Focus 3, which will initiate its own set of elevated CO₂ experiments on individual crops and agricultural systems. In addition, these FACE experiments will provide important information toward Focus 2 and 4 objectives over the longer term.

Further details of these facilities are given in the body of the Operational Plan.

Cross-Cutting Activities

A number of issues – soils, water, and land-use change – cut across the entire GCTE research programme, and further unify it. Although water and soils are addressed specifically in only one Activity each (Activities 1.3 and 3.3, respectively), they are integral components of the GCTE research effort within all Activities – being critical to understanding the physiological response to global change at the ecosystem level, to predicting change in ecosystem structure and composition, and to developing robust models of agricultural and forest production ecosystems.

As mentioned earlier, change in land use will be the dominant component of global change in the short term for most parts of the world. Land-use change involves more than just the commonly described conversion of forest to arable land. It includes changes in land-use practices (usually agricultural intensification), such as cultivation vs. zero-tillage, fertilization and drainage. GCTE's role is to determine the effects of changes in land use on the functioning of ecosystems, along the entire spectrum from natural to intensively managed, and to incorporate projections of land-use change into

predictive models of ecosystem dynamics at the landscape and larger scales. Thus, land-use change is a crucial element of most of the Activities described below.

Flexibility

The Operational Plan provides a strong but flexible framework for organising the GCTE research effort. As in all science, the outcomes of this Plan are not entirely predictable, and the discovery of new effects and the generation of new ideas and approaches will prompt modifications and changes of direction. The GCTE Scientific Steering Committee (SSC) will monitor cumulating evidence from research in progress around the world, and will initiate changes to the Operational Plan when and where appropriate.

UV-B Radiation

An example of GCTE's flexible approach to this Operational Plan is the potential impact of increased harmful ultraviolet radiation (UV-B) on vegetation. Earlier assessments by terrestrial ecologists involved in the GCTE planning process had placed UV-B effects at a lower level, in terms of relative importance, than CO₂ or climate change effects. There is now growing evidence that the decreases in stratospheric ozone concentration, which are evident in northern high and mid-latitudes as well as the in the southern hemisphere, are leading to potentially more serious UV-B radiation effects. It has been established that some species of plants show detectable damage in response to expected increases in UV-B (Caldwell *et al.* 1989). As a result of such evidence, the GCTE SSC recommends phasing research on UV-B effects, where appropriate, into this flexible Operational Plan. GCTE's role is to augment the existing work on individual plants to determine the effects of enhanced UV-B at the level of whole ecosystems and agricultural production systems. The emphasis of the GCTE work will be on the impacts of UV-B acting in combination with the other components of global change.

The Research Plan

The detailed components of the Operational Plan, at the Task level, are outlined below for the first three Foci. Each Task includes a brief background, the objectives, an implementation strategy, and a proposed timetable for its development. Focus 4, on Global Change and Ecological Complexity, is currently under development, and its detailed Operational Plan will be published separately.

Definitions

To many, the following definitions will appear self-evident. However, given the surprising amount of confusion that arose in the planning sessions of the GCTE programme as a consequence of different interpretations of their meanings, they are stated here in unambiguous terms.

Ecosystem: Throughout the Operational Plan the term *ecosystem* is used as a general term for an interactive ecological unit, generally involving a set of functionally different biological entities and a dynamic abiotic component. Ecosystems normally include primary producers, decomposer micro- and macro-organisms, a pool of dead organic matter, herbivores, predators and other natural enemies, and an abiotic environment. The term *ecosystem* by itself does not connote any specific dimensions.

Patch, landscape and region: The term *patch* indicates a land unit treated as homogeneous for the purpose at hand, and integrated for the ecological property in question. The term *landscape* indicates a unit of terrain consisting of a number of contiguous patches. The dimensions of patches and landscapes are also nonspecific, but as a general rule, patches are of order 10-100 m (100-10,000 m²) and landscapes of order 1-10 km (1-100 km²). The term *region* indicates a number of contiguous landscapes, and is generally at least 100 km (10,000 km²) in dimension up to the size of several GCM grid cells each c. 500 km (250,000 km²).

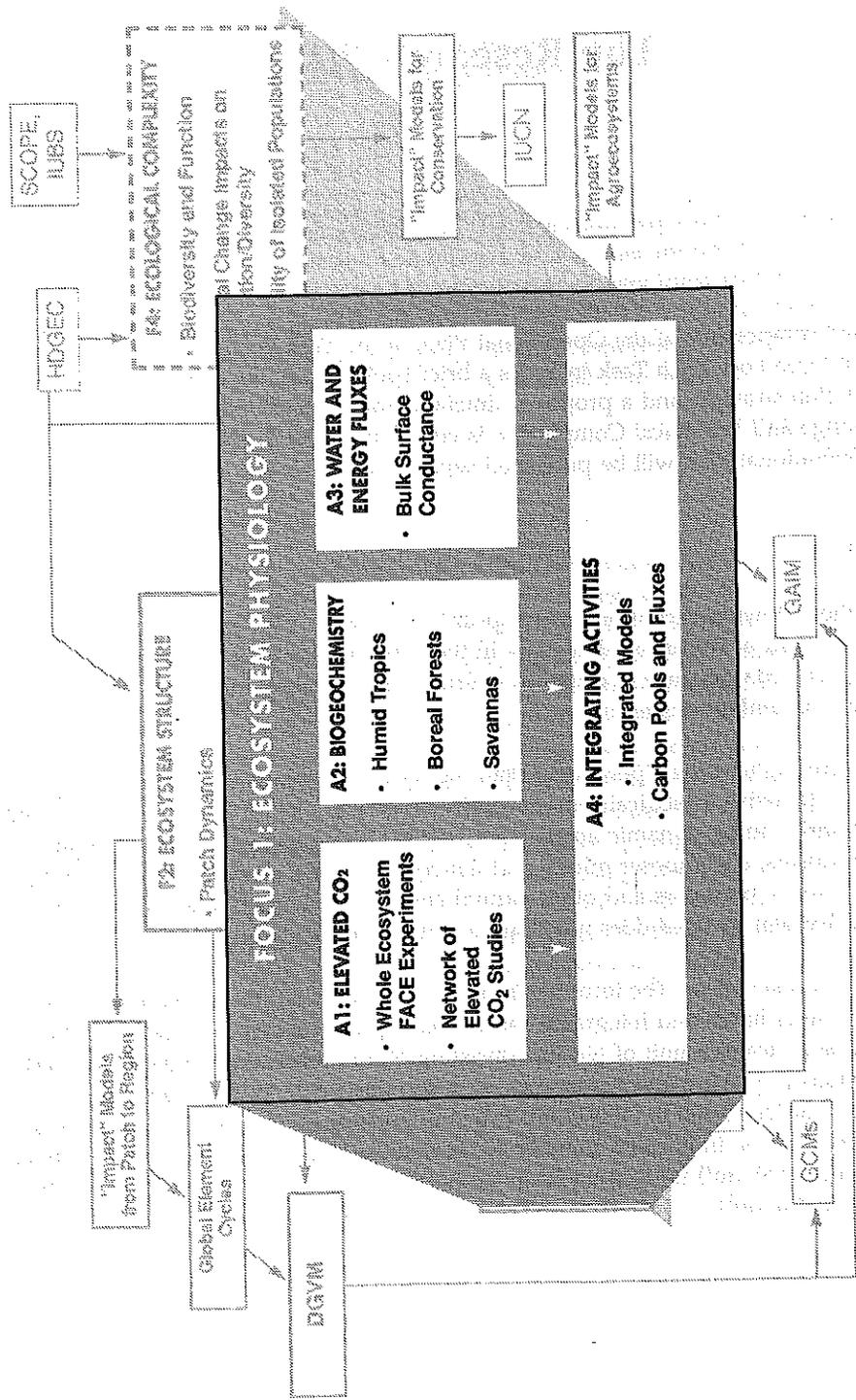


Fig.2 Focus 1 structure: relationships of Activities and Tasks

Focus 1: Ecosystem Physiology [Leader: H.A. Mooney]

The primary aim of Focus 1 is to understand and model the effect of global change on primary ecosystem processes, such as the exchange of energy, water and trace gases with the atmosphere, element cycling and storage, and biomass accumulation or loss.

A central thesis of Focus 1 is that the ways in which ecosystems function – their physiology – will be strongly affected by the combined and interactive suite of changes in atmospheric CO₂ (which will continue to increase beyond the recent 30% rise above pre industrial levels), land-use practices, and the likely changes in the means and extremes of temperature and rainfall.

In order to address these changes, Focus 1 is organized into four Activities. The first emphasizes the direct effects of elevated CO₂ concentration on plant physiology and ecosystem function. The second examines the response of biogeochemical cycles of carbon, nitrogen, and other elements to global change. The third studies changes in water and energy fluxes from the perspective of terrestrial ecosystems. The fourth activity integrates the first three through developing patch and regional models linking carbon, nutrient and water dynamics. Figure 2 shows the structure of Focus 1.

Activity 1.1: Effects of Elevated CO₂ [Leader: H.A. Mooney]

Although we know fairly well the responses of individual plants, under controlled conditions, to enhanced levels of CO₂ and other changed environmental factors individually, we are unable to predict responses at the ecosystem level because of higher-level interactions among environmental factors and between plants and other groups of organisms, some of which are nonlinear. Thus, it is virtually impossible to predict ecosystem responses based on laboratory studies that are generally of short duration and concentrate only on plant parts or, at best, whole plants. Conceptually there is a critical need for information concerning ecosystem-level interactions between CO₂ and other resources, especially nitrogen and water, and for experiments that explore the suite of ecosystem feedbacks, including changes in soil nutrient availability and herbivory. Figure 3 indicates schematically these major experimental Activities of Focus 1 and their interrelationships.

Long-term objective:

- To determine and predict the effects of elevated CO₂, interacting with other environmental factors, on ecosystem physiology at the patch scale, and to investigate potential feedbacks to the atmosphere.

balance, herbivory). CO₂ treatments will employ current ambient CO₂ concentration and 700 ppm CO₂ in air as the elevated treatment.

The whole ecosystem experiments will be closely linked to the development and operation of dynamic ecosystem models. This linkage will guide the interpretation of the results, sharpen the focus on understanding the mechanisms underlying the observed responses, and ensure the broader applicability of the results to other systems.

FACE experiments incorporating nutrient and water interactions will be large, complex and expensive undertakings. They are as yet unproven technology in natural ecosystems, and in order to achieve a successful set of such experiments, a phased development of the program will be undertaken. The Phase 1 pilot experiment will involve a small number of FACE rings with elevated CO₂ concentration (plus a number of control rings) as a "proof-of-concept" phase during which technical and logistical problems can be solved and the design of the full experiment can be fine-tuned and modified. Following the successful completion of Phase 1, the whole ecosystem experiment simultaneously manipulating CO₂ concentration and other environmental factors will be undertaken.

FACE experiment site selection (both among ecosystem types and for particular locations within ecosystems) will emphasize the following criteria:

- (i) CO₂ sensitivity - initial sites should represent ecosystems for which large vegetation responses are anticipated in order to generate a strong "forcing" for other ecosystem processes and carryover to Activities 2 (biogeochemical cycling) and 3 (water and energy fluxes).
- (ii) Feasibility - sites should be manageable in terms of access, ability to control environmental factors, and likely time scales of the responses.
- (iii) Knowledge gaps - sites should be in ecosystems for which the need for understanding is most critical in terms of present or expected global change.
- (iv) Interactions - experimental sites should be designed for maximum benefit from interactions with the other Activities of Focus 1, Activities 1 and 2 of Focus 3, the regional and global modelling efforts of Focus 2, and the experimental programmes of other IGBP core projects.

Based on these criteria, four geographic areas have been selected for initial emphasis.

Temperate grasslands are the most attractive initial system for study as they present the fewest technical difficulties due to their low-stature vegetation and structural similarity to the agricultural systems on which FACE technology has been successfully used in the past. In addition, there are grassland sites with extant whole-ecosystem models that consider the dynamics of the system in response to simultaneous changes in CO₂ concentration and other driving variables. Because the goal is to understand mechanisms, the generality of the results of experiments on grasslands will be high, and

will give a large advance in the understanding of ecosystem function. The first component of this project is a New Zealand grasslands programme, which is a component of Task 3.1.3 on pastures and rangelands and will contribute directly to this Task as well. The New Zealand programme includes a FACE experiment which is in an advanced stage of planning. A second grassland site, most probably a North American prairie, will be promoted as the first complex, natural grassland ecosystem to be studied with FACE technology.

The *temperate forest* is also an attractive system for early study because it is logistically simple, although technically challenging due to the requirement of controlling CO₂ concentration throughout a tall and aerodynamically complex canopy profile. Full-scale implementation of a temperate forest FACE system would proceed only after these technical challenges are met, perhaps following an initial installation in a low-stature, developing forest.

Tropical savannas and semi-arid ecosystems have been assigned high priority because of the sensitivity of savanna/desert boundaries to climate change and the potential for dramatic changes in ecosystems dominated by plants with different life forms (trees and grasses) and different photosynthetic pathways (C₃ and C₄). In addition, it is the savannas of the world which are absorbing the brunt of the human population increase. The potential for widespread human-driven changes to land cover in savannas necessitates the understanding of their contribution to the global CO₂ cycle.

The *boreal forest/tundra* transition comprises the fourth area to receive initial emphasis because of the large store of carbon in these ecosystems and the large warming predicted at high latitudes. Thus, there is a potential for significant change and for significant feedback to the physical climate system. However, the technical problems of heating a boreal forest (and elevating CO₂) are considerable and presently unsolved, and thus the experiments on these systems will be phased in after experience in designing and operating large, integrating, elevated CO₂ experiments has been gained in temperate forests.

Parallel designs in boreal forest and savanna are a potentially very useful feature. Systems could be matched in physical stature of the vegetation (with trees and/or woody plants a few metres high), but would contrast sharply in terms of role of temperature, and the relative importance of water and nutrient limitations.

Task 1.1.2: Integrating Experiments on Ecosystem CO₂ Response

Information from individual FACE experiments will be complemented by knowledge derived from a network of investigations utilizing an array of experimental approaches (open-top chambers, ecocosms, growth chambers, glasshouses) toward understanding the CO₂ responses of any natural system. Experiments with elevated CO₂ using open-top chambers are now in progress in several natural ecosystems including saltmarsh, chaparral, and two temperate grasslands. Although subject to chamber effects not present with FACE systems, the lesser expense and ease of replication of

open-top chambers means that they will remain an important component of the CO₂ experimental network.

Information from this network will provide details of responses not addressed in the early FACE experiments. Furthermore, the network will provide an understanding of the interactions of enhanced CO₂ with stress factors including enhanced UV-B and atmospheric pollutants.

Proposed Timetable

- | | |
|------|--|
| 1992 | Identification of existing ecosystem experiments; meeting of principal investigators. Establish framework for supporting network (co-sponsored by Focus 3). Meet with Activity 1.2. Initiate Phase 1 (pilot FACE) experiments. |
| 1993 | State-of-science workshop on "Ecosystem Responses to Elevated CO ₂ – Estimates and Uncertainties". Evaluate FACE feasibility and initiate Phase 2 (full-scale FACE) experiments. |
| 1994 | State-of-Science workshop on "Terrestrial Ecosystems as Sources and Sinks for Carbon" (jointly with Focus 3 and IGAC). |
| 1995 | Initial evaluation of FACE experimental network (jointly with Focus 3). |
| 1997 | First synthesis meeting (with all Activities). |

Activity 1.2: Changes in Biogeochemistry [Leader: P.M. Vitousek]

The overall emphasis of the biogeochemistry Activity is the terrestrial regulation of element pools, transformations, gains, and losses as they are altered by the components of global change. At this time, the single largest gap in our understanding is inadequate knowledge of the biogeochemical effects and feedbacks of elevated CO₂ concentration. An essential component of this Activity therefore is participation in the design, execution, and analysis of the CO₂ enrichment experiments described in Activity 1.1.

In addition, there are a number of regions in which changes in land use and atmospheric composition (including air pollution) and anticipated climate change are likely to alter the biogeochemistry of terrestrial ecosystems significantly, and consequently to cause significant feedbacks to components of global change. Among the most important of these are: (i) humid tropical forest areas undergoing land-use change; (ii) high latitude ecosystems near the boreal forest/tundra transition; and (iii) tropical semi-arid ecosystems along the transition from dry savanna to humid

woodlands. Other regions are important as well, and they will be included within the GCTE Core Research Programme as it develops, but these three are the initial priorities.

The critical regions identified above can be viewed as representing environmental gradients – of the intensity of land use, of temperature, and of precipitation, respectively. The effects of components of global change on the biogeochemistry of these regions can be determined most effectively by distributing measurements and experiments along a gradient of each underlying controlling factor. This is true for several reasons. First, in the past comparative studies have been most useful in understanding the patterns and putative controls of ecosystem biogeochemistry, and comparisons that are based on well-defined and continuous variation in an environmental factor yield still greater insight into how that factor controls biogeochemical processes. Second, ecosystem-level experimentation that is replicated along an environmental gradient can be used to analyze interactions among the underlying environmental factor, other environmental variables, and biotic components of ecosystems. Finally, carrying out research and modelling along gradients enforces an extensive, regional, and realistic (in terms of human influences) perspective upon biogeochemical studies.

Long-term objective:

- To determine the interactive effects of land use, altered atmospheric composition, and climate change on the biogeochemical cycles of carbon, nitrogen, and other elements. [The more immediate objectives are specific to each of the three critical regions.]

Implementation

This Activity will be implemented through three Tasks, one for each of the critical regions. Tasks may be added as additional regions are identified for study.

Task 1.2.1: Humid Tropical Forests Undergoing Land-Use Change

Much of the research proposed in this area is also part of Task 3.3.4.

Short-term objective:

- To determine the effects of land clearing and agricultural intensification on quantities and pathways of carbon and nutrient loss (and their regulation) in several humid tropical regions.

In many parts of the humid tropics, land-use change, usually the conversion of forests to agricultural use, is having a profound impact on biogeochemical cycles. The impact occurs in two phases: (i) the initial clearing of the forests, the techniques of which are important in determining the short-term alterations to biogeochemical cycles, and (ii)

the type and intensity of the subsequent agricultural use, which are critical in determining the longer term effects.

The most important missing information in studies of tropical land-use change is relatively coarse scale analyses of the pathways of, and processes driving, element loss during and following land clearing and during agricultural intensification. Such measurements should include all of the major pathways of loss, hydrologic as well as atmospheric. This means that watershed-level measurements of losses must be combined with atmospheric and soil-plant process measurements on scales of up to several kilometres. Measurements should include controlling processes such as the effects of cattle grazing on soil structure and the effects of an altered microclimate following land clearing on fire frequency and on litter decomposition in residual forest fragments as well as microbial process measurements.

One appropriate starting point for studying element loss in the humid tropics is the Brazilian Amazon. There is already multinationally supported research coordinated by a number of interacting Brazilian institutions underway or entrained there that includes watershed-level, basin-level, and atmospheric efforts. With additional process measurements on the soil-plant system, this large, integrated research project would be an ideal component of this GCTE Activity.

Another developing research programme that could make a substantial contribution to the tropical land-use change effort of GCTE is the project "Alternatives to Slash and Burn Agriculture", sponsored by a consortium of international agricultural research organisations. This project, which is an important component of the Focus 3 effort on soil organic matter dynamics (see Task 3.3.1), incorporates elements of the ongoing Tropical Soil Biology and Fertility Program (TSBF) of the International Union of Biological Sciences (IUBS) and includes a network of sites in all of the major tropical regions. With the inclusion of research on elemental fluxes across ecosystem boundaries (including trace gas fluxes), this project could extend the GCTE Amazonian study to a network of sites in Africa and Southeast Asia.

Task 1.2.2: High Latitude Systems

Short-term objective:

- To determine the interactive effects of increased temperature and changes in nutrient availability on carbon and nutrient pools and fluxes across the transition from boreal forest to tundra.

High latitude systems have been identified as critical in the context of global change effects because of the likelihood of significant temperature change there, the substantial stocks of carbon and nutrients in soils, and the contrast in dominant life-form across the boreal forest-tundra transition. Alaskan, Fennoscandian-European, and Russian sites have been identified as potential GCTE transects. The three candidate regions differ significantly in their topography and in the influence of permafrost.

At least five experimental sites should be established along each of the GCTE transects. At these sites, experiments should be established to evaluate the effects of elevated temperature and nutrient amendments upon rates of decomposition, carbon and nutrient transformations, plant growth, and trace gas fluxes. Nutrient amendments will be used because increased temperature itself is likely to cause increased nutrient availability, and because some boreal areas are now receiving increased loadings of nitrogen from the atmosphere.

The nature of trace gas emissions from these systems, and especially the balance between carbon dioxide and methane release, is strongly dependent on soil moisture. Hence, experiments designed to analyze temperature/moisture interactions (through supplementation, drainage, or even rain-out shelters) should be carried out at sites along these transects. Experimental manipulation of species composition and colonization should also be undertaken across the boreal forest/tundra ecotone.

Measurements to be made in the experimental plots and elsewhere include productivity, grazing, tissue quality, decomposition, soil moisture, soil nutrients and their dynamics, root dynamics, and trace gas fluxes. The relatively slow dynamics of high latitude systems means that a long-term commitment (10 to 20 years) will be required for this research. Each gradient will also provide an organizing framework for more extensive measurements of vegetation, biogeochemistry, and land use in the region.

Task 1.2.3: Semi-Arid Tropical Ecosystems

Short-term objective:

- To determine the interactive effects of altered precipitation and changes in land use (especially grazing and fire frequency) on the biogeochemistry of semi-arid tropical systems along a moisture gradient.

Semi-arid tropical ecosystems were selected because of the importance of and possible changes in precipitation as a controlling factor, and because of the pervasiveness of human modification in this region. Additionally, moisture gradients in the tropics are marked by strong contrasts in dominant life forms and even dominant photosynthetic pathways.

Two transects have been identified as initial GCTE gradients for intensive study: the established Savannas in the Long Term (SALT) transect in West Africa and the Northern Australia Tropical Transect (NATT) from Darwin to Tennant Creek. Two additional transects are under consideration: an east-west transect in Brazil, from the caatingas through to humid forest, and a transect on Kalahari sands in southern Africa.

At least five experimental sites should be distributed along each transect. It is intended that these will maintain experimental manipulations of water (through supplementation in all sites and possibly rain-out shelters in some), grazing and fire. Additional treatments could include manipulation of nutrient inputs and modification of species

composition or colonization. Parallel measurements in areas of more intensive agricultural use would contribute to our understanding of regional biogeochemistry, and to the Focus 3 research programme.

In all of the savanna transect experiments it will be necessary to determine and to maintain appropriate grazing and burning regimes. Complete protection from either factor constitutes an unusual (and extreme) 'treatment' for tropical savannas.

The minimum set of measurements to be collected in the experiments and along the gradients are similar to those listed for high latitude systems, although these will need to be supported by physiological as well as ecosystem-level analyses of alterations to soil and plant water regimes.

Future Tasks: Additional Priority Regions

Additional regions beyond the three identified here may be included in the GCTE programme as appropriate. Strong candidates include well-studied moisture gradients from grassland to forest in the temperate zone (from the central to the eastern United States; in the Ukraine), a temperate arid zone transect in the Patagonian region of Argentina, a temperate-tropical forest gradient in east Asia, and gradients of atmospheric deposition/oxidant concentration in temperate forest regions (northern Europe and northeastern United States).

All three of the critical regions identified here were also selected as priority research areas by the IGBP International Global Atmospheric Chemistry (IGAC) project. The approaches of the IGAC and GCTE programmes should be fully complementary in these areas, and indeed planning for joint research is already underway in specific research sites and transects. This collaboration should be encouraged and extended; it will make the overall research effort much more complete and useful. There are also some shared interests with the IGBP Biospheric Aspects of the Hydrological Cycle (BAHC) project, especially in the semi-arid tropics.

Proposed Timetable

- 1992 Joint GCTE (Foci 1 and 3)/IGAC meeting on tropical land-use change, including groups from the Brazil project and the proposed Alternatives to Slash-and-Burn project.
- 1993 Meeting of participants in semi-arid, boreal, and other GCTE transect studies. Discuss and decide treatments, experimental design, and initial models. Select final sites and initiate baseline measurements.
- 1993-4 Initiate coordinated experiments on transects and tropical land-use change gradients.

- 1994-5 On-going research, and meeting to discuss initial results, problems and pitfalls.
- 1997 First synthesis meeting.

Activity 1.3: Effect of Changes in Vegetation on Water and Energy Fluxes [Leader: E-D. Schulze]

Modelling evaporation from land surfaces in the context of General Circulation Models (GCMs) requires knowledge of the bulk surface conductance for water vapour transport, which determines the partitioning of energy into sensible and latent heat. This strongly affects continental hydrological cycles, including evaporation, exchanges between surface and ground water and the runoff of surface water. The bulk surface conductance is determined by both the structure and the stomatal properties of the vegetative cover, together with the evaporative properties of the soil surface. The vegetation canopy responds readily to changes in climate and to soil water availability. Evaporation from land surfaces can be modelled in SVAT (soil-vegetation-atmosphere-transfer) models as a submodel of GCMs only if the bulk surface conductance is taken into account. In addition, knowledge of bulk surface conductance is not only important for surface evaporation, but also for the water balance of ecosystems and its nutrient and carbon fluxes, which in turn feed back to influence vegetation structure and stomatal conductance. The aim of Activity 1.3 is to quantify bulk surface conductance, which combines stomatal regulation and physical structure of the vegetation to determine terrestrial evaporation.

This aim is not only important to GCTE, but also to the IGBP Biospheric Aspects of the Hydrological Cycle (BAHC) project. Therefore, Activity 1.3 will be conducted jointly with BAHC.

Task 1.3.1: Bulk Surface Conductance

Bulk surface conductance, G_s , combines into a single parameter a variety of physiological and physical factors describing a complex, multilayered system. One way of modelling G_s is to consider a maximum conductance, $G_s(\text{max})$, which is modified by environmental factors such as light, vapour pressure deficit, soil water status, and also by canopy structural parameters including vegetation height and leaf area index. It is expected that $G_s(\text{max})$ and G_s will change as ecosystems change, due to changes in land use and climate. The primary objective of GCTE is to develop the capability to predict effects of changes in ecosystem structure and function which are caused by global change; the goal of BAHC is to develop the same capability for the prediction of hydrological changes. It is therefore necessary that G_s and its response to

climate are measured and modelled. GCTE and BAHC will undertake this task jointly, as GCTE Activity 1.3 and BAHC Activity 1.2.

Although the main emphasis of this Activity presently aims at understanding canopy evaporation, it is quite clear that the water balance of a habitat will affect plant water relations and community composition. This aspect of ecosystem physiology is presently included in the studies of Activity 1.2 and in Focus 2. At some later stage of this project it may be necessary to create an additional task under Activity 1.3 to study in greater detail effects of plant water relations.

Long-term objective:

- To develop the capability to predict the effects of vegetation changes on water and energy fluxes between land surfaces and the atmosphere, and in particular the changes in bulk surface conductance with season, succession and long-term CO₂ increase.

Short-term objectives:

- To quantify, as far as possible, bulk surface conductance for the major biomes of the earth, from data in the literature
- To assess the requirements in terms of accuracy and spatial representativeness for current and foreseeable models of bulk surface conductance, for the purposes of (i) parameterizing land surfaces in GCMs; and (ii) investigating ecosystem responses to climate or composition changes
- To develop a patch-scale model of bulk surface conductance, based on plant physiological mechanisms and the physics of transfer through the soil-plant-atmosphere continuum, accounting for the responses of bulk surface conductance to climatic factors (light, vapour pressure deficit), soil water availability and nutrition
- To extend the available data on bulk surface conductance by means of appropriate ground-based measurements
- To develop the capability for inferring bulk surface conductance from remotely sensed data.

Implementation

This will be undertaken in phases, consistent with the short term objectives.

Phase 1: Evaluation of existing data on bulk surface and leaf conductances. This implies a decision about the classification scheme used to define the biomes of the earth.

As a starting point, a Matthews (1983) or equivalent map will be used, but the classification scheme itself is a research question for Phase 1. An output will be a list of regions from which new data must be gathered. Phase 1 will also include a sensitivity analysis on bulk surface conductance, to be undertaken in conjunction with a GCM modelling group, to determine the precision with which G_s needs to be determined.

Phase 2: Development of a globally applicable model for bulk surface conductance. The model must deal with variability of canopy structure, including the distributions of height and vegetative cover among the components of a multilayered canopy, and must also account for differing nutrient regimes. Techniques for extrapolating patch-scale values of bulk surface conductance to GCM grid cells will be developed.

Phase 3: Ground-based measurements in major biomes of the world for which data do not exist (determined in Phase 1). A preliminary estimate is that about three person-years of effort is needed for each biome studied. It is intended to include with these ground-truth measurements flux measurements of other gases, especially CO₂.

Phase 4: The development, in conjunction with models (Phase 2) and ground-truth measurements (Phase 3), of the capability for inferring bulk surface conductance from remotely sensed data.

Proposed Timetable

| | |
|--------|--|
| 1992 | Literature survey and sensitivity analysis. Start of the modelling work. |
| 1993 | Planning meeting on field measurements. |
| 1994-6 | Ground-based measurements. |
| 1995 | Planning meeting on progress in field measurements. Start of remote-sensing component. |
| 1997 | Synthesis meeting. |

Activity 1.4: Integrating Activities [Interim contact: H.A. Mooney]

Global change will lead to the simultaneous alteration of a number of environmental variables. The whole-system CO₂-enrichment studies, the gradient studies in critical regions, and the water and energy flux studies to be conducted in Focus 1 are designed to provide insights into how global change will affect key ecosystem processes involved in the carbon balance, nutrient dynamics and hydrologic cycling. The final requirement in Focus 1 is to bring these changes together so that we can predict the net effects of their simultaneous actions. Task 1.4.1 undertakes this integrating effort, while Task

1.4.2 develops one of the important products of the integrating models - a better understanding of terrestrial ecosystems in the global carbon cycle.

Task 1.4.1: Integrated Models of Ecosystem Physiology under Global Change

The results of the field research carried out in the first three Activities of this Focus will be used to develop and test ecosystem-scale models of carbon, nutrient and water cycles that are useful for global change research. Such models will also be valuable in guiding the design and execution of the experiments themselves. In addition, this integrating Task will provide the direct link from Focus 1 to the other three Foci. Specifically, it will provide much of the experimental and process model foundation for the development of patch-scale dynamics models in Focus 2. It will provide a link to Focus 3 by providing a direct comparison with the ecosystem-type process models to be developed for agricultural production systems. Finally, it will provide the patch-scale process models needed to underpin the Focus 4 Activity on the relationship between ecological complexity/biodiversity and ecosystem function.

Long-term objective:

- To develop (and/or improve) integrated carbon, nutrient and water models at the patch scale to predict how global change will affect the physiology of terrestrial ecosystems in the decades to century time-frame.

Short-term objectives:

- To develop linked plant-soil models of carbon, nutrient and water interactions at the patch scale to operate at time scales of days to decades.
- To use the models to predict the consequences of resource changes (CO₂, nutrients, water) for carbon fluxes and storage in conjunction with (i) CO₂-enrichment experiments, and (ii) gradient studies in the critical regions identified by GCTE - semi-arid tropics, wet tropics, and tundra/boreal regions.
- To incorporate the multiple-resource patch-scale models into the development of Activity 2.1's patch-scale models of change in ecosystem structure and composition.

Implementation

This integrating activity will begin with a workshop that documents the state-of-the-art in whole-system modelling of terrestrial ecosystems. Existing models will be presented and their usefulness for global change research will be reviewed. Based on these reviews, a minimum set of criteria will be defined for models to be used as synthesis tools for Focus 1.

A cooperative confederation of ecosystem modelling groups will be formed following this workshop, and included in the LEMA network. Each group will be asked to develop and/or refine models for use in Focus 1. These teams will meet periodically to review progress, and will also cooperate with empirical researchers from Focus 1 to test the models against field results. There are strong links between this Task and the following one (on carbon-pools and fluxes), and the models will be used as an input to this second Task.

Proposed Timetable

| | |
|--------|--|
| 1992 | Meeting of modelling teams to review state-of-the-art patch-scale biogeochemical models and to define the minimum set of criteria for a Focus 1 model. |
| 1992-3 | Initiation of modelling activity by modelling teams. |
| 1994 | Meeting of modelling teams with field researchers to discuss modelling results, problems and pitfalls. |
| 1997 | First synthesis meeting. |

Task 1.4.2: Carbon Pools and Fluxes in Terrestrial Ecosystems

The major goal of this Task is a better understanding of terrestrial ecosystems as sources and sinks for atmospheric CO₂. The overall effort can be viewed as consisting of both top-down and bottom-up components. The top-down approach makes use of the seasonal and spatial patterns in atmospheric CO₂ concentrations determined by atmospheric sampling networks, together with global circulation models, to calculate source/sink distributions for CO₂. The effort has made enormous progress in the past five years, but it is now limited by the sparseness of monitoring stations, especially in continental regions.

In contrast, bottom-up approaches calculate a source/sink distribution for CO₂ based on measurements and/or understanding of CO₂ exchange in local areas extrapolated regionally and globally. The top-down approach is more likely to be successful in determining current sources and sinks (including, for example, the present day importance of deforestation and the northern hemisphere terrestrial sink), while the bottom-up approach has the potential to explain why any pattern occurs, and to make projections into the future.

Objective:

- To understand and model the emissions and sequestration of CO₂ by terrestrial ecosystems for global carbon models.

Implementation

This Task will build on the experimental results of Activities 1.1 and 1.2 and the integrated models of Task 1.4.1 to develop a better mechanistic understanding of the role of terrestrial ecosystems in the global carbon cycle. The models developed in this Task will integrate information on carbon storage and release from experiments with elevated CO₂ and from studies along environmental gradients. These models will then be used interactively with results of atmospheric-based measurements of carbon sources and sinks to develop an understanding of the systems and mechanisms that serve as sources and/or sinks for CO₂. In some cases additional measurements may be necessary to resolve sources and sinks, and the modelling effort will be most useful in determining both the appropriate measurements and the sites at which they should be made.

There are a number of specific components of this Task that must be accomplished in order to assist the larger scale modelling of CO₂ exchange. The most important of these are:

- (i) A better understanding of what is involved in the stabilization of soil organic matter. We can predict rates of litter decomposition reasonably well, but are less successful at predicting what fraction of litter carbon goes into more recalcitrant soil pools, or what determines its turnover once there. This project will be carried out in close collaboration with Activity 3.3.
- (ii) Refined understanding and set of general models for the determinants of plant allocation and plant respiration on coarse scales. This modelling project will be carried out in cooperation with the IGAC programme, which has the responsibility of extrapolating the patch-scale models to regions and continents.

Proposed Timetable

- | | |
|------|--|
| 1992 | Collaboration with atmospheric scientists to choose additional terrestrial stations for monitoring atmospheric CO ₂ . |
| 1993 | Initial development of mechanistic models for CO ₂ emissions and sequestration by terrestrial ecosystems. |
| 1994 | State-of-science workshop on soil organic matter (SOM) dynamics and the global carbon cycle (jointly with Focus 3). |

Focus 2: Change in Ecosystem Structure

[Leader: I.R. Noble]

Changes in atmospheric composition, climate, and patterns of human land use will undoubtedly lead to changes in both the distributions of plant and animal species and the species composition of ecosystems. Changes in ecosystem composition will, in turn, lead to changes in habitat for many other species, and to changes in aspects of ecosystem physiology, such as evapotranspiration and nutrient cycling.

Of the driving forces of global change, the most important for determining the distribution and performance of organisms are the range and seasonality of temperature, precipitation, and other environmental factors; the intensity and frequency of severe, episodic events, such as fires and hurricanes; and, for much of the earth, the group of demographic, economic, and social pressures related to human activities. These factors, combined with physiological responses such as sensitivity to high CO₂, longevity and ability to disperse, will determine the future structure of the world's ecosystems.

The goal of Focus 2 is to model this complex suite of impacts and responses so that the pattern of change in ecosystem composition and structure can be predicted. This modelling effort will be closely linked to the other three Foci of GCTE. At the patch scale, the integrating Activity 4 of Focus 1 will provide the ecosystem-level physiological and biogeochemical understanding needed for relating change in function to change in structure. Focus 2 will build on the Focus 1 process models by extending them to longer time scales, and by incorporating the other driving forces of global change noted above.

At larger spatial scales, particularly regional and global, the direct human driving forces of change will come into play. Landscapes consist of a mosaic of patches, some of which are natural, some intensively managed for agriculture, and others managed with varying degrees of human intervention. At these scales the Focus 3 research on the responses of agricultural production systems, which include soils, pests and weeds in addition to crops, to changing environmental conditions will provide a useful basis for estimating potential change in land use patterns. The demographic, economic, and technological factors so critical in patterning landscapes modified by humans will be included through close links with the HDGEC programme.

The ability to predict change in ecosystem structure and composition is being developed for two distinct purposes:

- (i) The first, and more important, purpose is to predict the impacts of global change on terrestrial ecosystems in their own right (i.e., independent of their feedback to the atmosphere). If human societies are to adapt to and perhaps benefit from global change, then we must be better able to predict what will happen to the terrestrial ecosystems on which we depend. Thus, much of the emphasis of

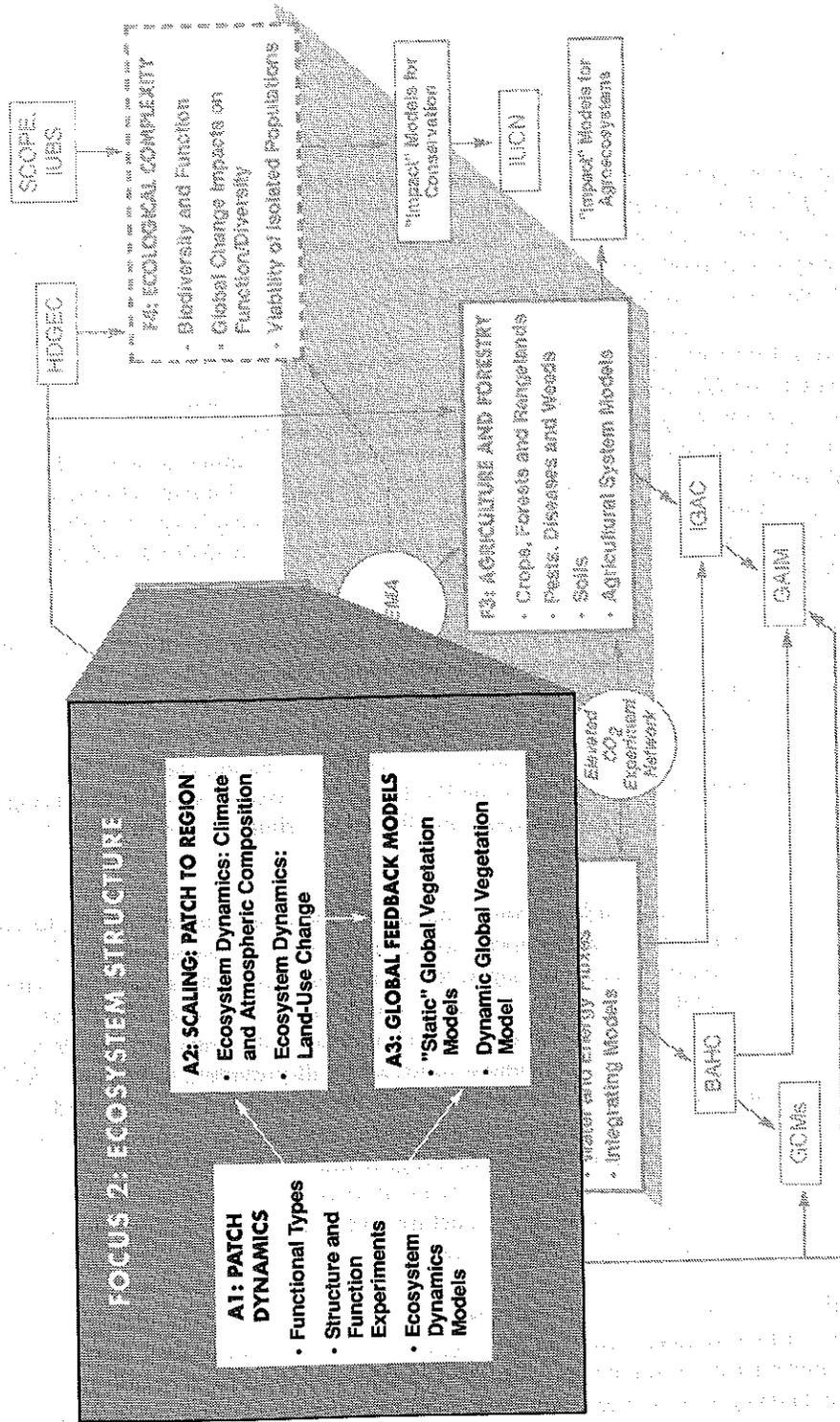


Fig. 4 Focus 2 structure: relationships of Activities and Tasks

Focus 2 will be on the development of a nested set of "impacts" models to predict changes in ecosystem structure at a wide range of scales, from patch to landscape to region. In addition, it is essential that models are developed for all the major biomes of the earth.

- (ii) The second purpose is to build a dynamic global vegetation model that will capture the feedback effects that changes in ecosystem structure and function will have on further atmospheric changes, and which can be linked to the general circulation models (GCMs) that predict future climate. At present the only global models predicting vegetation distributions are static and thus not capable of forming an interactive component in GCMs. GCTE aims to produce a mechanistically-based dynamical model of global vegetation for incorporation in GCMs.

Focus 2 is structured around three Activities. The first is based on the development of ecosystem dynamics models at the patch scale. This Activity links the Focus 2 effort to the other two Foci, and provides the basis for the extension of the predictive capability to larger spatial and temporal scales. Activity 2.2 is centred on scaling up the patch models to landscapes and regions, primarily for predicting the impacts of global change on the management of landscapes. Activity 2.3 aims to develop regional and global scale models of vegetation change for element cycles and climate feedback. Figure 4 shows the structure of Focus 2.

Activity 2.1: Patch Scale Dynamics [Leader: F.I. Woodward]

The wide range of experiments in Focus 1, and the associated process models, will improve our understanding of the effects of global change on plant and soil processes at the patch scale. These functional responses will underpin the efforts of Activity 2.1 to predict the future composition and structure of patch scale systems under novel combinations of climate, CO₂ concentration, and UV-B levels. A mechanistically-based prediction of the effects of global change on structure and composition of communities can be achieved only by understanding processes. Central to this predictive capability will be the development of one or more models of patch dynamics, which will be both the nucleus of this Activity and the basis for integrating over large areas such as landscapes and regions.

Task 2.1.1: Global Key of Plant Functional Types

It will not be feasible to develop models for every ecosystem of the globe nor represent every species within those ecosystems. Thus, the concept that the complexity of nature can be reduced in models by treating a smaller number of 'functional types' (FTs) is central to the work of Focus 2. The idea that a functionally oriented (as opposed to a phenetic or phylogenetic) classification of organisms may be an effective way of reducing the complexity of modelling ecosystem processes has been around for some years.

It has often been argued that the essential dynamics of ecosystems can be captured by grouping species into a restricted number of FTs, (Grime 1979; Noble & Slatyer 1980; Woodward 1987). Various robust, but partial, keys of FTs have been developed for specific ecosystems. However, there seems to be little congruity between such *ad hoc* schemes (Raunkier 1904; Box 1981), nor agreement about their capacities to predict dynamic responses of the functional types to change.

The FT approach is based on a minimum set of functional attributes that are considered to be most critical in reliably predicting the present-day distribution of plants from climatic input variables. This set of attributes (e.g., frost resistance, phenology, stomatal conductance, response to high CO₂, longevity, etc.) defines a FT. The entities (e.g., species) that possess the same set of attributes are all classed in the same FT. The emphasis on a minimum set of functional attributes allows the global scope of the approach, with a strong avoidance of non-essential detail about attributes that are of secondary or lower importance in controlling distribution. A major task of this Activity will be to develop simple rules or keys to help recognise FTs.

Functional types can be defined on epistemological grounds and the convergence in ecosystem structure and function in different parts of the world suggests the existence of actual groupings of organisms. These groups are the result of physical and biological constraints and trade-offs. Consequently, the number of realisable functional types will probably be a small fraction of the total number of combinations of attributes.

Long-term objective:

- To develop a general classification system of plant (and eventually animal) functional types appropriate for predicting the dynamics of change in ecosystem structure due to the impacts of global change.

Short-term objectives:

- To review the current state of knowledge of the functional type approach at a global scale
- To elucidate the ecological constraints and trade-offs in morphological and physiological attributes which define functional types
- To initiate case studies where a functional type approach can be tested and assessed.

Implementation

The FT programme will be implemented in a number of stages, beginning with an international symposium to stimulate the agreement as to the purposes of a FT

classification (within the GCTE context), leading to the necessary research and the development of the classification, followed by experimental protocols to determine plant and FT responses to new combinations of climatic variables and atmospheric composition.

Phase 1: A review of the present state of knowledge will be undertaken as a lead-up activity to the symposium. The review will compile the existing models and experimental results related to the FT approach, identify the major gaps and weaknesses that must be addressed, and indicate the future research needed to develop a global change-related classification of FTs.

Phase 2: A major international symposium will be held to bring together current researchers interested in the FT approach and to stimulate further interest in the topic. The meeting will focus on those attributes of plants and vegetation that are responsive to global change parameters and on an initial classification of plant FTs relevant to global change.

Phase 3: On the basis of the results of the first two phases, a comprehensive research programme will be initiated. The experimental component of the programme is described in Task 2.1.2 below.

The experimental programme for the definition and testing of FTs will take place at a small number of sites in the major biomes of the world, so far as possible taking advantage of the experimental projects to predict the direct influence of CO₂ enrichment. The process models developed in Activity 1.4 should be able to predict the most sensitive attributes for use in defining FTs. Equally, it might be possible to use the slopes of attribute response surfaces determined from local site variability in climate and CO₂ concentration to indicate sensitive functional attributes.

Phase 4: The final stage of predicting the responses of FTs to changes in climate and CO₂ concentration across all biomes of the world is difficult because it is likely that a knowledge of FT responses to novel combinations of climate and CO₂ will be required. Also, some biomes have poorly established models of the climatic control of FT distribution and will eventually require a wide range of experimental, observational, and modelling endeavours. Building on the first three phases, a research programme will be initiated to tackle these difficult issues.

Proposed Timetable

- | | |
|------|---|
| 1992 | Phase 1: small meeting to complete the task of reviewing existing knowledge of FTs (latter half of 1992). |
| 1993 | Phase 2: symposium and publication of comprehensive review of state-of-the-art in FT research (mid-1993). |

- 1993 Phase 3: initiation of GCTE FT research programme in selected areas, as case studies, based on results of Phases 1 and 2.
- 1994 Phase 4: extension of research effort to all biomes to determine FT responses and develop classifications based on new combinations of global change parameters.

Task 2.1.2: Experiments on Ecosystem Structure and Function

Much of the GCTE experimentation is concentrated in Foci 1 and 3. However, some experimental work in Focus 2 is necessary to understand the interactive processes between ecosystem structure and function that will govern changes in community composition. In addition to contributing to the FT classification, these experiments will also be central to the developing and testing of ideas about assembly rules that define the structure of communities in terms of functional types.

The work will be based on a series of manipulative experiments in which biological composition (structure) and abiotic environment (factors affecting physiological function) are separately altered, and the effects on each other measured. The aim is to determine how much change, in which functional types of species, will lead to significant changes in function; and *vice versa*, how much change in which environmental factors (total rainfall, seasonality, extremes of temperature, grazing pressure, etc.) will lead to significant changes in community composition. A good example of the technique is a "reciprocal experiment", in which plant FTs are added and/or subtracted at different locations in parameter space and simultaneously, on adjacent sites, resources such as water and nutrients are added and/or subtracted. The results will be used to relate FT performance to changing functional input variables (thus contributing to developing and refining the FT classification), and will be instrumental in answering questions about how much of what sorts of changes are important in global change predictions.

Objective:

- To identify (and, so far as possible, quantify) the important mechanisms that link change in ecosystem structure to change in function, and *vice versa*.

Implementation

The experiments will concentrate on the manipulation of the physical (temperature and precipitation) and chemical (C, N, P, S) environments, and plant functional types. Observations will be made of structural and population variables, and of biogeochemical and hydrological pools and fluxes.

Experimental sites will be closely linked to the other components of the Focus 2 and the overall GCTE research effort. Thus, it is logical to locate the initial set of experiments in the two intensive study areas identified below in the Focus 2 Integrating Activities.

Proposed Timetable

- 1992 Site selection, establishment of research groups, and initial experimental design and preliminary manipulations at two intensive study sites.
- 1993 Final experimental design and establishment of major projects at two intensive study sites.
- 1995 Extension of experimental programme to additional study sites.

Task 2.1.3: Patch Models of Ecosystem Dynamics

The models developed in Focus 2 aim to predict the dynamics of structural and functional change at the scales of the patch, landscape and region. Therefore, the basic modelling unit of the patch must also contain the elements needed to predict these dynamics, and the capacity for linking changes in function with those in structure. This modelling effort will be carried out in close collaboration with the integrating Activity 1.4 of Focus 1, which will also develop process models at the patch scale. The process models, however, will operate on a shorter time scale than the structural dynamics models of this Task.

Long-term objective:

- To develop patch models of ecosystem dynamics for global application, incorporating mechanistic information on the responses of plant processes to global change and the influences of these responses on ecosystem structure.

Short-term objective:

- To develop models of patch dynamics for two study sites, based on the FT approach and the experiments on ecosystem structure and function.

Implementation

The approach will be to develop assembly rules for plant FTs (Task 2.1.1) at regional and global scales. The assembly rules will indicate the range of possible structural types of species which could occur in a patch. Given this potential range, either a

subset of these FTs will be allowed to compete in the patch model, or the number of types that can occur will be determined as the potential set for the surrounding and/or adjacent biomes. This approach will also be taken up in the dynamic global vegetation model (Task 2.3.3) to model the potentials for migration at the landscape scale.

Proposed Timetable

1992 Identification of candidate patch models and modelling groups, via LEMA.
1994 Test of models on two study sites.

Activity 2.2: Models From Patch to Region [Leader: I. R. Noble]

The dual objectives of GCTE are to predict the impacts of global change on terrestrial ecosystems, both natural and managed; and to determine the consequent feedbacks to the atmosphere and physical climate system. This and the next Activity are the culmination of GCTE's research effort to meet these objectives, and are built firmly on the experimental programmes of the other Foci and on the smaller scale modelling efforts of Activities 1.4 and 2.1.

Although the patch models of ecosystem dynamics to be developed in Activity 2.1 may be of direct use to management authorities in some cases, most management units are of landscape size or larger. For example, managing nature reserves to maintain biodiversity (see Activity 4.3) requires information on ecosystem response at larger than patch scales. Likewise, management strategies for sustainable harvesting of forests over large areas or decisions on whether to crop or graze marginal lands under global change demand a solid understanding of ecosystem dynamics at scales of tens or hundreds of kilometres.

The goal of this Activity is to build on the experimental and modelling efforts elsewhere in GCTE to develop a suite of models, from patch through landscape to region. These models will be specifically designed to understand and predict the impacts of global change on ecosystems. While changes in atmospheric composition, particularly CO₂ concentration, and climate will have significant effects on ecosystem composition and structure at the landscape level, it is at this level that human-driven changes in land use, and the consequent changes in land cover, will also have a profound impact. Thus, the two Tasks within this Activity clearly emphasize the importance, but different nature, of both major driving forces of global change. Although atmospheric composition/climate change and land-use change are formally separated into two Tasks, it is clear that the *interactive* effects of these forces will have to be taken into account in understanding and predicting impacts on ecosystems.

Task 2.2.1: Ecosystem Dynamics from Patch to Region, Based on Change in Climate and Atmospheric Composition

The models of ecosystem dynamics at the patch scale, which will incorporate the fundamental understanding of ecosystem-level physiology under global change developed in Focus 1, will provide an excellent basis for the larger scale models. However, building landscape and regional models from the patch scale is not a simple process of aggregation. New processes, which can have a profound effect on ecosystem composition and structure, come into play at larger scales. The most important of these processes are dispersal/migration, disturbances/extreme events, and the impact of human land use (see Task 2.2.2).

Migration is an important factor in determining how vegetation composition will change under changing environmental parameters. Therefore, the ability of a species or FT to disperse, including the ability of the dispersing agent itself to survive changed conditions, becomes critical in determining how ecosystems will change. Not all species or FTs of a given ecosystem will be able to migrate at the same rate. Existing vegetation may persist through the changed conditions and thus exclude invading species. In addition, humans will greatly enhance the rate of spread of some species. These and other interactive effects are complicating but important factors in modelling migration.

Ecosystems often change, not by a slow invasion of species, but by a rapid change-of-state due to a disturbance or extreme event. Fires, droughts, extreme wet years and severe storms are examples. Accounting for these effects in landscape and regional models requires knowledge of how, for example, the intensities, frequency and patterns of fires and severe storms will change as a result of global change. For the latter, "weather generators", to be developed with BAHC and/or WCRP, will be necessary to predict the individual events which, averaged together, determine the changing climate.

Long-term objective:

- To develop a suite of models of climate- and atmosphere-driven ecosystem dynamics, based on patch models and incorporating landscape effects, on scales relevant to management decisions.

Short-term objective:

- To establish, via LEMA, a core of modelling groups operating at the landscape level, and develop agreed model protocols to meet GCTE requirements.

Implementation

At present there are a number of candidate models and approaches for predicting changes in ecosystem dynamics at the landscape and larger scales. GCTE will foster and stimulate this diversity of approaches by incorporating the appropriate modelling groups within LEMA and providing a common framework for developing robust and generalisable models that can handle changing environmental conditions. In addition, the LEMA and GCTE Study Area facilities will provide standardised databases, promote model comparison tests, and sponsor synthesis workshops.

The Task will be implemented in a number of stages:

Phase 1: Appropriate modelling groups will be identified and invited to participate in Task 2.2.1 by joining the LEMA network. The initial group will not be exclusive; additional groups can join as their interests and expertise develop.

Phase 2: A coordinating workshop will be held to determine protocols for the model development: input/output parameters, processes to be modelled, format of data to be provided, etc.

Phase 3: Model development will be undertaken based on the initial two GCTE intensive study areas. This will be followed by a model comparison and identification of most appropriate models for further development.

Phase 4: Model development will be extended to other biomes. Management-oriented model output packages will be developed at appropriate points in Phases 3 and 4.

Proposed Timetable

| | |
|------|---|
| 1992 | Identification of initial modelling groups and linkage to LEMA. |
| 1993 | Workshop to determine protocols for model development. |
| 1995 | Model comparison based on initial two GCTE study areas. |
| 1996 | Extension of model development to other biomes. |

Task 2.2.2: Ecosystem Dynamics from Patch to Region, based on Change in Land Use

Direct, human-driven change in land use will be a crucial factor driving change in the Earth's land cover. The deforestation of the humid tropics and desertification in the semi-arid tropics are oft-cited examples, but land-use change may also be important in temperate zones and developed countries. For example, economic pressures are predicted to change large areas of Western Europe from intensively cropped farmland

into forests, and the recent political upheavals in Eastern Europe are likely to lead to significant changes in agricultural practices.

Any prediction of ecosystem dynamics at landscape and higher scales must therefore account for these human-driven impacts. The goal of this Task is to determine the effect of land-use change on ecosystem structure and composition. The effects will be scaled to the regional level, and implications for management and amelioration strategies will be determined.

Much of the direct change in land use will be in agricultural production systems, both in the management of existing agricultural areas and the extension of agriculture to new areas (or the removal of agriculture in some cases). The Focus 3 work on the responses of agricultural and forestry production systems to a changing environment will provide a sound basis for projecting potential change in the extent and type of these systems across the earth's surface.

However, the actual changes that will occur are heavily dependent on demographic, economic, political, and technological factors. GCTE will need projections of how these factors might determine future patterns of land use, and thus lead to consequent changes in land cover. Therefore, this Task will be carried out in close collaboration with the Human Dimensions of Global Environmental Change (HDGEC) programme, which, in conjunction with IGBP, has proposed a joint project on global land-use/land-cover change (ISSC/IGBP 1992).

Objective:

- To develop, in collaboration with Focus 3 and HDGEC, spatially explicit models of land-cover change; and to determine the effects of these land-cover changes on ecosystem structure, composition, and function.

Implementation

The task will be implemented in two phases:

Phase 1. While the joint HDGEC/IGBP core project on land-use/land-cover change is being developed, GCTE will undertake a preliminary analysis, in the form of a number of pilot studies, of the impacts of human-driven land-use change on terrestrial ecosystems. The studies, which will be undertaken in close collaboration with the Focus 3 programme, will include both tropical and temperate systems:

- (i) humid tropics – clearing of forests for agriculture and intensification of agriculture
- (ii) semi-arid tropics – encroachment of cropping on marginal lands and intensification of grazing pressure on rangelands

- (iii) boreal forest – encroachment of the wheat zone because of increasing temperature
- (iv) temperate agricultural belts – changes of agricultural practices in the U.S.A. Midwest and in Eastern Europe.

These pilot studies will be based on current projections of likely scenarios for these regions, and will be designed to develop and refine the methodologies for incorporating land-use effects into dynamic models of ecosystem structure.

Phase 2: When the HDGEC/IGBP project on land-use/land-cover change is fully operational, this Task will be linked closely with that effort to obtain the best possible predictions of land-use change and to share data and modelling methodologies.

Proposed Timetable

- 1992 Support the HDGEC/IGBP working group in its review of current state of projecting land-use change into the future.
- 1993 Initiate pilot studies to develop methodologies for incorporating land-use change in ecosystem dynamics models.
- 1994 Collaborate with HDGEC/IGBP in a project on land-use/land-cover change.

Activity 2.3: Regional-to-Global Models of Vegetation Change for Element Cycles and Climate Feedback [Leader: H.H. Shugart]

At present there is no mechanism for incorporating the feedback of a changing land surface in a dynamic, interactive way into global models of the physical climate system or of biogeochemical or hydrological cycles. Global vegetation is assumed to be static. However, as a result of global change, the earth's distribution of vegetation will change, and this will lead to feedbacks to climate. The ultimate goal of this Activity is to develop appropriate dynamic models that can be used to calculate direct feedbacks through changes in surface conductance, albedo, and surface roughness and indirect feedbacks through changes in biogeochemical cycles.

Task 2.3.1: 'Static' Models of Global Vegetation Change

There are currently no global models of vegetation change that incorporate natural dynamics. Many predictions of present, past, or future vegetation are based on a grid-by-grid correlation of climate and biome types, with some rules to account for the

effect of soil type and competition between potential biomes. These grid-sized predictions are then summed to obtain the global response. Other models have predicted biomes from climate on the basis of ecophysiological mechanisms.

Although GCTE aims to ultimately replace these essentially static approaches with a dynamic global vegetation model, for now these direct patch-to-global techniques are valuable in providing 'first-cut' estimates of future vegetation distributions. Thus, an important task of Focus 2 will be the continued development and testing of techniques for directly extrapolating patch results to the globe (e.g., Emanuel *et al.* 1985; Henderson-Sellers 1990; the IIASA BIOME model of Prentice *et al.* in press).

In addition to global vegetation distribution, the correlative technique is used in other modelling endeavours. For example, it is the method for inferring past climates from paleo-ecological data, and it is the way that point estimates of fluxes of CO₂, CH₄, and other trace gases are scaled up for testing against global budgets or measurements. Therefore, improvements in the methodology for predicting vegetation distribution will have ramifications for other global modelling efforts.

Objective:

- To improve methodologies for directly scaling up predictions of vegetation distribution from the patch to the globe.

Implementation

Initial investigations will focus on the interpretation of GCM scenarios, both in terms of changes in vegetation distribution and in the consequent potential feedbacks to the physical climate system. For example, changes in precipitation, resulting in a change in vegetation distribution, will change albedo, and this could lead to strong feedback to further climate change (e.g., Paltridge 1991). The direct patch-to-global models will also be useful in calibrating the dynamic global vegetation model, to be developed in Task 2.3.2.

The improved methodologies for patch-to-global models developed in this Task will be evaluated by a number of relatively simple tests. For example, a reconstruction of climate from the vegetation inferred from paleo-ecological data can be tested for consistency with GCM or mesoscale meteorological models. Carbon uptake models summed over points can be tested against fluctuations in ambient atmospheric CO₂.

Finally, there is a direct link to Focus 1 (particularly 1.4.2) and to other IGBP core projects in the implementation of this Task. Critical to the overall IGBP objective of understanding the earth system as whole is the development of a suite of models of biogeochemical and hydrological feedbacks to the atmosphere, in addition to direct feedbacks from the land surface. GCTE has an important role to play in this effort by elucidating the ways in which terrestrial ecosystems regulate portions of these cycles.

The understanding of ecosystem physiology gained in Focus 1, coupled with the expertise in extrapolating from patch to globe developed in this Task, will provide the base needed to make this important GCTE contribution.

This Task, then, represents the initial contribution of GCTE to the overall IGBP modelling effort. GCTE will also contribute by developing a dynamic, global model of vegetation structure and composition, for incorporation in GCMs (Task 2.3.2).

Proposed Timetable

| | |
|------|---|
| 1992 | Review of current state of "static" global vegetation modelling and identification of candidate models for further development. |
| 1993 | Initiation, via LEMA, of strategies for refinement of methodologies. |
| 1994 | Tests of models against paleo-ecological data (with PAGES) and distribution of ambient CO ₂ ; calibration of dynamic global vegetation model |

Task 2.3.2: Dynamic Global Vegetation Model (DGVM)

Although patch-to-global models have made a significant step in understanding change in global vegetation, they have not been used interactively and are thus not on a direct development path to a dynamic global vegetation model (DGVM). What is needed is a mechanistic model that can predict change in vegetation structure and composition, and consequent change in direct and indirect feedbacks to the atmosphere, on time steps and spatial scales compatible with GCMs. The model must then be capable of taking the altered output of the next step of the GCM and determining further change in vegetation; that is, it must be fully interactive.

The DGVM must also account for the various components of global change. That is, in addition to predicting change driven by a changing climate (as predicted by the GCMs), it must also include the direct impacts on global vegetation of changes in atmospheric composition and their consequences (e.g., elevated CO₂, enhanced UV-B, etc.) and the changes to land cover resulting directly from changes in land-use patterns. Incorporating a comprehensive DGVM, including these latter two components, into GCMs will require the development of sophisticated linkage techniques.

The essential features of a DGVM are that:

- (i) it must provide predictions of the variables which link the land surface to the atmosphere while being responsive to the atmospheric changes predicted by the GCMs

- (ii) it must predict the transient changes in the major vegetation types over the period of interest (decades to centuries)
- (iii) in doing so, it must generate stochastic disturbance regimes, and dispersal and migration patterns while providing suitable input to the GCMs
- (iv) it must use initial conditions and driving variables that are available or that are feasible within the next few years
- (v) it must incorporate the effects of projected change in land use, through close collaboration with Focus 3 and the HDGEC programme.

There are no suitable models in existence or known to be in development. However, the expertise gained in Activity 2.2 in scaling from patch to landscapes to regions will be invaluable in developing a DGVM, and some of the same modelling groups participating in that Activity may use components of the same models to construct a DGVM. Also, the techniques developed in Task 2.2.2 in modelling the effects of land-use change will be critical in building a realistic DGVM.

Objective

- To develop a dynamic model of change in global vegetation that can be linked to GCMs.

Implementation

Development of a DGVM will be facilitated by LEMA, which also will coordinate the development of a number of models designed to predict the impacts of global change on terrestrial ecosystems from the patch to the regional scale.

Figure 5 shows a possible strategy to produce a DGVM. The modelling of change will be done with an ecosystems dynamics model at the patch scale, driven by a weather generator that uses the mean-value outputs of GCMs and regional climate predictions to generate realistic weather patterns statistically. For each major vegetation type such patch-scale ecosystem dynamics models would be run for sites representing the extremes and means of the climatic variables (e.g., mean annual rainfall and mean temperature of the coldest month) correlated with that type.

The results of the individual patch simulations would then be linked into landscape units, based, for example, on land form data and using an interpolation procedure for climate variable space. These would then be aggregated to the regional level, and the links to the GCM made through a nested mesoscale model and a soil-vegetation-atmosphere-transfer (SVAT) model.

Proposed Timetable

| | |
|------|---|
| 1992 | Determination of representative sites within biomes; development of the ecosystem dynamics models at the patch scale (see Activity 2.1) |
| 1993 | Test of patch-scale models on two intensive study areas; linkage of patch models into landscape and regional units (see Activity 2.2). |
| 1994 | Development of the full DGVM and calibration with 'static' global vegetation models. |
| 1995 | Coupling of DGVM into GCMs. |

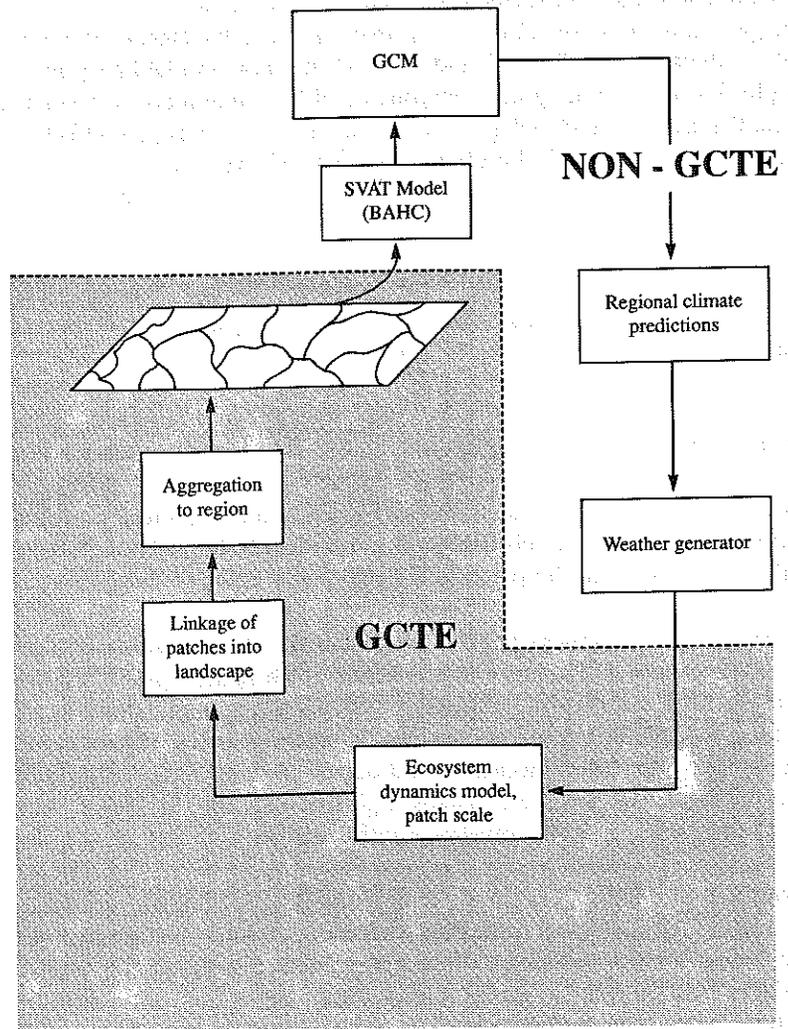


Fig. 5. Proposed strategy for developing a dynamic global vegetation model (DGVM).

Focus 2 Integrating Activities

Long-term Ecosystem Modelling Activity (LEMA)

[Although LEMA is formally placed with Focus 2, it will facilitate the entire GCTE modelling effort, across all Foci, as outlined in the Introduction]

The GCTE research programme is designed to produce an improved understanding of the dynamics of the terrestrial surface under a range of novel conditions. The interpretation of these results at a nested hierarchy of scales (patch, landscape, region, globe) and the integration of GCTE research results into the overall IGBP programme will be accomplished, in part, by using a nested set of computer models.

Significant modelling efforts are already underway at a number of centres around the world. This activity forms an excellent base on which to develop the GCTE modelling programme. Indeed, the increased interest in interfacing models of different processes, in using models to scale results at one level of spatial or temporal resolution to others, and in sharing model development and testing among a wide net of colleagues has been catalysed to a great degree by the discussions prior to the IGBP. The sharing of model development and applications in the geophysical sciences also inspires the parallel development of such models in the ecological sciences.

To maintain and enhance this interaction, GCTE will establish a network of modelling centres called LEMA (Long-term Ecological Modelling Activity). Its goals are to:

- (i) facilitate collaborative research, particularly in the development and improvement of models essential to the GCTE programme
- (ii) focus the international modelling effort on a coherent and mutually agreed set of objectives
- (iii) synthesize GCTE results into a set of robust models designed to meet GCTE objectives
- (iv) provide feedback to experimental efforts as priorities for model parameters, investigation of additional phenomena, and needs for model testing information arise.

The LEMA modelling programme will draw on projects from all Foci – for model components from the functional types, landscape and nested mesoscale model projects, and for experimental data for testing and validation from the intensive study areas, the GCTE monitoring network, and the reciprocal experiments. LEMA centres will be the core integrating activity of Focus 2, and will be closely linked to the Focus 1 whole ecosystem physiology programme, and to the crop and forest modelling components of the Focus 3 programme.

LEMA will be structured to promote coordination of the GCTE modelling effort while allowing a diversity of individual initiatives and specific local organisational and funding structures. LEMA will be a collection of research groups (LEMA Centres), each consisting of about 3-10 staff most directly concerned with modelling and often with a wider range of collaborators involved in experimental and monitoring studies related to the modelling. The main task of coordination will fall upon the LEMA Coordinating Committee, which will be made up of members from each of the LEMA Centres augmented by other members appointed by the SSC of GCTE. There will also be a small coordinating secretariat.

Each LEMA Centre will have professional modelling staff, designated model and data managers, and a member assigned to the LEMA Coordinating Committee. Each LEMA Centre will be individually initiated, peer reviewed, and funded via whatever source is most appropriate for their circumstances. In many nations the core of a LEMA Centre will be achieved by the active collaboration of a few colleagues and their successful application for support through their normal funding channels. The important features that define a LEMA Centre are its adherence to goals consistent with those of GCTE and the inclusion of staff and support to facilitate the ready exchange of model developments and data.

The network will be initiated by the linking of existing modelling groups that are already funded in their own countries. As a high priority, GCTE will seek funds from major national and international agencies to establish a small secretariat to support the LEMA Coordinating Committee.

The Coordinating Committee will monitor the spread of LEMA Centres and foster bids for particular modelling projects both with appropriate research groups and with funding agencies. LEMA will not be an 'exclusive club'; rather it will be an "inclusive" one of all those effective modelling groups willing to support GCTE's goals and to assist others in achieving them. In particular, LEMA Centres will actively involve the scientific community, in general, by open workshops on focal topics. Individual scientists will be aided by the LEMA centres through fellowship and exchange programmes. An active training role will also be fostered by GCTE-LEMA post-doctoral and doctoral fellowships.

Although one of the strengths of LEMA Centres will be the day-to-day interactions of the small groups of modelling specialists within a Centre, inter-Centre links will be emphasized via regular electronic mail communication and periodic workshops, conferences and training sessions. The model and data managers will maintain in a readily accessible form versions of their publicly available software and data sets, and will ensure the earliest possible release of information to other LEMA Centres.

Links between Centres in different countries will also be encouraged, which will assist developing countries to train additional staff in relevant areas. Exchange of staff and students between the Centres will further enhance communication.

GCTE Study Areas for Model Development

This second integrating activity under Focus 2 is also designed to facilitate the overall GCTE modelling effort.

Since one of the major goals of GCTE is to develop a set of nested ecosystem dynamics models, the linkage of models designed for varying spatial and temporal scales is a critical issue. For example, it is known that aggregation errors occur in models that operate at arbitrarily fixed spatial scales. Additional problems arise when phenomena and processes, such as long-range migration rates and large-scale disturbance regimes, that are not relevant at one temporal and spatial scale have to be incorporated in models operating at other scales.

The nested set of Focus 2 models will require care in their coupling strategies and mechanisms. Thus, it is essential that the evolving models be calibrated and validated with real data at critical stages of their development. The establishment of GCTE intensive study areas will facilitate this validation procedure.

The two initial study areas will be located in the GCTE high priority regions (biomes) – the deciduous forest-boreal-tundra system and the gradient from dry to humid tropical savannas. In addition, the study areas should have existing patch-scale models and data; appropriate personnel and computing resources; and should correspond to a GCM grid cell at the largest scale.

Results in the study areas will facilitate model development, linkage across scales, and validation against available data. Generality of methods and results should then be tested by application of the models to different patch types, landscapes, and regions.

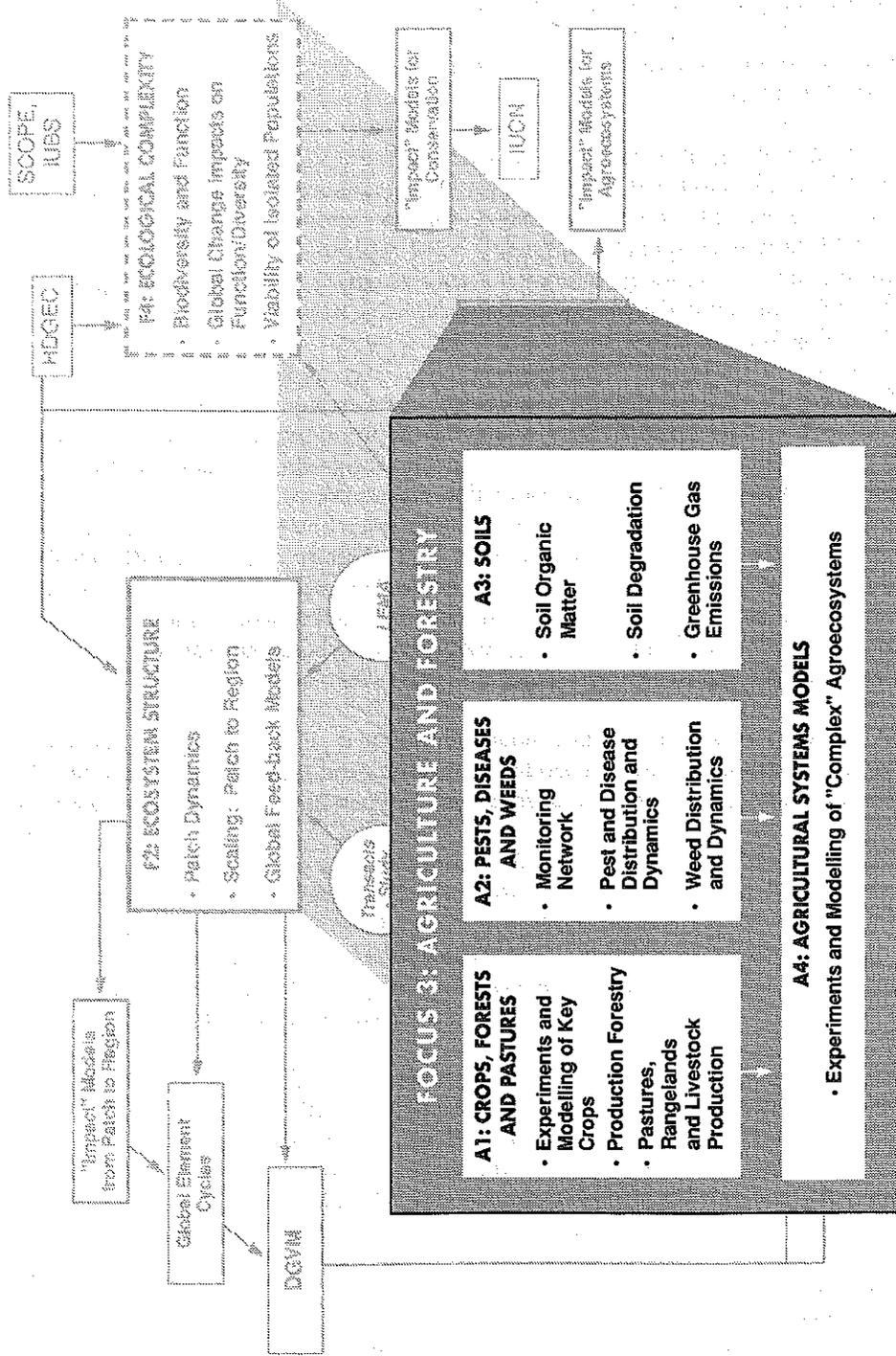


Fig. 6. Focus 3 structure: relationships of Activities and Tasks.

Focus 3: Global Change Impact on Agriculture and Forestry

[Leader: P.B. Tinker]

The world's terrestrial ecosystems constitute a continuum from virtually pristine to intensively managed and highly modified systems devoted to production. Agroecosystems fall at the latter end of the spectrum and are essential to human well-being. They supply the bulk of humanity's food and fibre, and they cover a large portion of the Earth's land area.

Many of these systems are already threatened by damage to soil and water resources through poor technology. Major land-use changes will greatly increase this stress, driven by the demands of increasing population for agricultural and forest products. Climate and atmospheric changes will further impact upon these stressed and rapidly changing systems, providing both opportunities and hazards in ways we cannot yet predict with any accuracy. The ability to capitalise on the beneficial effects of global change, while avoiding adverse effects, requires an improved predictive capability.

While the lack of knowledge over the precise climate in the future makes exact predictions impossible, it is important to be able to predict the consequences of defined scenarios and to identify the most sensitive components of agricultural systems. To this end, GCTE aims to initiate strategic, interdisciplinary research to improve our general predictive ability for key agronomic species and for forests and rangelands. The research results will help national programmes to plan near and medium term, site-related management strategies.

Agro-ecosystems around the world share a number of common characteristics so that an integrated research effort on global change is possible. Although some of the Tasks outlined below will be designed for specific agro-ecosystems, general applicability will be maintained as much as possible. As with other GCTE Foci, the main thrust will be on monitoring, experimentation and modelling; this Focus will, however, differ from other Foci by including a management component and emphasising the effects on harvestable products.

Many nations and international research institutions (e.g., CGIAR, FAO, IBSNAT, IUBS) are launching or developing their own programmes in global change issues. The work of this Focus will interact with, and strongly build on, the very large body of existing agronomic and forestry related work throughout the world.

GCTE research will collaborate with, complement and coordinate national and international studies as appropriate. GCTE initiated research will be general in nature, addressing principles rather than local issues, devoted to major crops so that its impact is substantial, and integrative.

Focus 3 is structured around three interrelated subject areas: it aims to predict the effects of global change on key species and agroecosystems (Activity 3.1); on the dynamics and distribution of pest, pathogen and weed populations (Activity 3.2); and on the processes affecting the quality of soils and their contribution to global change (Activity 3.3). Activity 3.4 brings together these three aspects of global change impact on agriculture and forestry by developing models of multi-species production systems. In close collaboration with Activity 3.1, it thus develops a capability to predict the effects of global change on complex production systems, as opposed to merely on crops, pests and soils alone. It will also assist in the integration of Focus 3 with the other three Foci of GCTE, with other IGBP core projects, and with non-IGBP international scientific groups. Figure 6 shows the structure of Focus 3.

Activity 3.1: Effects of Global Change on Key Agronomic Species

[Leader: J. Goudriaan]

Anticipated changes in global rainfall and temperature patterns together with the established increase in atmospheric CO₂ and UV-B will affect the production of crops throughout the world. Increased tropospheric ozone may also affect agricultural production; however research will initially concentrate on the former issues. Activity 1 will determine the interactive effect of these factors on key agronomic species through the development of crop models that are robust under a wide range of atmospheric and climate change conditions.

GCTE research aims to develop generic models for crops of major agronomic importance. A "short list" for initial research (see Table 1) includes a range of tropical and temperate, nitrogen fixing and non-nitrogen fixing, and tuber and above-ground crops, selected so as to cover the range of crop functional types. The criteria for selecting these species were economic importance, level of physiological process understanding and availability of existing models. While the importance of many other crops is recognised, the GCTE research effort must be sharply focussed, both to obtain valid results as early as possible and to test its methodology.

Table 1. 'Short list' of priority crops for GCTE studies.

| Characteristic | Tropical | Temperate |
|----------------|-----------|-----------|
| Short grain | Rice | Wheat |
| Tall grain | Sorghum | Maize |
| N-fixing | Groundnut | Soybean |
| Tuber | Cassava | Potato |
| Fruit tree | Coffee | Citrus |
| Fibre | Cotton | Cotton |

GCTE crop studies will therefore start with crops for which models are already well developed and the crops' physiology is well understood; wheat and rice are excellent choices in these respects. Wheat is of further interest as it is the crop whose immediate global distribution will likely be most affected by global warming (i.e., a more northerly growth limit), and it is of paramount importance in countries currently best equipped to undertake elevated CO₂ experimentation.

Following research initiated for wheat and rice, the next selected research crops will be cassava, maize, groundnut and potato. The many other crops that warrant attention (e.g., beans) will be addressed via IGBP national committees and other agencies.

Task 3.1.1: Experiments on Key Crops with Changed Atmospheric Composition and Climate, on Different Soils

While it is often possible to determine the effect of a change in a simple variable on a crop grown in the laboratory, the complex interactions occurring in the field often yield unexpected results. Several aspects of crop physiology will require experimentation under altered climate and CO₂ regimes. In this regard, the following plant processes are considered of prime (but not exclusive) importance for plant productivity:

- (i) phenology (e.g., the photoperiod control on the switch from the vegetative to the reproductive phase, or branching and leaf formation as components of leaf canopy development)
- (ii) carbon exchange as photosynthesis, respiration and carbohydrate status (e.g., acclimation of photosynthesis to elevated CO₂)
- (iii) partitioning of carbon and other elements to organs (including root:shoot changes)
- (iv) water use efficiency and the water balance of crops
- (v) nutrient content and cycling with particular reference to N and P (e.g., the interaction of N availability and atmospheric CO₂ levels in determining C:N ratios of plant residues)
- (vi) plant competition, above- and below-ground, with special reference to intercropping.

Objective:

- To determine and predict the effects of elevated CO₂, increased UV-B and temperature, and changed rainfall patterns on growth and yield of selected crops on different soils.

Implementation

Within an overall network, a series of sites representing gradients in temperature and rainfall will be identified for particular crops. Sites along the transects will be selected to provide samples of crops grown at both the centre and extremes of their normal varietal range, with other variables (e.g., CO₂, nutrients, moisture, UV-B) manipulated to test the impact of environmental changes on particular varieties. These gradients will become increasingly important as test sites for new varieties of crop species as they are developed in response to global change.

Elevated CO₂ studies have been conducted with several technologies, but the most promising for system-level research is Free-Air CO₂ Enrichment (FACE; see Task 1.1.1). Due to the substantial infrastructure and CO₂ supply requirements needed to run a FACE experiment, the choice of sites is somewhat restricted. Initial suggestions for the tropics are Kenya, Brazil and the Philippines, while FACE experiments at several temperate locations (New Zealand, USA, Germany, and UK) are either currently available or planned. While it would be desirable to implement FACE experiments over wide-ranging environments, their expense and logistic complications dictate a modest use. Focus 3 will aim to mount a few FACE experiments in temperate regions and hopefully one or two in the tropics. One of the important tasks of FACE research groups will be to compare their results with those from the considerably cheaper, but smaller and less natural, greenhouse and open-top chamber (OTC) techniques.

The Focus 3 FACE experiments will be closely coordinated with those of Focus 1 to create an integrated GCTE FACE programme. This programme will consist of a series of system-level experiments on ecosystems of varying diversity and complexity, from the heavily managed systems of intensive agriculture to more complex natural systems.

In addition to sharing results of system-level experiments with GCTE Foci 1 and 2 and with Activities 3.2 and 3.3 of Focus 3, major links will be established with the agronomic research community, where many of the experimental techniques to be employed have been developed. These links are of paramount importance, as this Activity will further promote the integration of ecology and agriculture, the desirability of which has been identified by many research groups worldwide.

Phase 1: The experimental programme will be launched with a review and planning workshop. This will establish links with on-going elevated CO₂ experiments, and prepare experimental protocols for establishing FACE experiments in the tropics and the calibration of this technique with OTC and greenhouse studies.

Phase 2: Experiments with the selected crops will be conducted along transects covering environmental variables, with elevated CO₂ treatments, of which a limited number will be FACE.

Proposed Timetable

- | | |
|------|---|
| 1992 | Background state-of-science paper on elevated CO ₂ studies and joint workshop with Focus 1 on elevated CO ₂ techniques. Workshop to review current global change research on wheat; establishment of collaborative links with on-going FACE experiments in the temperate region; establishment of collaborative links with major international agriculture research institutions. |
| 1993 | Formalisation of network sites on environmental transects and establishment of OTC sites in the tropics. |
| 1995 | Establishment of FACE experiments in the tropics. |
| 1996 | Review and synthesis workshop. |

Task 3.1.2: Modelling Growth of Key Crops Under Changed Atmospheric Composition and Climate

Robust, reliable crop models are the key to predicting the responses of agronomic species to changing environmental conditions. Many different crop models have been developed with a wide range of characteristics and initialization requirements. In close collaboration with Activities 3.2 and 3.3, this Task will aim to further integrate pest, disease, weed and soil components with the current crop models for the selected species to allow better predictive capabilities under changed environments.

Crop models in this area should include simulation of the important plant processes listed in Task 3.1.1.

Output from the models would essentially be those parameters identified in that Task, but at present the validation of such models is unsystematic. In general terms, however, models of annual crops grown as monocultures are well developed.

In comparison, models for intercropping and tree and forest models are weak. As most of the tropics is intercropped, often including an agroforestry component, models for these complex agroecosystems must be improved. Building on the strong foundation provided by this Task, the modelling of complex agro-ecosystems will be addressed in Activity 3.4.

Objectives:

- To determine the reliability of selected crop growth models under changed atmospheric composition and climate, and for soils different from those on which the crop is normally grown

- To adapt and further develop these models for predicting crop growth and yield under elevated CO₂, UV-B, and temperature, and changed rainfall patterns.

Implementation

A limited set of models will be selected based on relevance to key crops, aims of the experiment, and their ability to use particular data sets. The structure of the input and output data will also be considered with a view to maximising data transferability. The International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) programme is already well advanced in many of these respects. An initial goal will be the identification of general and specific models, or modules to models, for particular application to the field experimental programmes. To achieve this, links will be established with other major crop modelling and experimental projects planned or already underway under the auspices of national or international agricultural research organizations. A major aim for this Task is to determine the robustness of existing and new models to environmental changes, and to provide a guide to the application of crop models under global change within national programmes.

To achieve this, the models will be validated under the experimental conditions implemented by Task 3.1.1. These Tasks will therefore be planned jointly to ensure that comparable data sets are used for the various models.

This modelling approach will involve the following components:

Crop Modelling Working Group. A small working group dedicated to overseeing the GCTE crop modelling programme, will be established. The working group will coordinate the other components of the project, many of which will be undertaken by existing research groups around the world. It will be linked to the LEMA network (see General Introduction and Focus 2 Integrating Activities) to share expertise on developing components that are common to both natural and agricultural ecosystem models (e.g., water balance and carbon dynamics).

Generic Crop Model Development. Based on existing crop models, a set of generic crop models, specifically designed to cope with changing environmental conditions and new varieties of crops, will be constructed and tested.

Standardization of Crop Experimental Data. Protocols for the collection and dissemination of data from agricultural experiments. The structure of input and output data for the models will be standardized for ease of model comparison and interchange of model components. The IBSNAT input format will be a useful basis. This will be carried out in close collaboration with Task 3.1.1 to ensure that the data sets generated there are compatible with the information requirements of the models.

Model Comparison. The GCTE Crop Modelling Working Group will sponsor comparison of crop models to determine which models, or components of models, most accurately simulate crop behaviour under various altered environmental conditions. It

is hoped that the models, which normally will have been developed from experimental data from closed chamber and OTC experiments, will eventually be tested against data sets generated by the GCTE FACE experiments proposed for Task 3.1.1. The comparison will not be a competition, but will be designed to stimulate further the development of generic crop models by identifying strengths and weaknesses in existing models.

Model Extension. As robust, reliable crop models for global change are being developed, decision support systems (DSS) will also be developed. These "shells" facilitate the translation of the scientific models into forms suitable for use as management tools. The IBSNAT Decision Support System for Agrotechnology Transfer (DSSAT) is a useful starting point. Linkage of the GCTE generic crop models to Geographic Information Systems (GIS) extends the models spatially and allows predictions to be made of aggregated agricultural outputs.

Proposed Timetable

| | |
|------|--|
| 1992 | Review of candidate models for incorporation of global change variables. |
| 1993 | Establishment of GCTE Crop Modelling Centre. |
| 1993 | Development of protocols for crop experiment data sets; initiation of generic model development. |
| 1994 | Initiation of DSS development; establishment of linkages between models and GIS. |
| 1995 | Model comparison. |
| 1998 | Review and synthesis workshop. |

Task 3.1.3: Global Change Impacts on Production Forestry

In many respects modelling the impacts of global change on forests and on agricultural crop systems is similar, as they share many of the same physiological processes. There are, however, some fundamental differences: trees are much longer lived and thus have a capacity to survive change (but have a more limited capacity to adapt to change); they store carbon for much longer times; they have lower nutrient input requirements; and they show a high degree of genetic diversity. Furthermore, with a typical single rotation of about 50 years in temperate latitudes, it is very difficult to predict the integrated system response to global change over such a period.

The GCTE research programme on production forestry will concentrate on two high priority areas: semi-arid tropical regions and boreal forests. These biomes were chosen because of the likely large impact of climate change: precipitation regimes in the

semi-arid tropics, and temperature in boreal forests. The species selected for study are *Acacia* spp., *Eucalyptus* spp. and *Tectona grandis* in the tropics, and *Populus tremuloides* and *Pinus sylvestris* in the boreal region.

Objectives:

- To develop a predictive understanding of the effects of change in climate and atmospheric composition on the growth and function of forest crops
- To quantify the importance of diversity/plasticity in forest crops.

Implementation

The GCTE effort will be a combination of coordinating existing research work and initiating a new programme specifically designed to meet the Task's objectives. To complement developed and planned research on the effects of enhanced CO₂ (often using OTCs) on trees carried out in many national programmes, sites in the USA and in Germany will attempt FACE experiments in forests; the latter is already formally part of GCTE. This technique, originally designed for short monocrops, now needs to be developed and carefully tested for applications in tall, heterogenous systems (collaboration with the Focus 1 elevated CO₂ experiments in temperate forests will be particularly useful here). In addition to the proposed FACE initiatives, a European network of global change research on spruce, birch, beech and oak has been established, and GCTE could play a useful role in helping to integrate this work with other studies worldwide.

The GCTE-initiated component of the project will be based on experimental sites chosen at the mid-points in each of the two climatic zones. A stand of trees composed of the widest number of provenances available for the chosen species will be established at the sites. Initially the experiment, which ideally should run for a minimum of 20 years, will be used to examine effects of climate on physiology and yield. CO₂ enrichment will be added later as FACE-type technology is further developed for forests.

The data generated from these experiments, and from the network of existing research projects, will be used to test and enhance existing models and to create new ones. These physiologically-based models will then be extended through decision support systems to become effective management tools. The development of models for agroforestry systems, which, like intercropping (Activity 3.4) and weeds (Activity 3.2), include an element of plant competition, will be a longer-term aim.

Proposed Timetable

1992 Identification of initial research groups and selection of experimental sites in semi-arid tropics and boreal regions.

1993 Workshop to bring together existing research efforts on production forestry and global change, and assessment of existing forestry production models for use under global change scenarios.

1995 Initiation of a FACE experiment at one of the GCTE experimental sites in the semi-arid tropics.

Task 3.1.4: Global Change Impacts on Pastures and Rangelands, and the Resulting Effects on Livestock Production

This Task deals with both intensively managed, planted pastures receiving regular inputs ("improved pastures") and extensive native rangelands. The latter includes all forms of extensive management of grazing animals, ranging from nomadic pastoralism to ranching in developed countries. Grazed rangelands are often very similar to the natural grasslands and savanna ecosystems studied in Focus 1, and there are thus strong connections to that effort. However, it is the impact upon the animal production component in which this Task is ultimately interested.

Initially the work will concentrate on herbage production as the basis for pastoral systems. The first goal is to develop models for pastures and rangelands that are responsive to increases in CO₂ concentration and changes in climate, as well as to changes in land use (e.g., changes in improved pasture fertilization, and stocking rates). For improved pastures the emphasis will be on developing models that predict the seasonal course of fodder production (including fodder quality in terms of protein content) and the consequent economic yield of wool, meat, and other products.

For rangelands the project will concentrate on predicting the impacts on species composition and on forage production and quality, with an estimate of the consequent effects on livestock.

The direct effects of climate change on livestock (cattle, sheep and goats), for example, through changes in availability of drinking water, and effects on fertility, will also need consideration, and an additional Task will be developed later to address these questions.

Objective:

- To predict the effects of global change on pasture and range composition and production, and the consequent effects on livestock production.

Implementation

The improved pasture component of the project will focus on elevated CO₂, climate experiments and modelling. A multi-component, national project in New Zealand

(already adopted as part of this Task) aims to produce a predictive model of impacts of CO₂ increase and climate change on pastures and sheep production. Closed chamber experiments are already underway and a whole ecosystem FACE experiment is planned to begin in 1992. The work also contributes to Focus 1. Further improved pasture models and experiments will be developed in other temperate and then tropical regions. The rangelands part of the project will deal with four combinations of environment, as shown in Table 2.

Table 2. Examples of rangeland categories classified according to temperature and rainfall.

| | Humid | Dry |
|-------|---------------|-------------------------------|
| Cold: | Hill pastures | Mongolian/Argentinean steppes |
| Hot: | Wet savannas | Arid tropical rangelands |

One or more research groups from each category will be invited to separately develop prototype models and present them at a workshop (provisionally associated with the International Grassland Congress in early 1993). The models must predict change in species composition and forage production and quality, and form the basis for models on impacts on livestock.

Following the rangelands modelling workshop a working group will formulate a "generic" model and identify research projects needed to develop and test it, including experiments with elevated CO₂.

Proposed Timetable

| | |
|------|--|
| 1992 | Continuation of New Zealand improved pastures project; identification of rangelands research groups. |
| 1993 | Rangelands model comparison at the International Grassland Congress (New Zealand) and establishment of group to develop generic rangelands model. Identification and initiation of Northern Hemisphere 'improved pastures' projects. |
| 1994 | Workshop to test the generic rangelands models; interim reports on 'improved pastures' projects. |

Activity 3.2: Changes in Pests, Diseases and Weeds

[Leader: J.H. Lawton]

Pests and diseases often dictate the success or failure of a crop, and weed encroachment is a common reason to abandon a site in shifting cultivation systems. As new varieties and crops are introduced in a given site, pest populations and the incidence of disease can rise rapidly, owing to life cycles and, in some cases, the ability to migrate. On the other hand, changes in the incidence of pests, diseases and weeds of existing crops may occur as the pest populations respond to changed environmental parameters. In either case, pests, diseases and weeds are likely to be early indicators of global change.

Pest-crop interactions will be directly affected by rising CO₂ levels through alteration of host-plant attributes such as C:N ratios and secondary plant chemistry, and through indirect modifications in patterns of stomatal opening, leaf water content, and leaf temperature. The combination of direct CO₂ effects on plant growth rates and change in average and extreme environmental conditions will have major impacts on pathogens and pest-animals, particularly insects. In addition, rising CO₂ levels are likely to change competitive interactions between crops and weeds, for example by altering plant growth rates and allocation of above- and below-ground biomass.

The distribution, dynamics and abundance of a given organism are tightly coupled. The time-course measurements proposed for Task 3.2.1, together with the simultaneous monitoring of other environmental variables, will allow life-tables to be determined for the pest, pathogen and weed species in question. This will greatly help in the understanding required to predict the local dynamics (hence the local distribution and abundance) of the given pest, pathogen or weed under a given global change scenario.

GCTE will limit its initial effort to those pests and diseases of the key agronomic species identified for initial emphasis in Activity 3.1 (wheat, rice, cassava, maize, groundnut and potato).

Activity 3.2 is divided into three Tasks. The first deals with the establishment of a global monitoring network for pests (insect and other animal), pathogens and weeds. The second and third deal with pests and pathogens, and weeds respectively.

Task 3.2.1: Global Monitoring Network and Data Sets for Pests, Diseases and Weeds

Continuous long-term monitoring is an essential pre-requisite to detect changes in distribution, abundance and dynamics of pests, diseases and weeds due to global change. Commitment to long-term support is vital to ensure an adequate time-series for valid conclusions about the effects of environmental change, both to make predictions about the impacts of change and to check the predictions of crop and pest models.

Support should first be directed to the continuation of current long-term monitoring activities. In addition, GCTE will encourage research institutes and agencies to initiate new long-term monitoring of pest species, particularly in regions that may be sensitive

to global change and along transects across ecotones, together with complementary weather variables and other data.

Objective:

- To establish an integrated, global monitoring network and develop global data sets for pests, diseases and weeds.

Implementation

A catalogue of long-term data on pest species will be compiled specifying location, source and availability. Agencies will be encouraged to computerize long-term survey or census data and make them available to the scientific community.

GCTE will coordinate and oversee the development of a standardized sampling protocol, to be used across a range of sites, worldwide. For pests and diseases, the sampling networks will be based on a variety of techniques, including insect suction traps, light traps, specific traps (e.g., pheromones) for particular insect taxa, and spore traps for pathogens. The network will be based on a framework of existing international research institutes, e.g., the Consultative Group for International Agricultural Research (CGIAR) network of research stations. Each institute will run a series of sampling stations in a grid or transect according to the agreed protocol, and act as a repository of regional expertise and data. New sampling stations will be added to existing networks as required.

Minimum data sets for the surveys should include the following:

- (i) distribution and abundance of selected species in space and time across the grid or transect
- (ii) life-table data for a very few key pests of important food and forest crops
- (iii) complete meteorological data collected from stations as near as possible to the sample sites
- (iv) satellite data for sample sites, and correlations between these data and important biological parameters.

The global monitoring programme will require a commitment from funding agencies of at least 10 years. Sampling stations must have secure sites and control over site access, and will be positioned among, or adjacent to, the crops and production systems selected for detailed study in other projects of Focus 3.

Proposed Timetable

- | | |
|------|---|
| 1992 | Publish catalogue of existing long-term pests data; development of standardized sampling protocol. |
| 1993 | Identification of existing sites for sampling stations; establishment of first regional sampling networks; identification of gaps in networks. Establishment of additional sites. |

Task 3.2.2: Distributions, Dynamics and Abundance of Pests and Diseases under Global Change

There are two approaches to understanding the distribution of organisms. To date, both have proved to be better at predicting where a species cannot occur than where it actually does occur.

In the first approach – a statistical one – the known distribution of a species (over time and space) is compared with the assumed important environmental variables (e.g., temperature, humidity, soil nitrogen), and a series of weighting functions is selected from which predictions are made. Although this is a quick method requiring minimal information about each species, it assumes that the future will be the same as the past, i.e., the same weights are used. Predictions usually suggest that an organism's distribution should be much more extensive than it actually is. It is usually assumed that the additional areas identified by the model predictions are at risk from invasion by the species, but it is also possible that some important limiting factor (biotic or abiotic) is missing from the analysis. Multivariate techniques should be ideal for this correlative approach, and should produce a series of non-arbitrary widths and statistical criteria for the step-wise inclusion or exclusion of predictor variables.

In the second approach – a biological one – the dynamics of a species in one place over time is examined and correlations of demographic processes (birth, death, immigration and emigration) with environmental variables are used to make predictions of the species' distribution over space, e.g., Moran-curve analysis. In this method predictions about the future do not assume it will be the same as the past, since any nonlinearity in demographic responses to climate should be revealed during the course of the analysis. As with the first method, species are generally predicted to occur over a much wider area than they actually do.

Objective:

- To refine existing models to predict the responses of key pests (animal and pathogens) to change in climate and atmospheric composition.

Implementation

The Task will be phased, beginning with the prediction of pest and disease dynamics and distributions under current environmental conditions, before their responses to future environmental conditions are projected.

The data sets produced in Task 3.2.1 will be used to test the predictions of existing statistical models and standard multivariate techniques. Output of the models will be classified in terms of the percentages of correct predictions, with particular emphasis on cases where a pest is predicted to be absent but, in fact, is present.

In addition, other data sets of the abundance of particular crop pests over time in a limited number of places will be used to test the biological approach of predicting distributions, and also the dynamics of the species in different areas. The utility of satellite imagery in assessing changes in important biological variables will be investigated. In the analysis of past data sets, particular attention will be paid to selecting a variety of pest types (migrants or nonmigrants; vectors or pathogens; polyphagous or monophagous; short or long-generation species). It is important to know whether studies from particular species can be generalised and extended to other, similar species. Accordingly GCTE will explore whether it is possible to identify pest functional types. This kind of analysis will be pursued further to develop a classification for pests, pathogens and weeds in regard to their likely response to global change. To achieve this, a working group will be formed (comprising researchers from Foci 2, 3 and 4) to develop the Functional Type project.

Specific aspects which must be addressed in this Task include the following:

- (i) Additional effort to make existing crop and pest models compatible, and to modify them as necessary for global change conditions, so that the interaction between crops and pests can be studied in an integrated modelling programme (cf. Task 3.1.2).
- (ii) Field and laboratory experiments (in collaboration with Activity 3.1) are required to explore how critical parameters in crop and pest models change under new combinations of temperature, photoperiod, humidity, rainfall, UV-B and CO₂ levels.
- (iii) There is a need to develop "tactical" general models of pests and associated natural enemies, to gain an understanding of the kinds of dynamic behaviour that might be generated in simple food webs in which different species have different temperature thresholds, different phenologies, and different responses to slow environmental changes.
- (iv) Predictions from these modelling efforts should lead to large-scale experimental tests, for example, in open top chambers, greenhouses and FACE experiments.

Proposed Timetable

- | | |
|------|--|
| 1992 | Identification of existing models (distribution and dynamics) and data sets; establishment of sites and determination of protocols for collecting new data sets. |
| 1993 | Tests of these models using existing data sets. Select experimental sites along environmental transects, (including CGIAR centres and substations where possible). |
| 1994 | Refinement and improvement of models. Test models using new data sets; prediction of future pest and disease distributions. |

Task 3.2.3: Weed Distribution, Dynamics and Abundance Under Global Change

Global change will impact upon weeds in complex ways. For instance, weed seed banks that have been dormant for many years may suddenly germinate under a particular set of environmental conditions; rising atmospheric CO₂ levels will change competitive interactions between crops and weeds through differential effects on C₃ and C₄ plants, and natural enemies may exacerbate or diminish these effects. In addition hitherto benign species may become a weed as new crops are introduced to a region.

Research on weed dynamics and distributions clearly overlaps with the other Foci, and methods of weed seed dispersal, the integration of plant physiological responses and the competitive effects on crop species need to be considered.

Objective:

- To determine the effects of global change on the distributions, dynamics and competitive capabilities of major weeds.

Implementation

Phase 1: Select major weeds of the priority crops chosen for Activity 3.1. For each combination, develop predictive models of their current distribution and in-crop dynamics.

Phase 2: Refine the models, and where necessary conduct experiments to parameterise them for predictions under future environmental conditions. The research will take place in conjunction with the crop modelling and experimentation in Activity 3.1, and the implementation schedule will be essentially the same.

Proposed Timetable

| | |
|------|--|
| 1992 | Selection of major weeds of priority crops; initial model development. |
| 1993 | Testing and refining models on data sets from crop experiment network. |
| 1994 | Model predictions of future weed distributions and dynamics on initial crops; extension of methodology to additional priority crops. |

Activity 3.3: Effects of Global Change on Soils

[Leader: P.B. Tinker]

Changes in climate and atmospheric composition will impact on the world's soils, and changes in land use have already had, and continue to have, substantial impacts, notably in the tropics. Soil biological processes underpin many aspects of present and predicted soil changes, hence alterations in these (as a result of changes in climate, CO₂, and possibly other atmospheric constituents) are a key area for research. GCTE will therefore continue to strengthen collaborative links with research programmes investigating this area of soil science. Particular emphasis will be placed on impacts on soil fauna, both from decomposition and from physical (especially macroporosity) points of view.

To extend the results of soils research at specific sites or networks through global interpretation and modelling, better geo-referenced soils databases are needed. Such databases should include information not only on soils but also on terrain and land use. The databases need, however, to be critically evaluated in terms of both accuracy of analytical techniques and representativeness. Improved soil databases are essential in support of the IGBP projects: Bispheric Aspects of the Hydrological Cycle (BAHC) and International Global Chemistry (IGAC), as well as to GCTE. The IGBP Data and Information System (IGBP-DIS) is working with other international and national agencies to develop a global soils database as a matter of high priority.

Task 3.3.1: Global Change Impact on Soil Organic Matter

Soil organic matter (SOM) is the decomposition product of organic inputs to soil. The main controls on decomposition are the physical environment (including climate), the resource quality and the decomposer community. These factors are dynamically interactive. Change in climate, atmospheric composition and land use all affect SOM to some extent either directly or indirectly, which in turn influences soil erosion and fertility. At present the main global change effect in much of the tropics is land-use change, where reductions in SOM are strongly correlated with changes from natural to agricultural systems.

Increased atmospheric CO₂ concentration is unlikely to modify the soil air-space CO₂ concentration directly, as the latter is much higher than the former. However, plants grown under elevated atmospheric CO₂ may yield residues of a higher C:N ratio. This will affect the decomposition process, leading to different decomposition products, and hence SOM-mediated soil conditions. Another likely outcome of elevated CO₂ is a change in the below- to above-ground allocation ratio of photosynthetic products, notably root exudates. This will have a major impact on rhizosphere processes and below ground litter production. Existing SOM models need to be expanded to accommodate these possible changes, and linked to Geographic Information Systems (GIS) to allow their application over large areas.

Objective:

- To determine the impacts of global change, as expressed at the plant physiological, vegetation and ecosystem levels, on soil organic matter dynamics.

Implementation

As far as possible, GCTE experimentation will complement ongoing soils research by introducing global change variables as appropriate. One of the main manipulative experiments will be the study of the fate of residues from key crops when grown under elevated CO₂ conditions. Above- and below-ground biomass measurements and SOM dynamics will therefore be included at all elevated CO₂ study sites, and will be planned in coordination with Tasks 1.1.1, 1.1.2 and 3.3.1. This work will overlap with other research groups investigating SOM dynamics and stabilization, but the introduction of global change variables will provide a unique component to the overall SOM investigations.

Within the extensive international research effort focusing on agricultural soils in the tropics, two initiatives are particularly well-suited for interaction with GCTE:

- (i) The "Alternatives to Slash and Burn" project, being developed by a consortium of international agricultural research institutions. The objective of this project is to devise alternative technologies and policies to the slash and burn techniques of shifting cultivation used in many parts of the tropics. Understanding the effects of such technologies on soil fertility, structure and biology will be an important component of the project. Field sites planned in the South American, African, and Southeast Asian humid tropics offer the possibility for including GCTE CO₂ and SOM dynamics research.
- (ii) The Tropical Soil Biology and Fertility Programme (TSBF), which coordinates a diverse network of well characterised research sites. Direct collaboration with TSBF sites, and the adoption of TSBF methodologies for soil fauna-macroporosity studies and soil carbon modelling elsewhere, would be advantageous.

In temperate regions organic matter decomposition is often temperature-limited, and integrated decomposition experiments and models are needed to estimate the effects of increasing temperatures on SOM. Elevated CO₂ effects, will also be important in temperate and high latitudes, both on plant physiology and the subsequent decomposition of litter and SOM dynamics. FACE experiments are now planned in various European and North American countries, in both crop and forest systems, where changes in SOM dynamics can be studied together with plant growth work.

High latitude areas are also liable to undergo massive land-use change if rises in mean temperatures permit cropping on what is presently land under boreal forest. This will have major consequences on SOM oxidation through tillage and potential erosion.

Proposed Timetable

- | | |
|------|--|
| 1992 | Participation in "Alternatives to Slash and Burn" workshop; subsequent working group to prepare collaborative strategy. Preliminary assessment of SOM changes in the wheat ecosystem during GCTE Wheat Ecosystem Workshop. |
| 1993 | Methodological standardisation workshop; time-zero measurements for SOM studies at elevated CO ₂ sites. |
| 1994 | Workshop to review SOM models and their applicability to global change scenarios. |
| 1995 | Mid-term review workshop with Task 3.1.1. |

Task 3.3.2: Soil Degradation under Global Change

Soil degradation ranges from mass loss via erosion, through chemical depletion, to solute accumulation. GCTE will initially concentrate on the impacts of global change on (i) water erosion in the humid tropics, and (ii) wind erosion in semi-arid regions, two phenomena that require urgent attention and are wide-ranging. Both forms of erosion are caused primarily by land-use change, presently the main manifestation of global change. Technologies aimed at reducing erosion often overlap with those aimed at improving soil nutritional fertility – the common features are maintaining soil cover and improving or maintaining the soil organic matter levels. This project is thus closely linked with Task 3.3.1 at the micro scale, but also needs to consider the wider issues ultimately causing erosion. Essential links must therefore be initiated with the HDGEC programme, and with the International Soil Science Society (ISSS), the International Soil Reference and Information Centre (ISRIC) and the Food and Agriculture Organisation (FAO) to refine both erosion hazard algorithms and global extent maps.

In recognition of the major political changes underway in Eastern Europe and the former Soviet Union, GCTE will consider a Task addressing soil changes resulting from

changes in land-use in these regions. Many such changes may be beneficial (e.g. improved nitrogen-use efficiency), but there may also be the potential for increased emissions of greenhouse gases as agriculture intensifies in some areas.

(i) Water Erosion in the Humid Tropics Under Global Change

Increased water erosion in the humid tropics is likely both as a result of land-use change and climatic change (notably changes in rainfall, especially storm profiles). Many research groups are already addressing the former, and are considering the ameliorative management of water erosion, at both catchment and plot scales. GCTE will promote activities directed at improving predictive capacity under global change scenarios, and will offer an international coordinating role as appropriate. GCTE-initiated research will concentrate on modelling erosion potential from changes in rainfall patterns and intensity for soils with changed land use, vegetation cover and SOM status. The models should cover the scales from patch to catchment, and include redistribution of soils and nutrients in the landscape, as well as net loss of soil from the catchment.

Objective:

- To develop the capability to predict soil degradation by water erosion caused by interactive changes in land use and climate.

Implementation

This task will link with other, existing projects in the tropics, notably the "Alternatives to Slash and Burn" proposal (see Task 3.3.1). Joint sites throughout the humid tropics will conduct simulated rainfall experiments for the varied land management strategies envisaged to help refine erosion potential models.

(ii) Wind Erosion in Semi-Arid Areas

Wind erosion is a potentially serious problem in many parts of the world. However, the phenomenon is most relevant in semi-arid areas, not necessarily in the geographical tropics. At the micro scale, the studies involve SOM relations and ground cover, whereas at the macro scale other factors are important, e.g., shelter belts. The forcing factors which exacerbate wind erosion include both changes in land use and climate. As with water erosion, land use change is the major issue at present, with increased population pressure accelerating the problem. Climate may also play a role; for example, a change in rainfall in the Sahelian region may cause a shift the northern limit of land that can be used for agriculture.

The maintenance of ground cover and the introduction of shelter belts are technologies currently advocated to limit wind erosion. Nevertheless, there is usually a period when

the soil is left exposed, during which time the maintenance of aggregate stability is an important consideration. This warrants further research in SOM relations, minimum tillage and physical protection measures.

Objective:

- To develop the capability to predict soil degradation by wind erosion, and subsequent deposition, caused by interactive changes in land use and climate.

Implementation

There is already a substantial multinational research effort on wind erosion, mainly concentrating on macro-scale factors. The Sahelian site proposed for studies led by France will be important for wind erosion studies; additional sites in Central Asia, Australia, Argentina and North America would also be appropriate as representative of current wind erosion high-risk areas. The two erosion studies will proceed in parallel.

Proposed Timetable

| | |
|------|--|
| 1992 | Planning workshop with representatives from other relevant groups. Establish links as necessary with other projects and with HDGEC, ISRIC and FAO. |
| 1993 | Initiate modelling group and field start-up at two or three sites in the humid tropics. |
| 1995 | Mid-term review workshop. |
| 1996 | Extension of research sites to six throughout the humid tropics. |

Task 3.3.3: Greenhouse Gas Emissions from Agricultural Soils

There is much interest in determining the terrestrial pools and fluxes of greenhouse gases on a global basis. Both Activity 1.2 (particularly Task 1.4.2) of GCTE and a substantial component of the IGAC research effort are aimed at achieving a better understanding of biogeochemical processes.

Soil is a major store of greenhouse gas precursors and is an important medium for organisms which produce the gases. The goal of this project is to provide the expertise in soil microbiology needed to understand the biological processes within agricultural soils that affect emission of greenhouse gases. This project, to be carried out in close collaboration with IGAC Activity 2.1 and with GCTE Activity 1.2, will investigate selected forcing variables of global change, thereby complementing other Focus 3 work.

Objective:

- To determine how microbiological processes and environmental conditions within agricultural soils affect greenhouse gas fluxes (with an emphasis on CO₂, CH₄ and N₂O) under global change.

Implementation

This task is closely related to Activity 1.2 and Task 1.4.2 of Focus 1 and to components of the IGAC programme. The Focus 1 work aims to understand and quantify the role of terrestrial ecosystems in regulating element pools and fluxes, while IGAC is concerned with trace gas exchange with the atmosphere and the effect of elevated CO₂ on trace gas emissions. The role of Task 3.3.3 is to determine how microbiological processes within agricultural soils contribute to the global budgets of key elements. A range of sites from the world's major agro-ecological regions will be selected, concentrating on those where greenhouse gas emissions are known to be significant. The task will involve collating existing information and initiating new measurements.

Proposed Timetable

| | |
|------|--|
| 1992 | Small planning meeting with IGAC to ascertain work areas for each group. |
| 1993 | Initiation of study. |

Activity 3.4: Integrated Experimental and Modelling Programme on Multi-Species ('Complex') Agricultural Systems [Interim contact: P.B. Tinker]

Plants, pests (including diseases and weeds) and soils are important components of agricultural production systems. Given that there is already considerable ongoing work on the responses of components of agricultural systems to global change variables, GCTE has two roles. The first is to bring this work together into a coordinated, international effort. The other is to initiate integrating research projects, with both experimental and modelling phases, that examine the impacts of combinations of environmental variables, acting together, on whole agricultural production systems. This linkage of plant, pest and soil experiments and models under global change will be undertaken in Task 3.1.2 for monocropping systems.

Modelling agro-ecosystems that are spatially (intercropped) or temporally (rotationally) mixed, at the scale of the minimum management unit (i.e., 'patch' in an ecological sense, 'field' in an agricultural sense), is in its infancy. GCTE nevertheless considers this to be a key area for global change research. The single Task in this Activity will be

built on the strong foundation of the experimental and modelling exercises for monocrop systems in Task 3.1.1, incorporating in multi-species systems elements of the three components of agricultural systems identified in Activities 3.1 - 3.3 above. The work's overall outcome will be robust system models, incorporating multi-species crops, pests, and soils, that can predict the performance of multi-species systems in new environmental space.

It will be difficult to develop this type of model for a rotational sequence of monocrops, and harder still for intercropped systems. The former systems are common in temperate agriculture, while the latter are predominant in much of the tropics. Furthermore, such systems are typical of those believed to be sustainable (given moderate population pressure), and are currently being further investigated as aspects of integrated plant nutrition and pest management systems. Modelling is the only way to predict yields from these systems under global change.

This integrating Activity also provides a strong link to the other three Foci of GCTE. It is closely related to Focus 1 through the development and use of patch-scale physiological models to predict agricultural system production under global change; to Focus 2 through a multi-component (plants, pests, soils) approach to modelling system performance; and to Focus 4 through the connection of system function (productivity, stability, resilience, etc.) to complexity (monocropping, intercropping, etc.).

Task 3.4.1: Global Change Effects on Yields of "Complex" Agro-ecosystems

The overall objective of GCTE Focus 3 is to predict the effects of global change on the world's agriculture and forestry production systems. To this end, Activities 3.1, 3.2, and 3.3 each address distinct, yet related, components of the issue. Task 3.1 will extend existing crop models to incorporate the effects of global change on basic plant processes in the simpler monocrop situation. Task 3.2.1 and 3.2.2 will address the global change impact on pests, diseases and weeds of the major species of agronomic importance, while Task 3.3.1 will address the possible changes in soil organic matter dynamics.

This Task aims to integrate crop, pest and SOM research to produce the robust models required for predicting the effects of global change on "complex" agro-ecosystems. The modelling component of this Task will be a continuation and extension of Task 3.1.2 from monocrops to multi-species systems. In addition, maximum collaborative use will be made of the extensive experimental programme to be established by GCTE Foci 1 - 4 to help develop, validate and refine complex system models.

Objective:

- To determine and model the interactive effects of changes in climate and atmospheric composition on multi-species agricultural production systems (including crops, pests and soils), with an emphasis on predicting changes in yield.

Implementation

The first phase will involve the development of present models, in close collaboration with Tasks 3.1.1 and 3.1.2, but involving two or more of the priority crops. The second phase will refine the models to accommodate global change scenarios; it will also develop stronger links with GCTE Activity 2.1 with respect to patch-scale dynamics, and with Focus 4 to address the complexity issue.

A typical intercropping system would be a cereal with a legume, thus maize and groundnuts would be a suitable starting point. Alternatively, woody, perennial crops often constitute one of the intercropped species. The International Centre for Research in Agroforestry (ICRAF), in collaboration with other international institutions, is developing an integrated programme of research on the tree/crop interactions, which would also be suitable for the intercropping modelling study. Rotational systems with crops have long been used in pest and disease management, and collaboration with international and national research stations could provide experience and further field sites.

The proposed work of Phase 1 will rely almost exclusively on the experimental components of Activity 3.1 and on other current intercropping research. Data from such experiments will be used to develop and validate generic, integrated models for complex production systems. Following the successful completion of this phase, the project will be extended to incorporate global change variables (Phase 2), where results from those studies proposed for other Activities within Focus 3 will be combined.

Proposed Timetable

Phase 1:

- | | |
|------|---|
| 1992 | State-of-science report on modelling intercrops. Participation in workshop on modelling agroforestry systems. |
| 1993 | Modelling workshop to review model interchange and compatibility. Joint modelling exercise launched. |
| 1995 | Review workshop. |

Phase 2:

- | | |
|------|--|
| 1995 | Initiation of intercropping experiments under changed atmospheric composition and climate. |
| 1998 | Review workshop. |

Focus 4: Global Change and Ecological Complexity (Proposed)

Foci 1 and 2 are concerned with predicting the effects of environmental change on ecosystem function and structure. These predictions aim for a global (or near global) coverage, which restricts species-level considerations. In Focus 2 taxonomic problems are avoided by developing a small global key of functional types. The consequence of this practical solution is that at least some of the interactions between species, at the same and different trophic levels, are excluded from models. The models therefore ignore direct impacts on species diversity, and the interaction between species diversity and ecological complexity in determining responses to environmental change.

Complexity is viewed as the suite of species interactions within an ecosystem. It includes the diversity of species, their connectivity and spatial diversity (patchiness). Connectivity, unlike species diversity, is considered to change with scale because it incorporates such effects as variations in landscape structure and migration. This Focus is therefore designed to understand and to determine the importance of species diversity and ecosystem complexity on the dynamic responses of ecosystem function to environmental change. It is also necessary to consider the reverse response, the influence of changes in ecosystem function on diversity and complexity, both to achieve this overall understanding and because it forms the basis of applied interest groups such as the International Union for the Conservation of nature (IUCN).

A specific issue to be considered is the vulnerability of species diversity in reserves to environmental change. Reserves for species conservation are typically isolated landscape units and will be vulnerable to environmental change because of disrupted networks for migration.

Global Change and Ecological Complexity was originally proposed as a separate IGBP core project (IGBP Report No. 12, 1990) and has only recently been incorporated within GCTE as a proposed Focus 4. Thus, its research plan has not yet been developed as thoroughly as those for the other Foci. Here only a brief description and long-term objectives are presented for each of the three proposed Activities.

Activity 4.1: Effects of Biodiversity and Ecological Complexity on Ecosystem Function

Relationships between ecological complexity and ecosystem function (e.g., nutrient cycling, carbon fluxes) are largely unknown. Two extreme effects on ecosystem processes envisaged following the loss of species. Thus loss of species might lead to progressive change in the magnitude of the processes; alternatively, providing that biomass is maintained, ecosystem processes might remain unaffected down to some critical (but currently unknown) reduction in number of species. In determining the

relationship between complexity and function, it is necessary to consider not only annual average processes under average environmental conditions, but also seasonal patterns and fluxes under extreme environmental events.

Long-term objective:

- To define relationships between species diversity, complexity and connectivity, and selected ecosystem processes for a range of major ecosystems.

Activity 4.2: Interactive Effects of Global Change on Biodiversity and Ecological Complexity

Current rates of regional and global species extinction are several orders of magnitude faster than at any time in geological history, including periods of "mass extinction". Driving forces include rising human populations, pollution, habitat degradation and destruction and uncontrolled hunting and poaching. At the same time, deliberate and accidental introduction of organisms, including human commensals, pests and weeds are increasing the alien species component of all continents and homogenising species composition across previously distinct fauna and floral regions. Species loss and taxonomic homogenisation are being accompanied by fragmentation of natural landscapes, disruption of species interactions, and massive changes in connectivity.

Future global change, including changing patterns of land use driven by human pressures, will exacerbate all these problems and accelerate species extinctions, the simplification and fragmentation of natural and semi-natural ecosystems, and further disrupt species' interactions.

Potential tasks for this Activity are:

- To incorporate the effects of global change into current trends in regional, continental and global biodiversity and ecological complexity.
- To predict rates of species' extinction in a globally changing world.
- To use knowledge about past and present distributions of organisms to predict future distributions, and hence patterns of diversity, under the impact of global change.
- To develop theoretical models for assembly rules in ecological communities, and to use these models to predict the disassembly and reassembly of species into communities in response to global change.
- To evaluate the consequences of homogenisation of biogeographic regions by the introduction by alien organisms, particularly the consequences for biodiversity of invasion of alien organisms favoured by global change.

- To improve taxonomic and systematic knowledge of poorly studied but potentially 'hyperdiverse' taxa (e.g., soil nematodes, fungi) to ensure that the full impacts of global change on biodiversity and ecosystem function are properly evaluated.

Long term objective:

- To link understanding of changes in ecological complexity at regional, continental and global scales to the functioning and stability of ecosystems and the entire biosphere.

Activity 4.3: Consequences of Global Change for the Viability of Isolated Populations

Population viability analysis seeks to predict the probability of survival of populations of organisms isolated in habitat fragments. The ultimate fate of all taxa is extinction (or evolution); habitat isolation increases the probability of local extinction through demographic or environmental stochasticity, genetic changes in isolated populations (e.g., inbreeding) and extreme environmental events (e.g., hurricanes, fire etc). Loss of key species from habitat fragments (such as top predators, fruit dispersers and pollinators) may severely disrupt ecosystem function.

Global change, via changes in average environmental conditions or extreme environmental events, will increase rates of species' extinction in isolated habitat fragments. Isolation will make it extremely difficult for many taxa to migrate to environmentally more suitable conditions as climates change. Changes in land use compound these problems.

Two potential Tasks are:

- To refine, develop and verify models to predict the viability of isolated plant and animal populations containing different total numbers of individuals, with different life-histories, on isolated habitat fragments, subject to changing average and extreme environmental conditions.
- To examine the implications of climate change for maintenance of biological diversity and connectivity in isolated habitat patches set in intensely managed (e.g., arable farmland) versus semi-natural landscapes; to explore the role of inter-patch migration by biota in maintaining biodiversity in rapidly changing landscapes.

Long term objective:

- To develop sufficient understanding of the links between ecosystem function and ecological complexity (species richness, their interconnections and the distribution of species across landscapes) to guarantee a sustainable biosphere in the face of massive habitat fragmentation and inevitable species loss.

Based on this overall structure for Focus 4, several critical links to the rest of the GCTE programme can be identified:

- (i) Use of the appropriate nodes in the LEMA network to develop models explicitly linking biological diversity to ecosystem function, including within patch models and landscape models.
- (ii) Use of the environmental transects to explore parallel changes in diversity and function (decomposition rates, nutrient cycling, etc.), coupled to explicit experimental manipulation of diversity levels.
- (iii) Links to the crop experimental network of Focus 3 to examine ecosystem function in greatly simplified agro-ecosystems. Ideally, some simplified agro-ecosystems and 'natural' transect sites will be close enough together to make valid cross-comparisons of function in complex v. simple systems with otherwise similar climates, soils, etc.
- (iv) Links to enhanced CO₂ experiments, enhanced UV-B studies, etc. carried out on natural, species-rich ecosystems which also measure key ecosystem processes.

Monitoring and Detecting Global Change

GCTE requires a global monitoring system for three reasons: (i) to provide well characterised sites for research projects along gradients of controlling environmental variables (e.g., temperature, precipitation); (ii) to calibrate and validate ecosystem dynamics models at a variety of scales; and (iii) to detect global change as evidenced by change in terrestrial ecosystems.

So far as possible, GCTE will collaborate with other groups, both within and outside IGBP, in establishing a joint terrestrial monitoring network that will serve the broader global change research community as well as GCTE specifically. The large number of experimental sites within GCTE will serve as a useful basis for a monitoring network.

New sites will also have to be established to provide data from areas of the world which are not currently covered and which have been identified as important to GCTE objectives. The IGBP Global Change System for Analysis, Research and Training (START), which aims to establish regional research networks for all the major biomes of the world, will provide the framework, as well as most of the new sites, for the GCTE system.

Collaboration with Other Monitoring Programmes

A number of observation and monitoring networks have already been proposed for global change research e.g., the Global Climate Observing System (GCOS), the Global Atmosphere Watch (GAW), and the World Weather Watch (WWW). The first step in the establishment of the GCTE network is to identify what networks already exist or are proposed, what their current status is, and the type of data which they collect (or propose to collect). It will be particularly important to ascertain the methodology used to obtain the data, the quality of the data (especially of historical records), and the accessibility of the data. In particular, the GCOS proposal emerging from the Second World Climate Conference specifically includes terrestrial ecosystems, and GCTE will be involved in the IGBP input to the development of GCOS.

Site Selection

The second step is to identify which sites from these systems fit the purposes of the GCTE network. To aid in this process of site selection and rationalization, we propose that sites be selected, as much as possible, on their locations in environmental rather

than geographic space. As an initial effort, sites will be located in a two-dimensional space of lowest monthly mean minimum temperature and mean annual precipitation. Such a classification will reveal any 'duplication' of existing sites which may be geographically separate but which are environmentally coincident. Using this kind of approach will bring a high degree of objectivity into the selection of existing sites and the identification of crucial areas not presently covered. Environmentally equivalent sites need to be established in different continents to ensure the inclusion of communities with different evolutionary histories.

For detecting global change in ecosystems, it will be important to examine changes which might occur both in the centre and at the boundaries of biomes. Under some circumstances, a given plant association could move spatially without undergoing any significant change in its structure or functioning. On the other hand, some systems may not move under global change but their structure or function may be altered. Thus, the network for detecting global change should include sites both in the centre of ecosystems and at ecotones.

Collaboration within IGBP

It is essential that GCTE liaises closely with other components of the IGBP programme, particularly IGAC, BAHC, IGBP-DIS and START, as they develop their own systems of experimental sites and monitoring stations. Links with IGAC and BAHC will be based on joint research projects (sharing of sites and personnel). IGBP-DIS will participate by providing remotely sensed data suitable as input or validation variables for models developed by GCTE, in collaboration with the IGBP Global Analysis and Modelling (GAIM) Project.

Proposed Timetable

| | |
|------|---|
| 1992 | Pilot study of methodology for locating sites in environmental space; small international workshop on establishment of GCTE monitoring network. |
| 1993 | Publication of GCTE proposal for establishing a terrestrial global change network; selection of initial sites. |
| 1994 | Extension of the network to additional sites. |

Research Strategy

The strategy adopted by GCTE to put this Operational Plan into action is based on a combination of existing research projects and new projects designed specifically for the GCTE programme. The detailed description of the research Tasks presented in this Operational Plan provides an overall organisational framework for assessing potential contributions to GCTE and initiating new research to fill gaps identified in the existing effort.

Existing Research

One of the key elements of the GCTE research strategy is, wherever possible, to incorporate and build on existing research. There is already much ecological research underway that is oriented to global change, some of which is directly relevant to the objectives of GCTE. Where appropriate and mutually agreed, this existing research will be adopted as part of the GCTE Core Research programme, rather than initiating duplicate research projects by GCTE.

New GCTE Research

Existing research included in GCTE will not cover all of the areas outlined in this Plan. To fill the gaps that will still exist, the GCTE Scientific Steering Committee will attempt to initiate new projects designed specifically for GCTE. Neither GCTE nor IGBP as a whole can directly fund new research work; however, the GCTE Project Office will provide what assistance it can to appropriate research groups seeking funding for these activities.

National Contributions

Most of the existing research that will be incorporated into the GCTE programme will be national in scope. The national IGBP committees (see below) are expected to play an important role in surveying, organising, and assessing the scientific quality of this work before it is formally offered as a GCTE contribution.

Integration

The GCTE research programme has been designed as a coherent, integrated package of closely linked components. In addition to this internal integration, described in detail within this document, GCTE is establishing close links to outside groups at two levels through collaborative research projects, shared research sites, and consultative management agreements.

The first level includes other IGBP projects, such as IGAC, BAHC, IGBP-DIS, and START. GCTE has already established relationships with these groups, as noted at the appropriate points in the Operational Plan, and will continue to build on these relationships as the research programme develops.

The second level includes a wide variety of organisations outside the IGBP framework. These groups range from individual universities and research institutes to large international research organisations and coordinating bodies. GCTE places great emphasis on establishing productive and mutually beneficial working relationships with other groups investigating global change impacts on terrestrial ecosystems and their consequent feedbacks to climate.

Categories of GCTE Research

Given the strong international interest in GCTE and the wide range of potential research projects that have been offered as GCTE contributions, the GCTE Scientific Steering Committee (SSC) has decided to characterize potential GCTE projects at three levels:

Core Research

This is large-scale, integrative research that is international in scope. The projects within the GCTE Core Research programme have been designed specifically to meet GCTE objectives. They come from two sources:

- (i) Initiation directly by the SSC
- (ii) Adoption by the SSC of appropriate components of national IGBP research programmes, where these components have been identified by the SSC as contributing directly to the GCTE Core Research Programme as described in the Operational Plan.

These projects will be eligible for GCTE assistance in obtaining funds from national and international agencies, and will maintain close communication with the GCTE Core Project Office.

Regional/National Research

This research arises from national IGBP committees or other national and regional groups of research organizations. It will be designed to meet GCTE goals but will be primarily national or regional in scope. Regional/national research is not automatically part of the international GCTE Core Research Programme. Only those components identified by the SSC as contributing directly to the Operational Plan will be incorporated into the GCTE Core Research Programme and will be eligible for GCTE assistance in obtaining funds.

Nevertheless, GCTE Regional/National Research will be an important part in the overall GCTE effort because it will provide a critical link between the global-scale Core Research and the national and regional scales which are of concern to individual countries and regions.

Relevant Research

This research is comprised of a large number of smaller projects initiated by individual investigators or institutions. These projects add incrementally, through case studies and locally specific research, to the broad knowledge base that underpins the overall GCTE effort. The management and funding of this research will be the responsibility of the individual investigator(s). Some of these projects will be submitted to the GCTE SSC as potential contributions to the international GCTE Core Project. The SSC, however, cannot review all of these proposals itself, but instead will refer them back to the appropriate national IGBP committee for consideration and subsequent action.

Role of IGBP National Committees and ICSU

National IGBP committees are a crucial element in the implementation of the GCTE Operational Plan. As mentioned above in the description of Categories of GCTE Research, appropriate components of national IGBP research programmes will be adopted by the SSC for inclusion in the international GCTE programme. These national contributions, with their associated technical, logistical, and financial support, are critical in initiating and maintaining the overall GCTE effort.

National contributions will normally have been organised and reviewed by the appropriate national IGBP committee before submission to the GCTE SSC. The national committees thus play an essential role in ensuring high standards of scientific quality and in assembling the relevant components of their programmes for the international IGBP core projects. Based on this Operational Plan, GCTE aims to work closely with national committees to ensure the development of research projects that are both relevant to national needs and appropriate for the international GCTE programme.

The member unions and other bodies related to the International Council of Scientific Unions (ICSU) also have an important role to play in the operation of the GCTE research programme. Many of these groups, such as the Scientific Committee on Problems in the Environment (SCOPE), and the International Union of Biological Sciences (IUBS), have their own research and analysis programmes related to global change. ICSU has facilitated interaction between these groups and the developing IGBP research effort by inviting them to appoint liaison representatives to the IGBP. GCTE will maintain close communication with the representatives of the relevant ICSU member organisations.

Other Activities

State-of-the-Science Reports and Analyses

GCTE will publish, on a regular basis, state-of-the-science reports. These reports, which will be aimed at the general scientific community but with a policy-makers summary at the front, will provide an authoritative review of a global change-related issue. An example is "Can afforestation help ameliorate the greenhouse effect?" Later reports will focus on the implications of results from the GCTE research programme.

Workshops and Symposia

GCTE will periodically sponsor symposia and workshops on various aspects of its research programme. These meetings will be designed to bring together workers, both those within the GCTE Core Research programme and those in related projects elsewhere, to review the state-of-the-science in their fields and to chart future research directions. It will also assist, so far as possible, regional START committees in planning and running regional workshops on GCTE Activities and Tasks.

Facilitative Role

One of GCTE's most important functions is to play a facilitative role in the overall global change research effort. Since its research interests span a broad range of the biological, physical, and chemical sciences, and the results of its work have clear implications for policy-makers, GCTE is in a strong position to promote and enhance an interdisciplinary approach to global change questions. GCTE will thus take a lead in bringing together, in appropriate fora, researchers from different disciplines to discuss aspects of GCTE's programme from different points of view. Of particular importance is the interaction between natural and social scientists on the human aspects of land-use change.

Newsletter

Effective communication among those interested in GCTE is critical for its success. To this end, a newsletter – GCTE NEWS – is being published and distributed three times a year to provide an update on the progress of the project. Readers are encouraged to comment on any aspect of the GCTE programme through the Readers' Contributions & Correspondence feature of the newsletter.

GCTE - Core Project Structure
Core Project Office - Canberra

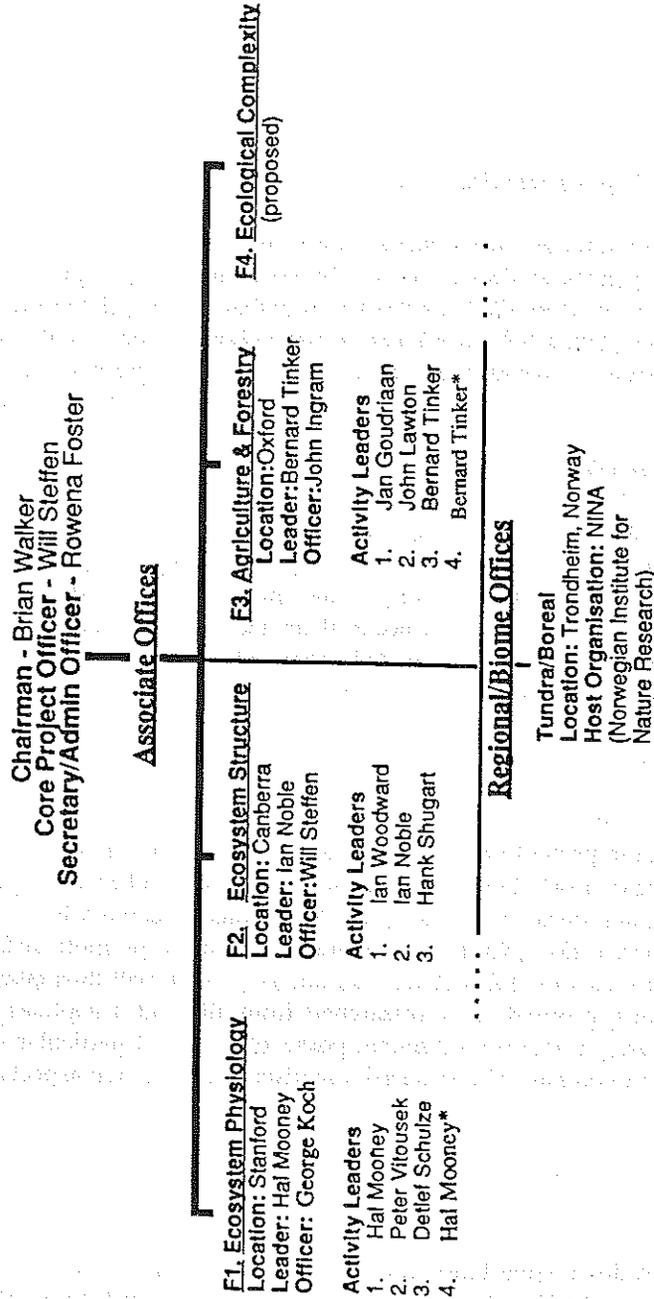


Fig. 7 GCTE Core Project Structure * Interim contact, substantive leaders to be appointed.

Organisational Structure

The GCTE organisational structure is shown in Figure 7, and the names, addresses, and contact numbers of GCTE SSC members and GCTE officers and offices are given in Appendix 2.

The overall effort is administered by the Core Project Office, located within the CSIRO Division of Wildlife & Ecology in Canberra, Australia. Associate Offices have been established for Focus 1 at the Department of Biological Sciences, Stanford University, U.S.A., and for Focus 3 at the Department of Plant Sciences, Oxford University, U.K.; the Core Project Office also serves Focus 2 specifically. An Associate Office for Focus 4 will be established as its research programme develops during 1992.

GCTE will also establish, as necessary and appropriate, a small number of Regional Offices. The first of these, to coordinate GCTE research in the boreal/tundra region, will be established under the auspices of the Norwegian Institute for Nature Research (NINA) in Trondheim. This office became operational in early 1992.

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Appendix 1: Summary of GCTE Foci, Activities and Tasks

Focus 1: Ecosystem Physiology

- Activity 1.1 Effects of Elevated CO₂
 - Task 1.1.1 Whole Ecosystem FACE Experiments
 - Task 1.1.2 Integrating Experiments on Ecosystem CO₂ Response
- Activity 1.2 Changes in Biogeochemistry
 - Task 1.2.1 Humid Tropical Forests Undergoing Land-Use Change
 - Task 1.2.2 High Latitude Systems
 - Task 1.2.3 Semi-Arid Tropical Ecosystems
- Activity 1.3 Effect of Changes in Vegetation on Water and Energy Fluxes (to be conducted jointly with BAHC)
 - Task 1.3.1 Bulk Surface Conductance
- Activity 1.4 Integrating Activities
 - Task 1.4.1 Integrated Models of Ecosystem Physiology under Global Change
 - Task 1.4.2 Carbon Pools and Fluxes in Terrestrial Ecosystems

Focus 2: Change in Ecosystem Structure

- Activity 2.1 Patch Scale Dynamics
 - Task 2.1.1 Global Key of Plant Functional Types
 - Task 2.1.2 Experiments on Ecosystem Structure and Function
 - Task 2.1.3 Patch Models of Ecosystem Dynamics
- Activity 2.2 Models from Patch to Region
 - Task 2.2.1 Ecosystem Dynamics from Patch to Region, Based on Change in Climate and Atmospheric Composition
 - Task 2.2.2 Ecosystem Dynamics from Patch to Region, Based on Change in Land Use

- Activity 2.3 Regional-to- Global Models of Vegetation Change for Element Cycles and Climate Feedback

- Task 2.3.1 "Static" Models of Global Vegetation Change
- Task 2.3.2 Dynamic Global Vegetation Model (DGVM)

Focus 3: Global Change Impact on Agriculture and Forestry

- Activity 3.1 Effects of Global Change on Key Agronomic Species
 - Task 3.1.1 Experiments on Key Crops with Changed Atmospheric Composition and Climate, on Different Soils
 - Task 3.1.2 Modelling Growth of Key Crops Under Changed Atmospheric Composition and Climate
 - Task 3.1.3 Global Change Impacts on Production Forestry
 - Task 3.1.4 Global Change Impacts on Pastures and Rangelands, and the Resulting Effects on Livestock Production
- Activity 3.2 Changes in Pests, Diseases and Weeds
 - Task 3.2.1 Global Monitoring Network and Data Sets for Pests, Diseases and Weeds
 - Task 3.2.2 Distributions, Dynamics and Abundance of Pests and Diseases Under Global Change
 - Task 3.2.3 Weed Distribution, Dynamics and Abundance Under Global Change
- Activity 3.3 Effects of Global Change on Soils
 - Task 3.3.1 Global Change Impact on Soil Organic Matter
 - Task 3.3.2 Soil Degradation Under Global Change
 - Task 3.3.3 Greenhouse Gas Emissions from Agricultural Soils
- Activity 3.4 Integrated Experimental and Modelling Programme on Multi-Species ("Complex") Agricultural Systems
 - Task 3.4.1: Global Change Effects on Yields of "Complex" Agro-ecosystems

Focus 4: Global Change and Ecological Complexity

(Proposed)

- Activity 4.1 Effects of Biodiversity and Ecological Complexity on Ecosystem Function
- Activity 4.2 Interactive Effects of Global Change on Biodiversity and Ecological Complexity
- Activity 4.3 Consequences of Global Change for the Viability of Isolated Populations

Appendix 2: GCTE Scientific Steering Committee, Officers and Offices

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Acronyms

| | |
|---------|---|
| BAHC | Biospheric Aspects of the Hydrologic Cycle |
| CGIAR | Consultative Group for International Agricultural Research |
| DIS | Data and Information System |
| DGVM | Dynamic Global Vegetation Model |
| DSS | Decision Support System |
| DSSAT | Decision Support System for Agrotechnology Transfer |
| FACE | Free-Air CO ₂ Enrichment |
| FAO | Food and Agriculture Organisation |
| FT | Functional Type |
| GAIM | Global Analysis, Interpretation and Modelling |
| GAW | Global Atmosphere Watch |
| GCM | General Circulation Model |
| GCOS | Global Climate Observing System |
| GCTE | Global Change and Terrestrial Ecosystems |
| GIS | Geographic Information System |
| HDGEC | Human Dimensions of Global Environmental Change |
| IBSNAT | International Benchmark Sites Network for Agrotechnology Transfer |
| ICRAF | International Centre for Research in Agroforestry |
| ICRISAT | International Crops Research Institute for the Semi-Arid Tropics |
| ICSU | International Council of Scientific Unions |
| IGAC | International Global Atmospheric Chemistry |
| IGBP | International Geosphere-Biosphere Programme |
| ISRIC | International Soil Reference and Information Centre |
| ISSC | International Social Sciences Council |
| ISSS | International Soil Science Society |
| IUBS | International Union of Biological Sciences |
| IUCN | International Union for the Conservation of Nature |
| LEMA | Long-term Ecological Modelling Activity |
| NATT | Northern Australia Tropical Transect |
| NINA | Norwegian Institute for Nature Research |
| OTC | Open-Top Chamber |
| PAGES | Past Global Changes |
| SALT | Savannas in the Long Term |
| SCOPE | Scientific Committee on Problems of the Environment |
| SOM | Soil Organic Matter |
| SPAR | Soil-Plant-Atmosphere Research |
| SSC | Scientific Steering Committee |
| START | Global Change System for Analysis, Research and Training |
| SVAT | Soil-Vegetation-Atmosphere Transfer |
| TSBF | Tropical Soil Biology and Fertility Programme |
| WCRP | World Climate Research Programme |
| WWW | World Weather Watch |

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