TOWARDS A GLOBAL TERRESTRIAL OBSERVING SYSTEM (GTOS)

DETECTING AND MONITORING CHANGE IN TERRESTRIAL ECOSYSTEMS

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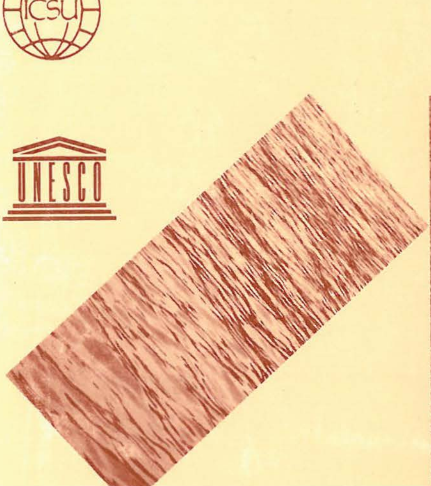

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TOWARDS A GLOBAL TERRESTRIAL OBSERVING SYSTEM (GTOS)

Detecting and monitoring change in terrestrial ecosystems

Report of a Workshop
Fontainebleau, France (27-31 July 1992)

Sponsored by:
Observatoire du Sahara et du Sahel (OSS)
Global Change and Terrestrial Ecosystems (GCTE) Core Project
of the International Geosphere-Biosphere Programme (IGBP)
UNESCO-Man and Biosphere (MAB) Programme

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PREFACE

About this series...

The MAB Digest Series was launched by UNESCO in 1989. Several types of publications are included: distillations of the substantive findings of MAB activities; overviews of recent, ongoing and planned activities within MAB in particular subject or problem areas; and proposals for new research activities. The target audience varies from one digest to another. Some are designed with planners and policy-makers as the main audience in mind. Others are aimed at collaborators in the MAB Programme. Still others have technical personnel and research workers as the target, irrespective of whether or not they are involved in MAB.

...and MAB Digest 14

The aim of this digest is to contribute towards the development of an integrated system for detecting and monitoring terrestrial responses to global change. It is hoped that the report will prove useful to those involved in the further planning of such a system, and more broadly to those interested in the study and monitoring of global change, long-term ecological research and the characterization of field research sites.

The need for an integrated multi-scale global monitoring system has been recognized for some time, and its establishment has been called for by a large number of groups. To develop the rationale, strategy, and organization for such a system, an international workshop on monitoring long-term changes in terrestrial ecosystems was held at Ury, Fontainebleau near Paris (France) from 27-31 July 1992 under the aegis of the Observatoire du Sahara et du Sahel (OSS), the Global Change and Terrestrial Ecosystems (GCTE) core project of the

International Geosphere-Biosphere Programme (IGBP) and the MAB Programme of UNESCO. The workshop was attended by 48 people from 20 countries (Annex 1), representing a wide range of disciplines and of national and international organizations.

The main outcome of the workshop was agreement on the need for a Global Terrestrial Observing System (GTOS). Recommendations were drawn-up on the basic framework and objectives, and on the setting-up of a Task Force charged with developing a science plan for GTOS. The present report is intended to provide a springboard for the work of that task force, as well as to encourage interest in the process of developing a Global Terrestrial Observing System.

CONTENTS

SUMMARY

Global changes in climate, atmospheric chemistry and land use are affecting the biological composition, productivity and sustainable use of terrestrial ecosystems. The need for improved and reliable information on the responses of natural and managed systems to global change is widely recognized. The data are required both to detect and monitor changes and to develop and test models for projection of future changes.

Remote sensing can increasingly provide comprehensive information on changes in land cover and land use and on measurement of some surface features, such as temperature and chemical composition. This information needs to be complemented by more detailed ground-based measurements such as species composition and performance, and environmental processes. Many changes in ecosystem structure and function can only be detected by field monitoring, which can also validate and enhance remotely sensed information

To develop the rationale, strategy, and organization for an integrated, multiscale monitoring system, a partnership of three international organizations held a workshop at Fontainebleau near Paris in July 1992. The Observatoire du Sahara et du Sahel (OSS) hosted the meeting, in collaboration with the Global Change and Terrestrial Ecosystems (GCTE) core project of IGBP and the Man and Biosphere (MAB) Programme of UNESCO. The workshop was attended by 48 people from 20 countries, representing a wide range of disciplines and of national and international organizations.

Based on their combined experience, information from previous studies and knowledge of existing research and monitoring systems, the participants agreed on:

- *a set of basic principles*
- *procedures for selecting priority regions for monitoring*
- *a sampling strategy combining intensive and extensive measurements integrated with remote sensing*
- *criteria for the selection of sites representing the full range of ecosystems, from pristine to intensively managed*

- *sets of measurements which characterize the sites, detect the forces of change, and monitor responses*
- *data management and quality assurance procedures*
- *an organization and management structure with national, regional and global components*

It was agreed that a cost-effective system to detect and monitor terrestrial responses to global change, based on 50-100 field sites, could be established within three years by integration of existing and planned research and monitoring systems. Particular attention should be given to the existing international biosphere reserve network and to long-standing agricultural and ecological research stations. The Global Terrestrial Observing System (GTOS) will cooperate with organisations such as START to provide benefits in research, training, information and facilities within developing countries as well as providing an early warning system of responses to global change and providing data for global models.

It was proposed:

- *That IGBP-GCTE, UNESCO-MAB, and OSS should urgently promote the establishment of GTOS.*
- *That GTOS should be established within the appropriate inter-governmental organization, UNEP, with an inter-agency structure[1] that allows for the full and active participation of FAO and UNESCO.*
- *That GTOS provide the major terrestrial component of GCOS[2], working in close association with relevant organizations and programmes such as START.*
- *That financial support and resources be sought from GEF and other appropriate organizations for enhanced site monitoring, particularly in developing countries; for development of data and information systems; establishment of a quality assurance programme; and coordination.*
- *That a Task Force be immediately established by GCTE, UNESCO, OSS, UNEP and FAO to implement initial activities and to ensure the complementarity of GTOS with* Diversitas, *SACTEMA, HEM, IUBS, SCOPE and other related groups.*

1 'Inter-agency structure' here means both UN agencies and international governmental and non-governmental organizations and programmes.

2 GTOS and GCOS would be separate entities. GTOS could provide the relevant data and information on terrestrial systems to GCOS.

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. The main forces of change are (i) atmospheric composition, particularly the rise in CO_2 concentration; (ii) climate change; (iii) land-use, as driven by demographic, economic, technological and social pressures; and (iv) the type, amount and distribution of pollutants.

Major research programmes are now targeted on specific global issues, including detection and prediction of climate change and establishment of remotely sensed monitoring systems. However the global scientific community has yet to organize an integrated monitoring system which can detect changes in terrestrial ecosystem properties, populations and processes and can discriminate between the effects of different forcing functions. Such a monitoring system requires not just a suite of measurements systematically recorded throughout a global network of sites but also the associated infrastructure to collate, analyze, interpret and disseminate the data. Various national and some regional networks have been established, usually with emphasis on particular issues such as pollution monitoring. Can we build on the combined experience of individual scientists and organizations to design an effective global network to monitor and detect change in terrestrial ecoystems?

Three international initiatives (OSS, IGBP-GCTE and UNESCO-MAB) with distinct interests and expertise combined forces with representatives from other disciplines and organizations in a workshop to outline the components of an operational plan for a Global Terrestrial Observing System (GTOS). OSS and GCTE require a global monitoring system, with regional networks, for three reasons: (i) to calibrate and validate ecosystem dynamics models at a variety of scales; (ii) to detect and monitor the responses of terrestrial ecosystems to global change; and (iii) to record changes in agro-ecosystems driven by new land-use practices. In UNESCO's Man and the Biosphere (MAB) Programme, 311 biosphere reserves have been designated as a global network of sites for conservation, research and monitoring and development. No formal monitoring programme has been established but MAB is developing a system of site characterization and monitoring which will enhance comparative analysis of ecosystems and detection of change. Of particular concern is the monitoring of change in arid and semi-arid regions. The Observatoire du Sahara et du Sahel (OSS) has a strong programme in this subject with a main objective of combating desertification.

The objectives of the workshop are outlined in Box 1.

Box 1. Objectives of the workshop

Overall Objective

To define and initiate a global terrestrial monitoring system for GCTE, OSS and MAB purposes collaborating and combining with, whenever possible, other existing and planned monitoring programmes.

Specific Objectives

1. To agree on the minimum set of processes and variables needed to detect global change and validate models, and on that basis to establish the parameters that need to be monitored;
2. To determine the optimal structure of the monitoring system based on the need for it to be hierarchical (different time/space scales), have a defined sampling strategy and be integrated so far as possible with the activities of other groups;
3. To define a phased, prioritized implementation programme;
4. With regard to ground-based measurements, to determine the protocols for
   - site and gradient selection;
   - establishment and maintenance of the experimental design and infrastructure for the sites;
5. To determine the operational, management and funding arrangements for the network;
6. To establish effective linkages to other networks/systems

OVERVIEW OF EXISTING ORGANIZATIONS AND NETWORKS

More than eighty international organizations and programmes are listed by Fritz (1991) as involved in global environmental monitoring, data management and harmonization. From amongst this plethora of effort the following summary, whilst not comprehensive, identifies some of the key organizations which relate to the development of a global terrestrial oberving system at global, regional and national levels of resolution and which perform distinct activities necessary in global networking.

Global networks[1]

International Geosphere-Biosphere Programme

The main organization with a research requirement for global monitoring is the International Geosphere-Biosphere Programme (IGBP). The objective of the IGBP is:

> To describe and understand the interactive physical, chemical and biological processes that regulate the total Earth system, the unique environment that it provides for life, the changes that are occurring in this system, and the manner in which they are influenced by human activities.

A number of IGBP core projects have a strong interest in global terrestrial monitoring: Global Change and Terrestrial Ecosystems (GCTE), International Global Atmospheric Chemistry Project (IGAC), Biospheric Aspects of the Hydrological Cycle (BAHC), and Land-Ocean Interactions in the Coastal Zone (LOICZ). In addition, the IGBP task force on Global Analysis, Interpretation and Modelling (GAIM) will be a prominent user of global data, while the Data and Information

1. Based on contributions by M. Gwynne, M. Hadley, B. Walker, T. Younès.

Systems (DIS) and Global Change System for Analysis, Research and Training (START) will both play key roles in the operation of GTOS. START is particularly relevant, as it aims to establish regional research networks for all the major biomes of the world, thus providing a potential regional framework and infrastructure for global change research and monitoring (Eddy *et al.* 1991) (Figure 1).

Of these IGBP groups, GCTE has been asked to take the lead in the development of GTOS. The objectives of GCTE are:

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

GCTE is structured around four foci; ecosystem physiology; change in ecosystem structure; global change impact on agriculture, forestry and soils; global change and ecological complexity. GCTE requires a global monitoring system (i) to provide well characterized sites for research projects along gradients of controlling environmental variables, (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 (Steffen *et al.* 1992).

Thus, GCTE and the other IGBP core projects with terrestrial components provide the central scientific rationale linking monitoring and research. However, GCTE explicitly proposes collaboration with non-IGBP organizations to establish a terrestrial monitoring system which will serve the needs of a broader range of scientific communities. To achieve this, the various scientific organizations interested in global terrestrial monitoring must combine forces to avoid duplication of effort and demands on the same limited set of researchers.

Global Climate Observing System

Any terrestrial research and monitoring programme will have to interface with and complement relevant climate programmes. The Global Climate Observing System (GCOS) is the focal point. The GCOS concept was outlined at the Second World Climate Conference in 1990 and is now accepted by the main international organizations involved, namely the WMO, the Intergovernmental Oceanographic Commission (IOC), the United Nations Environmental Programme (UNEP) and the International Council of Scientific Unions (ICSU). Its goals are defined as follows with those of particular relevance to GTOS shown in italics:

- Climate system monitoring, climate change detection and *response monitoring, especially in terrestrial ecosystems*;
- Data for application to national economic development;
- *Data for research towards improved understanding, modelling and prediction of the climate system*;
- Eventually, a comprehensive observing system for climate forecasting.

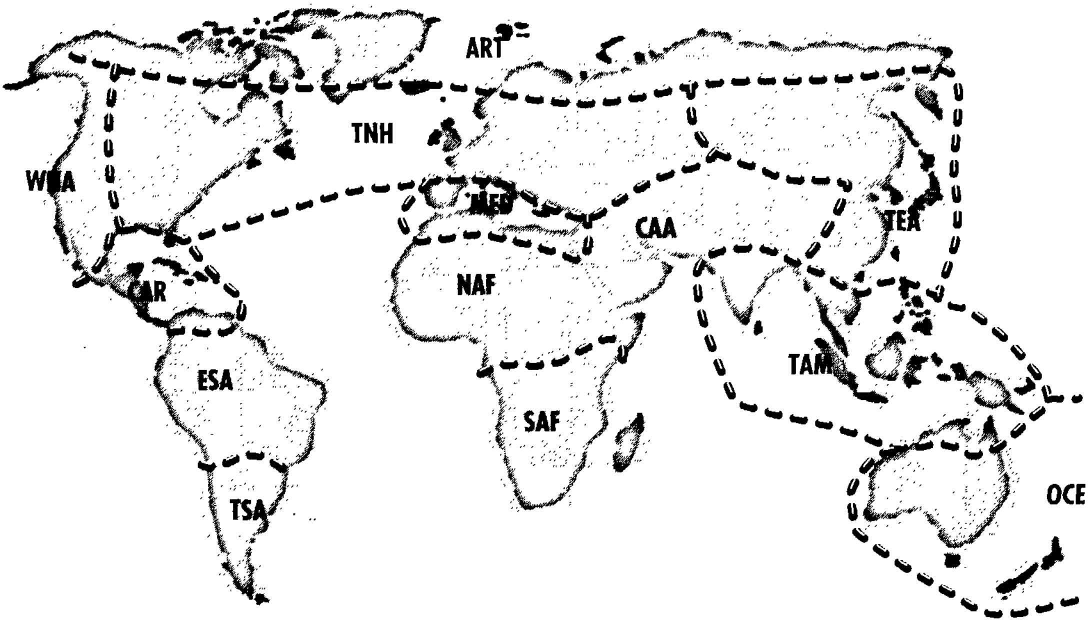

Fig.1 The 14 approximate geographic regions that are proposed as a possible global set of RRNs. Regions and boundaries that are adopted for the global START initiative will be based on regional needs and desires, through discussions with appropriate representatives from the nations involved. (From Eddy *et al.* 1991)

ANT	Antarctic (not shown)	OCE	Oceania
ART	Arctic	SAF	Southern and Eastern Africa
CAA	Central Arid Asia	TAM	Tropical Asian Monsoon Region
CAR	Caribbean	TEA	Temperate East Asia
ESA	Equatorial South America	TNH	Temperate Northern Hemisphere
MED	Mediterranean	TSA	Temperate South America
NAF	Northern Africa	WNA	Western North America

Top level data requirements for the data acquisition systems have been identified as follows:

- ▼ To upgrade the World Weather Watch (WWW) system;
- ▼ To accelerate the development of additional facilities for programmes such as Global Atmosphere Watch (GAW);
- ▼ Over the next two decades, to build on existing operational and research ocean programmes to develop a Global Ocean Observing System (GOOS);
- ▼ *To maintain and enhance operational and research monitoring programmes of changes in terrestrial ecosystems, clouds and the hydrological cycle, the Earth's radiation budget* and the cryosphere.

Satellite data will play a key role in satisfying these requirements, although quantitative specification of the required measurements is still being formulated.

International network of biosphere reserves

Both IGBP research programmes and GCOS require, in addition to remote sensing, a field based network of sites. The only such network which is truly global in extent is the network of biosphere reserves, organized through the Man and the Biosphere (MAB) Programme of UNESCO. The 311 biosphere reserves are distributed throughout the biomes of the world although not constituting a defined sampling regime. They vary in size from the almost regional scale of the 70000 km^2 biosphere reserve in northeastern Greenland to many on the landscape or almost the patch scale of less than 5 km^2. Activities within the biosphere reserves relate to three functions or 'concerns':

- *In situ* conservation of biodiversity;
- Development which allows sustainable use of land and water resources;
- The logistic concern providing an international network for research and monitoring.

Most of the biosphere reserves are natural or semi-natural ecosystems representative of major biomes, with the conservation function dominant. However, in addition, a significant proportion of the biosphere reserves fulfil a logistic function with strong research programmes and facilities which are linked into national or international monitoring networks. Thus they provide an important potential basis for GTOS.

Some of the biosphere reserves are already involved in specific global network programmes including collaboration with sites outside the biosphere reserve system. For example Tropical Soil Biology and Fertility (TSBF) is sponsored as a UNESCO-MAB programme and comprises a network of tropical sites, including agriculture and forestry, which is focused on sustainable management through manipulation of soil biological processes. A particularly relevant part of TSBF has been the development of protocols for standardized observation and experiments related to soil management (Woomer & Ingram 1991). Similarly the programme on Responses of Savannas to Stress and Disturbance (RSSD) has used comparative analysis and identified minimum data sets to be measured across savanna sites as a basis for modelling vegetation responses to moisture and nutrient availability (Solbrig 1991).

Diversitas

A new programme *Diversitas*, sponsored by IUBS, SCOPE and UNESCO and launched in 1991, aims to identify scientific issues and promote research requiring international co-ordination on the ecosystem function of biodiversity; the origins, maintenance and loss of biodiversity; and inventorying and monitoring of biodiversity. Within the last theme an open pilot network is proposed to conduct both intensive and extensive studies using agreed protocol and sampling methods. The actual sites will be chosen from - but not limited to - a number of biosphere reserves in selected biomes (di Castri *et al.* 1992).

United Nations Environment Programme

A key task in establishing a global terrestrial observing system, which builds on the research expertise and the network of field sites, is that of co-ordination, integration and dissemination of data. UNEP is responsible for environmental matters within the UN system and a UN-wide programme, Earthwatch, was initiated to monitor, assess and issue early warning of impending long-term environmental change. The problems involved in operating such an early warning system are considerable and will require integration of relevant activities in UN organizations, particularly UNESCO, FAO and WMO, combined with inter-and non-governmental, regional and governmental organizations. A number of elements of Earthwatch are of particular relevance:

- **Global Environment Monitoring System** (GEMS) aims to make comprehensive assessments of major environmental issues and has concentrated on developing techniques for monitoring, improving quality and comparability of data and enhancing existing networks. Working largely with and through other organizations, GEMS has concentrated on developing sectoral capabilities; an example is the World Conservation Monitoring Centre (WCMC), which compiles and disseminates data bases on the status, security and management of the world's biological diversity, including systematic information on biosphere reserves. WCMC is linked to Harmonization of Environmental Monitoring (HEM), which has created a meta-database on existing information, is harmonizing geo-ecological classifications, and is establishing procedures to assure data quality.
- **Global Integrating Monitoring** (GIM) promotes integrated monitoring, i.e. measurement of related variables in different biotic and abiotic compartments co-ordinated in time and space to provide a comprehensive picture of the system under study. From initial experience on sites in North and South America (Bruns *et al.*, 1991), about 50 candidate sites in Europe, North America and Asia are participating in development of a long-term integrated programme sponsored by respective governments or foundations.
- **Global Resource Information Database** (GRID) has established regional nodes to compile geo-referenced data from remote and ground based sources onto GIS and to form an interconnected network of data management and exchange. GRID is available to assist monitoring and assessment of terrestrial ecosystems as an analytical tool, as a mechanism for distribution of data, and in provision of advice on GIS and data handling.

The emphasis in many programmes mentioned is on the ‘natural environment’. Global change, however, influences and is influenced by intensively managed ecosystems. Trends in land use are driven by global changes in populations, economics and technology. The main organization with responsibility for managed ecosystems is the **Food and Agriculture Organization** (FAO) of the UN. In addition to its programmes providing technical advice and assistance to the agricultural community, FAO has, since its inception, collated, analyzed and disseminated data on trends in agriculture. Partly in association with other UN agencies such UNESCO and WMO, it has compiled global georeferenced data bases on natural resources, their actual use and their potential. Annual statistics and forecasts of longer term trends constitute an important global monitoring system but also provide an essential framework within which to sample representative sites for integrated monitoring. The FAO remit also includes monitoring of trends in forestry. Especially in its early days, 1950-1970, the Organization executed many large-scale natural resources inventories for land use planning in individual developing countries. Areas with such early data sets are of particular interest in the process of choosing sites for integrated monitoring, because of their 'back-tracking' ecological research component.

An important component of FAO activity is its sponsorship, along with World Bank, UNDP and others, of the **Consultative Group on International Agricultural Research** (CGIAR). Established in 1971, CGIAR is an informal association of governments, international organizations and private institutions. The mission is: 'through international research and related activities, and in partnership with national research systems, to contribute to sustainable improvements in the productivity of agriculture, forestry and fisheries in developing countries in a way that enhances nutrition and wellbeing, especially among low-income people'. Currently, seventeen international research centres, mainly in Africa, Latin America, Asia and the Middle East, are supported by the system. Although each centre is independent and autonomous, as an ensemble the centres constitute important foci of research expertise and information in developing countries, often associated with long-established field stations and experiments. Recent reviews of the priorities of CGIAR gave increased emphasis to merging productivity concerns with natural resource management in ecoregions, to addressing variations in climate and to protecting the genetic base of agricultural production.

It is apparent, even from this selective summary, that many of the important elements of a global terrestrial network exist - the research rationale, potential field sites, organizational and information systems. Many are in the process of development and all depend to a considerable extent on regional and particularly on national effort. What are the main regional and national bases on which the global system is, or can be, built?

Regional Networks[1]

The most highly developed networks, apart from the climatic recording, are concerned with air pollution. For example, the **Background Air Pollution Monitoring**

1. Based on contributions by L.-E. Lilljelund and J.-C. Menaut.

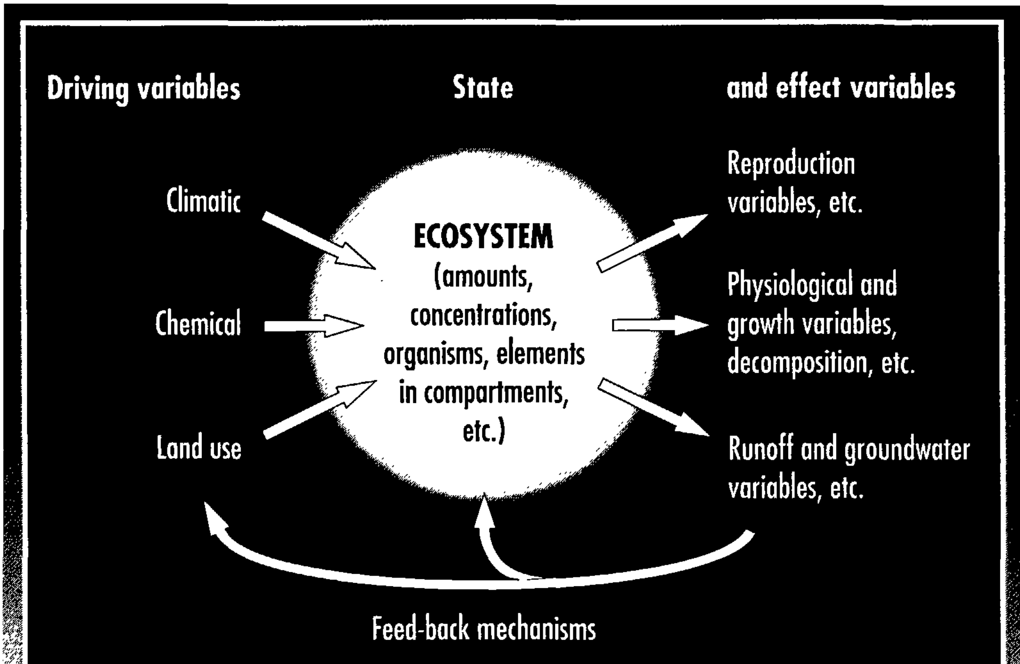

Fig.2 Illustration of driving, state and effect variables measurable in an ecosystem. The external driving variables are acting, usually independent of the other variables, upon the ecosystem. State variables are structural compartments of the ecosystem measured in quantitative figures. Effect variables are processes that are changed by the driving variables, usually causing changes of the state variables in the long-term, sometimes also of the driving variables by different feed-back mechanisms. (From Nihlgard & Pylvanainen 1992)

Network (BAPMoN) of WMO now consists of over 200 monitoring stations at remote locations, from which data on precipitation chemistry, wind particulate matter, etc, are collated to determine trends in chemical concentration of various substances in the atmosphere. Within this global network is a more intensive regional **Environment Monitoring and Evaluation Programme** (EMEP) involving stations in 25 European countries from which an **Integrated Monitoring Programme** (UN-ECE-IMP) has evolved to determine and predict the effects on ecosystems of anthropogenic transboundary air pollutants and their interaction with land use and climate (Figure 2). In the Pilot Phase of IMP, detailed field laboratory and data protocols have been established and tested. The Environmental Data Centre in Helsinki has collated data from 40 catchments in 16 countries and the application of data for continuous validation of dynamic mechanistic models has been investigated, the latter being of benefit in refining monitoring as well as for temporal and spatial projection (Nihlgard & Pylvanainen 1992).

The UN-ECE-IMP is probably the most highly developed multi-national network concerned with ground based monitoring of climate, pollution, plant, soil and water variables, although it is paralleled at national level in North America. Once established, the **European Environment Agency** (EEA) will play a major role in integration of data on air, land and water, including development and harmonizing of methods and standardization of date. The CORINE (**Coordination of Information on the Environment**) information system, established in 1985, already provides a GIS framework within which data on protected biotypes, air pollution and climate are integrated and represents an initial component of EEA. A wide range of CEC research-oriented networks provide the knowledge base for mechanistic interpretation and projection of environmental change detected through monitoring.

The direct link between research and monitoring and information exchange is considered essential in the **Observatoire du Sahara et du Sahel** (OSS). Within OSS, the target is the fight against desertification, combining four activities, (i) monitoring to determine the importance, distribution and evolution of land degradation, (ii) long-term ecological research to analyze the causes and consequences of the processes of land degradation, (iii) experimentation to identify solutions, and (iv) training to disseminate information and improve development. OSS is a sectoral network involving 20 developing African nations. It is currently under development and can both contribute to and gain from involvement in a global network. There are other such networks ranging from poles to tropics with considerable regional or sectoral capabilities. Their main contribution to the development of GTOS may be in providing the regional organization, co-ordination and infrastructure, especially in developing regions - the priority of the START programme.

National Networks[1]

The actual field sites which form the base for any regional or global network are at a national level and, to a large extent, sponsored by national governments and agencies. Many countries have developed national networks and, whilst some are limited to monitoring of selected environmental variables such as air quality, others combine research and experiment with long-term observation. The **US Long Term Ecological Research** (LTER) network comprises 18 research sites from the north slope of Alaska through to Puerto Rico and the Antarctic. The LTER sites include intensively and extensively managed as well as natural systems. Approximately 500 scientists participate in LTER work, and the focus is on ecological research involving time scales of decades to centuries and spatial phenomena of site, landscape and regional scales. Although the sites represent a very broad array of ecosystems and research emphasis, they share five core research topics:

- Pattern and control of primary production;
- Spatial and temporal distribution of populations selected to represent trophic structure;

1. Based on contributions by J. Vande Castle, V. Neronov, Zhao Shidong, P.B. Tinker.

- Pattern and control of organic matter accumulation in surface layers and sediments;
- Patterns of organic inputs and movements of nutrients through soils, ground water and surface water;
- Patterns and frequency of site disturbances.

The core themes and some common experiments provide the means of comparison of ecosystem response rather than measurement of a designated suite of variables defined by rigorous protocols. A computer network (LTERNET) provides a communication link between sites and acts as an access point to LTER databases with increasing collective capability to integrate GIS and remote sensing technologies within more conventional ecological research.

Similar national but continental scale networks covering a wide range of biogeographic zones are being developed in China and the Russian Federation. The **Chinese Ecological Research Network** (CERN) links 52 ecological research stations in (i) long term study of the structure, function and dynamics of ecosystems, (ii) long term monitoring of biotic and abiotic factors, and (iii) demonstration of sustainable management of natural resources, farm land and forests. A central Synthesis Centre co-ordinates accumulation of site data through subcentres for atmosphere, soil, biology and hydrology. The **Russian MAB Network** comprises about 30 biosphere reserves, including an Asiatic ecological megatransect. The emphasis is on conservation and biodiversity in natural or semi-natural ecosystems but, as with many other national networks, the Russian network is participating in the evolution of various regional or global activities including GCTE, the Biosphere Reserve Integrated Monitoring (BRIM) proposals of Euro-MAB, and the International Tundra Experiment (ITEX).

The continental scale networks of USA, China and the Russian Federation match and complement the multinational regional networks such as the UN-ECE-IMP. Other national networks can provide information at a finer level of biogeographical or climate variation. For example, the **UK Environmental Change Network** (ECN), representing oceanic temperate conditions, is being developed around eight initial sites along a combined environmental and management gradient from lowland arable to upland grazed moorland. Within ECN, long-term standardized measurements according to agreed protocols are complemented by intensive research on management and on impacts of global change as part of the GCTE programme.

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Other organizations and networks have not been included through lack of space rather than relevance. However, the sample considered reflects the diversity of interests and capabilities. The overwhelming conclusions from this brief review are:

- At global, regional and national levels, the essential elements for a global terrestrial observing system exist;
- Existing organizations have a variety of aims and approaches within the broad theme of detection of global change effects; no existing network has a fully established, integrated and comprehensive programme of measurement

and data management;

- Although there are similarities between networks, there is no generally agreed common set of variables and protocols;
- Although there are many candidate sites, the selection of sites within existing networks is based on pragmatism rather than a rigorous scientific rationale.

REMOTE SENSING IN RELATION TO A TERRESTRIAL NETWORK OF SITES[1]

Remote sensing has an important role to play in relation to a ground based network for modelling and monitoring of terrestrial responses to environmental change. Ways in which the contribution can be made are threefold:

- ▼ **Site characterization.** The extensive and globally consistent data derived from satellites can be used to define the main cover characteristics and their spatial variability at individual sites and to indicate the degree to which sites are regionally representative in terms of land cover.
- ▼ **Detection of change.** Both short-term and long-term changes in the distribution and state of land cover are detectable through remote sensing. The use of past data as well as future imagery is important.
- ▼ **Definition of properties.** Specific properties of vegetation or the environment can be directly measured to provide input to process models or to define structural parameters which have the potential to be related to community level biodiversity and other ecosystem characteristics.

A number of potentially important remote sensing data acquisition activities are of particular relevance to the definition, location and functioning of network sites. The LANDSAT Pathfinder Project is an interagency US effort to acquire global scale datasets of MSS and TM in three streams. Stream 1 is focussed on mapping tropical deforestation across the Amazon, central Africa and Southeast Asia. Data at three points in time - in mid 1970s, 1980s and 1990s - are being acquired. Stream 2 is focussing on acquisition of extensive data for non-tropical areas, particularly in North and Central America. Stream 3 is focussed on specific sites for purposes of test site validation and calibration. Sixty test sites of representative land cover types are currently under selection. The programme will extend the EOS record, in some cases, to 40 years. An important target is to ensure easy access to data.

A project specifically initiated and developed within the IGBP-DIS framework is the Land Cover Pilot Study. This is designed to support land cover classification and direct parameterization of land cover attributes. Algorithm testing

1. Based on contributions by C. Justice and D.L. Skole.

and validation will use high resolution test site data. This Advanced Very High Resolution Radar (AVHRR) mapping of land cover is currently being generated at 8 km resolution, with 1 km under development (Townshend 1992).

Intensive field site programmes targeted at particular biomes and problems have been developed in the ISLSCP Experiments. For example, HAPEX-MOBILHY focussed on regional scale (100 km square) meteorology and hydrology, using a test site near Toulouse, France. Synchronized remote sensed and ground data were used in mesoscale models which were more successful over forest than other cropped areas, and also defined relationships between effective and dominant land cover. The FIFE experiments at Konza Prairie, Kansas (an LTER site as well as a biosphere reserve) tested application of remote sensing at pixel scale and investigated scaling of critical parameters. It was shown that simple ratios can be used to infer APAR, CO_2 flux and conductance. A number of other such intensive field experiments are in progress or planned covering a range of environmental conditions and biome types from semi-arid Africa (HAPEX-Sahel) and Amazonian forest (ABRACOS) to North American boreal forest (BOREAS).

TOWARDS AN OPERATIONAL PLAN

The needs, opportunities and some of the problems in establishing an effective global terrestrial network have been outlined. Participants in the Fontainebleau workshop combined their experience in a series of discussion sessions to analyze the central issues and propose solutions. In doing so they drew on principles derived from previous reviews of long-term (Likens, 1989) and comparative research (Cole *et al.* 1991) and from previous workshops (Dyer *et al.* 1988; Risser, 1991) which had initiated proposals for global networking (Box 2).

Box 2. Some general principles for the design of long-term monitoring networks

1. Establish initial conceptual models
2. Build around scientists with common interests
3. Identify short-term as well as long-term goals
4. Capitalize on well-studied sites and past data
5. Design should be simple, flexible and adaptable
6. Design for extrapolation to scales of 100 x 100 km
7. Plan for detection of rare or unique events
8. Include experiments, and both managed and unmanaged systems
9. Sample transition as well as median conditions (gradients)
10. Include both intensive and extensive sites
11. Archive samples as well as data for future analyses
12. Quality Assurance must be built into the programme

Development of a Global Network for Modelling Ecosystem Dynamics[1]

To simulate the response of an ecosystem to novel conditions, a model should have a representation of fundamental processes appropriate to the relevant system. To apply at continental or global scales over relatively long periods of time, a model should be computationally efficient and parameterized to available extensive data.

These two model objectives are sometimes difficult to reconcile, and the simulation (or prediction) of global change impacts on terrestrial ecosystems is thus often approached by using a nested set of patch, landscape and regional models. The prototypes of such model sets exist and have been tested, intercompared and merged to some extent. While a considerable degree of model development will take place in the future, we know enough now about the model needs and the parameter requirements to provide some insights as to the data requirements for parameterizing and testing such sets of models.

An example of such spectrum of models is shown in Figure 3. The models at the lowest end of the size/space scale are leaf models. These predict the relatively fast response (minutes) of leaves and have modules that allow evaluation of elevated CO_2 or altered humidity effects. The global or biome vegetation models capture the long-term equilibrium vegetation state under a given climate.

The currently existing global vegetation models are essentially biogeographical in nature and have been successful in describing some important relationships between long-term (monthly) averages of meteorological variables and major units in potential natural vegetation. One recent model (BIOME, Prentice *et al.*, 1992) allocates 14 functional plant types on the terrestrial surface of the earth with a resolution of 10' in latitude and longitude. These types are combined to 17 biome types, which achieve a good fit with a subset from a database of global ecosystem distribution (Olson *et al.*, 1985) selected for relatively limited human impact. The validation of such a model is ultimately limited by the fact that the available data on global ecosystems have already been used to calibrate the model, a problem which is inherent to models with global coverage.

Given more comprehensive, high resolution databases for global ecosystem distribution, future models could be based on a more systematic validation procedure. Ideally this will be based on a limited number of sites being used to calibrate the model while the remainder of the available data can be used as test sites. In the context of global ecosystems monitoring, the compilation of databases with full spatial coverage at sufficiently high resolution should be given priority.

Network requirements for modelling of terrestrial ecosystem dynamics

Three levels of monitoring networks are appropriate for generating input, calibration and validation data for terrestrial ecosystem models. These networks can

1. Based on contributions by W. Cramer, H. Shugart, R. Scholes.

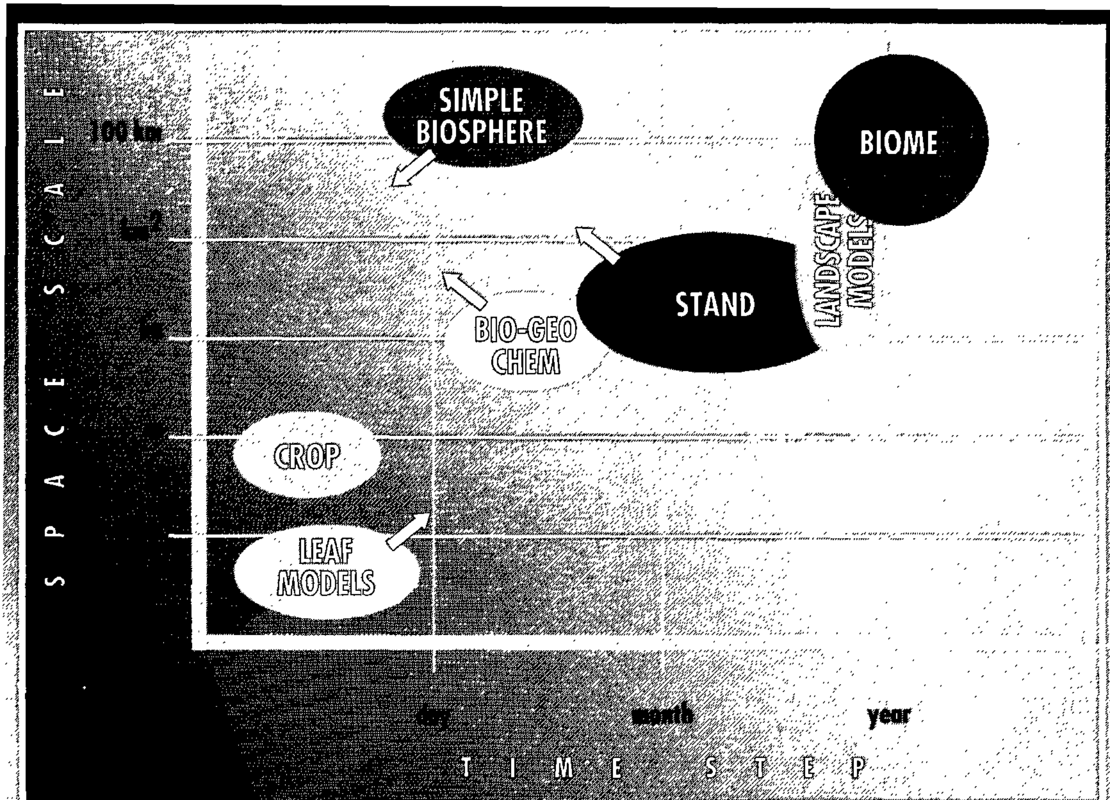


Fig.3 A spectrum of models with different time and space scales of resolution. Arrows indicate the direction in which various model clusters are evolving.

be ranked along a scale of decreasing monitoring intensity. Such a nested suite of sites for monitoring global change was identified by Dyer *et al.* (1988).

- ▼ Sites with **intensive** monitoring of many ecosystem variables and high temporal resolution are necessary to generate new understanding of ecosystem processes that may lead to the development of entirely new ecosystem models. The most likely candidates for sites within this group are intensive research sites that are already monitored or in the process of establishment within one of the existing networks and have a long-term commitment. This type of monitoring should continue and be extended.
- ▼ Sites with **less intensive** monitoring would be arranged along major environmental gradients (more than 10^2 km) that are appropriate for the validation of large-scale terrestrial ecosystem models. Examples for such gradients are the tundra-boreal transition, or the savanna-desert gradient. In this case, the selection of sites and variables to be monitored should largely be decided with respect to the data requirements for the ecosystem models. This means ensuring that the monitoring sites are located at suitable intervals along the selected gradient and that most other environmental parameters are kept constant as far as possible. The

selection of variables to be monitored, and the time schedule (frequency, duration) of measurements will depend on the selected model, but will most likely include aspects like phenology, local climate, soil moisture, atmospheric gas exchanges, etc., all of which would have to be recorded frequently.

- A third class of sites would be monitored **extensively** with the main aim to include as many sites as possible, while minimizing the costs. These sites will provide essential links for the extrapolation of results from models which are run at the more intensive sites to the entire terrestrial area of the earth. Quantitative, area-related estimates (e.g. for changes in gas exchange between atmosphere and biosphere) require this type of network, which would need a new organizational structure (although it could be established using many of the existing monitoring sites from other networks). Variables to be included would largely have to be ecosystem properties changing at low but detectable rates, such as plant species composition, stand structure, total standing biomass (including soil nutrient levels), and land use. Special attention should be paid to use of standardized, simple methods which would be insensitive to observer bias.

There is a basic requirement to integrate existing programmes to ensure cost-effectiveness. Existing networks do have common themes with many similar parameters measured/monitored across the networks. However, integration between networks will need to distinguish the three main roles of monitoring which require distinct (perhaps overlapping) subsets of variables to detect global change, to validate global change models, and provide validation of remote sensing models.

Selection of sites for monitoring will need to consider operational status as well as scientific suitability. Extensive (e.g. constituting transects or gradients) and intensive sites will be needed, and both will require detailed site characterization to assist model extrapolation. For the validation of global change models, complete global coverage is not essential. What is needed are carefully chosen sites or areas (gradients) that will test a model's ability to predict change of key processes on structure at particularly sensitive sites. For applications of remote sensing there needs to be careful definition of which parameters can be determined with remote sensing both for spatially data-rich (e.g. transect) and for intensive long term observation.

Rationale and Procedures for Selecting Monitoring Sites in a Global Network[1]

The objective of a global terrestrial ecosystem change monitoring system are taken to be:

- the verification and documentation of changes in performance, composition and pattern in terrestrial ecosystems; and
- the validation of models used to predict ecosystem change.

1. Based on contributions by J. Melillo, P.-E. Lilljelund, J. Robertson, W. Sombroek, B. Walker and Workshop participants generally.

The objectives of the various groups contributing to the network (GCTE, OSS, MAB, etc.) may contain additional clauses.

Of the three categories of sites of decreasing monitoring intensity (pages 27-28) selection procedures are focused on the middle level of this hierarchy ('less intensive monitoring'), in which the sites have the primary objective of monitoring terrestrial ecosystem change. It is anticipated that these will number about 50-100 worldwide. They will not be 'point' sites, but each will be a representative area at landscape scale. The need for a smaller number of highly intensive sites will continue, and there will be a need for a much larger number of extensive survey sites for extrapolation and inventory purposes.

What is the rationale by which sites are selected to constitute a global network? A **scientific or intellectual rationale** requires development of a regime designed to sample the expected main sources of variation. Within the global climate envelope, terrestrial ecosystems have developed or have been managed to produce characteristic dominant vegetation over large areas (i.e. biomes). The biomes represent the major biological variation to which site selection can be focussed in three ways:

- **Biome focus.** Selection of 'typical' sites which allows extrapolation over the major area of the biome. The ecosystems are relatively stable and therefore the signal of change will be large relative to the noise caused by environmental fluctuations.
- **Ecotone focus.** The transition zone between biomes (ecotone) is particularly sensitive to environmental change, including land use. Selection of such sites should allow early detection of change but the signal may be obscured by considerable noise.
- **Gradient focus.** Selection of sites along environmental gradients is designed to capture the variability of Biomes and can integrate both Biome and Ecotone approaches.

Whilst an intellectually satisfying scientific rationale can be developed, **operational criteria** must be applied in order to develop an effective network. Those should include the availability and interest of scientific talent; presence of a suitable organizational infrastructure; relevance to local and regional issues especially in developing countries; and economic criteria, particularly in the use of existing projects. The proposed approach outlined below combines the scientific rationale of 'environmental space' with a series of criteria and rules for site selection within that space.

A proposed approach

Detecting, understanding and predicting change in terrestrial ecosystems under global change will be based on responses to changes in the underlying environmental parameters that largely determine ecosystem distribution. Thus sites for the global change network should be chosen to give a scientifically valid distribution in environmental space.

The following principles in site selection are suggested:

1. Establish a minimum number of axes to define the appropriate environmental space. As a first approximation, mean monthly minimum temperature (of the coldest month), mean annual precipitation and mean annual total radiation are suggested. Figure 4 illustrates global climate space and how it can be related to biome classification.
2. Identify the existing sites which satisfy the infrastructural criteria for selection (length and detail of existing climatological, agricultural and ecological databases, facilities, support personnel, etc.). Set out a skeleton network based on a selection of these sites.
3. For each position in environmental space, it is necessary to establish replicated sites and identify sites representing the range of fine-scale ecosystem determinants, for example:
   - soil type;
   - management regime (e.g. an intensively cultivated site adjacent to a protected native forest);
   - genetic history (e.g. tropical rain forest sites at the same point in environmental space in South America, Africa and Southeast Asia).
4. Evaluate further offers of sites against the skeleton network and the criteria.
5. Identify particular regions in environmental space where there are no existing sites, and no offers in the foreseeable future. Within each of these regions, identify potential candidate areas and sites and seek offers. In many of these cases, IGBP may be able to help in the establishment of appropriate sites through support from the START initiative.
6. A biome-by-biome procedure will be used in the initial definition of environmental space and identification of existing sites (Fig.4). In the final analysis the network of sites will be tested against the full global range of environmental space, irrespective of the current biome distribution. This is necessary because future combinations of environmental factors may not now exist in recognized biomes (e.g. the boreal forest biome was much reduced or non-existent during the last inter-glacial period).

The application of this approach to site selection incorporates representation of major Biomes distributed within environmental space. Establishment of the primary or skeleton network is seen as the top priority, which can be followed by expansion to increase replication or to target particular conditions (e.g. transition zones).

Operational rules for site selection

Within the proposed approach, specific rules are required for site selection as outlined in Box 3. These rules have been designed to make the selection process as objective and transparent as possible. A list of information is required from each candidate site in order to perform the selection. A minimum outline of this list includes:

- Site name
- Latitude and longitude
- Responsible agency (including contact person and address)
- Legal status, with particular reference to the permanence of the site
- The biome and land-use type
- The main research foci: biodiversity, agriculture or ecological process
- The adequacy of access, scientific facilities and support services.

To be considered truly global, the site distribution must show a balance between land masses, biome types and the developed and developing world. The system also needs to strike a balance between coverage at the range of environmental conditions prevailing on the globe, and replication at a given level. Each participating organization is likely to have priority areas, which may change over time. For instance, GCTE has an explicit list of current priorities: the tundra-boreal transition, the humid tropics, the semi-arid tropics, temperate intensive agricultural areas, and multi-component agricultural systems in developing countries.

Box 3. Operational rules for site selection

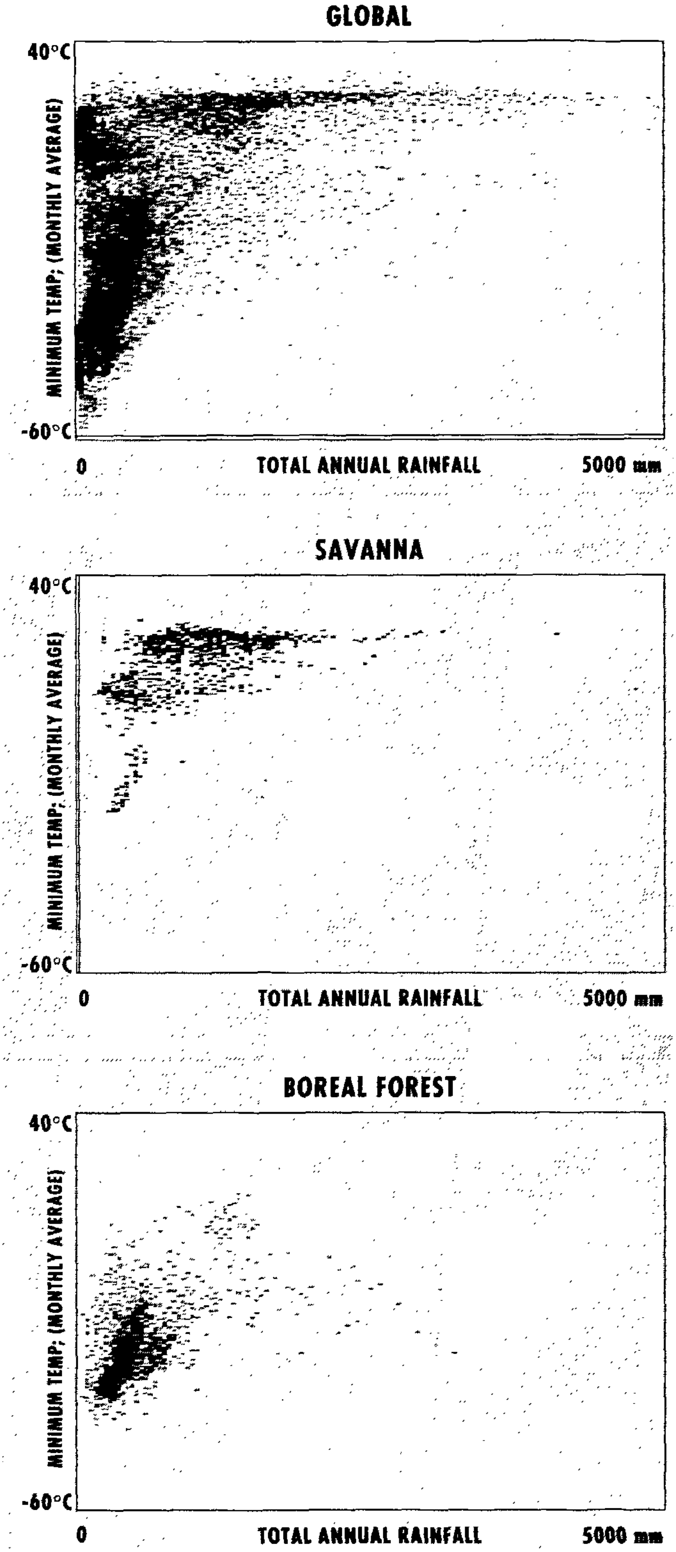
A. Mandatory: a site must satisfy the following:

1. On currently available evidence, the site must have tenure for monitoring for the next fifty years.
2. The site operating agency must be willing and able to provide the core set of monitoring variables, to the necessary quality standards, plus the core set within one or more of the following foci:
   a. Biodiversity and ecosystem composition change
   b. Change in agricultural performance
   c. Change in ecological function
   d. Change in landscape pattern and use.

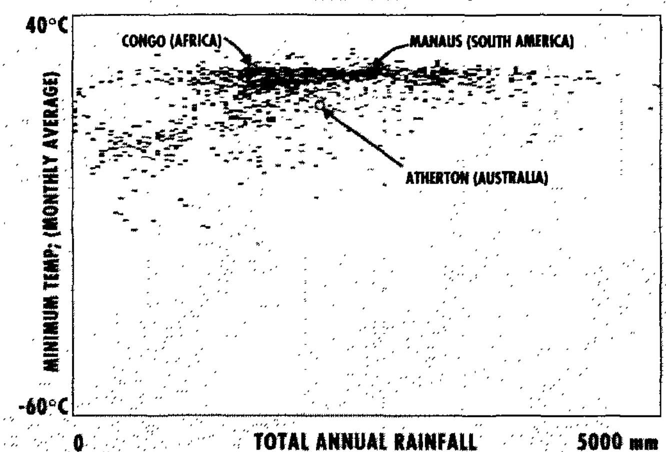
B. Preferential: these rules are for prioritizing sites which satisfy the above criteria:

3. Sites having a set of environmental characteristics not already represented in the network will be preferred over sites already represented. Environmental characteristics include climate, soil types and land use types and biotic richness.
4. Sites should impose the minimum additional costs at the local and international level, i.e. established, supported sites have preference over new sites.
5. Committed institutional support at the local level, or important to the national resource management or development needs.
6. Location in a priority region of one of the participating organizations.
7. Practical and economical to operate.

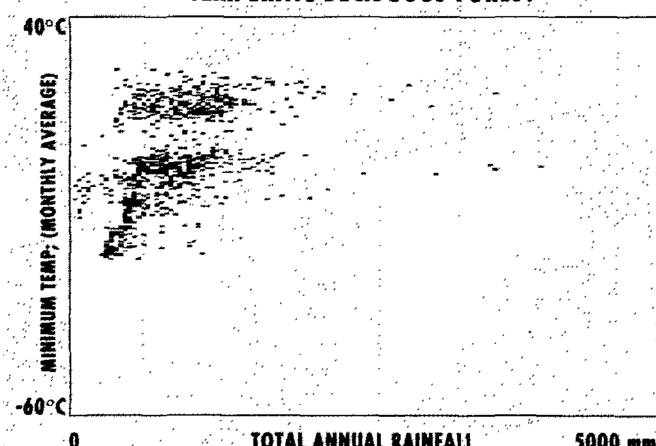
Fig.4. Environmental space defined by mean monthly minimum temperature (°C) and annual rainfall (mm). The global dimensions (top left) can be partitioned to approximate to biomes and to locate individual sites.



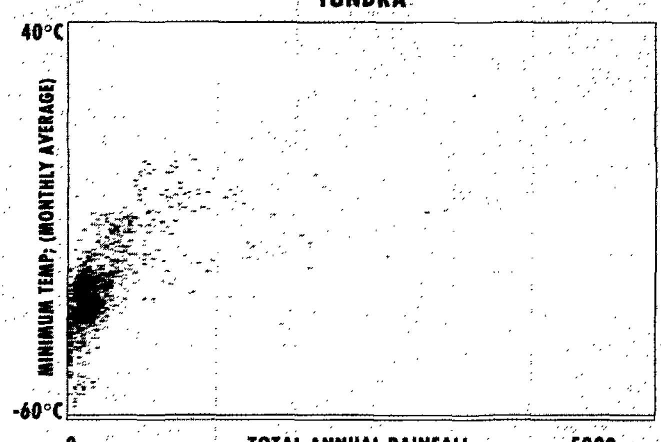
TROPICAL RAINFOREST



TEMPERATE DECIDUOUS FOREST



TUNDRA



Rationale for and Identification of a Core and Extended Suite of Variables to Model, Detect and Monitor Environmental Change[1]

A list of key variables has been developed to characterize the sites, to monitor change and to be used for testing and validating models in priority subjects. The collection of the measurements is expected to be conducted at the intermediate level of terrestrial monitoring stations and applied at 50-100 natural and managed sites across environmental space. The variables have been grouped into three tables based on their function and importance. The selection has been based on experience from many previous studies and although considerable care has been taken in the compilation, it is indicative rather than definitive.

Site location and characterization (Table 1). A primary set of standard information is necessary to locate the site and define its basic physical and land use characteristics. These variables are only measured initially or very occasionally. A further set of variables is needed to document the factors which have historically affected the status of the ecosystem. The historical variables are identified in Table 2 because they will be measured repeatedly. Similarly, climatic and other variables assist in basic site characterisation are included in Table 2.

Core variables (Table 2). This list of variables represents a 'minimum requirement' at each site to be used for model validation and for monitoring global environmental change. These variables have been selected to meet several objectives identified by GCTE and other groups. The core set of variables is designed to allow for change detection of structure and performance of priority areas, for minimum input data needed at the site level for a broad array of terrestrial models, and validation of models and remote sensing observations. The variables are also selected to facilitate long-term comparability between sites, to be as free as possible from observer bias, to use standard methods (automated if possible) and applicable over a 50-year period.

Variables describing site history and disturbance regime are needed to define the factors which affect current status of the ecosystem. Historical documentation is required of naturally occurring events such as fire, grazing, floods, etc., and human-induced events such as cropping management, logging practices, fire, etc. In addition, any ongoing changes in management or disturbance events need to be documented. Climate variables include a number of basic meteorological variables needed to run various terrestrial models as well as to relate to responses within the ecosystem.

Soil variables will be used for change detection, model inputs and validation. Many of these features will change moderately over time except when events occur related to soil disturbance, such as storm damage causing tree throw, grazing-induced compaction, or changes in land use. A five-year sampling interval will usually capture changes in the more stable variables. However, a number of more dynamic soil-related variables will need to be measured to assess

1. Based on Workshop discussions and compiled by D. Ojima and R. Scholes.

ecosystem dynamics. These include surface and below-ground litter and soil CO_2 fluxes as well as groundwater chemistry. Hydrological and hydrochemical measurements in soils, groundwater and streamflow represent a set of variables needed to run models but which are also selected as factors which indicate system responses to climate or land use change.

Vegetation variables are used for change detection and model validation. Annual measurements on dominant plant components will be adequate for most of the variables. However, the ability to measure the short-term dynamics of certain vegetation components to assess changes in performance and to validate terrestrial models and remote sensing observations are also needed. These include changes in intercepted radiation and phenological stages of leaf onset, flower initiation and dispersal of propagules.

Measurements of indicators related to biodiversity of flora and fauna will be made annually in order to assess change and to validate certain terrestrial models. Use of permanently marked plants and quadrats will be used to monitor long-term persistence and performance of these plants. Other variables such as bird counts will also be included in this component. (Definition of biodiversity variables and methods requires considerable further attention. See also section on Biodiversity, page 48).

Landscape composition is identified for core measurement. The spatial variability which is found at the site needs to be described in order to assess the range in measured values within the landscape for model extrapolation and for interpretation of remote sensing observations. At this time, a clear definition of what and how to make this assessment has not been made.

The variables outlined in Table 2 need further consideration but are presented as a basic list for further development. Some of the variables identified in Table 3 may need to be upgraded to core measurements.

Additional variables (Table 3). A number of additional measurements have been included as an 'extended list'. These can provide more detailed information on the structure and function of the ecosystem and will feed into a number of the models. The additional variables are desirable rather than 'essential.'

◆◆◆

The collection of the data is envisioned to occur at a range of temporal intervals (from one time measurements of site descriptors to daily meteorological measurements). At each site, it is planned that approximately 12 person-months will be spent collecting the core data per year. These should be fully standardized, and applied at all sites where it is scientifically justifiable to do so. Some measurements may have to be varied for technical reasons, but this should be kept to the minimum so that data can be compared and aggregated as far as possible. The selection of the final suite of variables, and the methods to be used, will have to be done by a separate Task Force, drawing on experience from existing monitoring networks and agricultural and ecological research organizations. The final selection of variables will be based on various technical criteria. However, it is essential that individual measurements have a clear functional relationship with other variables so that the combined set is effective as an integrated programme.

TABLE 1. PROPOSED GTOS VARIABLES: SITE LOCATION AND CHARACTERIZATION

These variables provide site characterization for direct comparison between sites and are measured only initially. Additional site history, climate, soil, vegetation and fauna variables from Table 2 will assist in characterization but will be measured repeatedly. As indicated, site characterization variables may also provide input to models. See Footnote for definition of the accuracy, type of measurement, frequency and source.

	Variable	Accuracy[3]	Model type[5]										Monitor Change	Method Source[4]
			CROP		CNPS CYCLE		STAND		LANDSCAPE		BIOME			
			TYPE[1]	FREQ.[2]	TYPE[1]	FREQ.[2]	TYPE[1]	FREQ.[2]	TYPE[1]	FREQ.[2]	TYPE[1]	FREQ.[2]	FREQ.[2]	
1	**Site Locators and Descriptors**													
1.1	Site name	-	c	ø	c	ø	c	ø	c	ø	c	ø	ø	
1.2	Latitude	20m	c	ø	c	ø	c	ø	c	ø	c	ø	ø	GPS
1.3	Longitude	20m	c	ø	c	ø	c	ø	c	ø	c	ø	ø	GPS
1.4	Altitude	20m	c	ø	c	ø	c	ø	c	ø	c	ø	ø	GPS
1.5	Landscape position	-	c	ø	c	ø	c	ø	c	ø	c	ø	ø	TSBF
1.6	Slope	5°	c	ø	c	ø	c	ø	c	ø	c	ø	ø	DEM
1.7	Aspect	45°	c	ø	c	ø	c	ø	c	ø	c	ø	ø	DEM
1.8	Biome type	-			c	ø	c	ø	c/v	ø	v	ø	10	?
1.9	Land use type	-	c	ø	c	ø							10	FAO/RS
1.10	FAO soil type	-	c	ø									10	FAO
2	**Soils**													
2.1	Total depth	0.1m			p	ø							ø	TSBF
2.2	Horizon depths	0.1m	p	ø	p	ø							ø/10	TSBF
2.3	Effective rooting depth	0.1m	p	ø	p	ø							ø	ASAI

2.4	Surface colour	-											5	TSBF
2.5	Surface litter mass	10%											y	TSBF
2.6	Minerology class/ Parent material												ø	ASAI
	Soils by horizon or 0-20, 20-50, 50-100 cm:													
2.7	Root length or fraction	1%			p	ø							ø	TSBF, ASAI
2.8	% gravel	2%			p	ø							10	TSBF, ASAI
2.9	% clay	5%			v/p	10							10	TSBF
2.10	% sand	2%			v	y							10	TSBF
3	**Hydrology** (by horizon)													
3.1	Water holding capacity	10%	p	ø	d	ø							ø/5	ASAI, TSBF
3.2	Water retention curve	10%	p	ø					p	ø			ø/5	ASAI
3.3	Sat.hydraulic conductivity	20%	p	ø					p	ø			ø/5	ASAI
3.4	Infiltration parameters	20%							p	ø			ø/5	ASAI

F O O T N O T E S :

1. Variable type

- c characterization
- d driving
- p model parameter
- v model validation

2. Frequency

- ø Once only, at initial survey
- h hourly
- d daily
- w weekly
- m monthly
- s seasonally (c.3 months or crop cycle)
- b twice per year, at maximum and minimum value
- y yearly
- 5 five-yearly
- 10 decade
- e event
- x twice daily, at maximum and minimum

3. Accuracy

- % standard error/mean value x 100/1
- 1%1 absolute percentage standard error
- Other units absolute standard error

4. Source

- FAO Food and Agriculture Organization
- GPS Global positioning system
- TSBF Tropical Soil Biology and Fertility (Anderson & Ingram 1989)
- ASA1 *American Society of Agronomy Methods Manual Vol 1*
- ASA2 American Society of Agronomy Methods Manual Vol 2
- WMO World Meteorological Organization
- EPN European Pollution Network
- UN-ECE United Nations Economic Commission for Europe Integrated Monitoring Programme

5. Model type

- [leaf] excluded from this compilation
- Crop e.g. CERES
- CNPS e.g. Century, BGclim
- Stand 1 Foret
- Landscape catenal, landscape, catchment
- [Biophysical] SIB, BATS (excluded from this compilation)
- Biome e.g. Prentice & Cramer, Holdridge, Box

TABLE 2. PROPOSED GTOS VARIABLES: CORE MEASUREMENTS

The Core measurements are for input to models and to monitor change. These are standard measurements to be made at all sites. See Footnote to Table 1 for definition of the accuracy, type of measurement, frequency and source.

	Variable	Accuracy[3]	Model type[5]										Monitor Change	Method Source[4]
			CROP		CNPS CYCLE		STAND		LANDSCAPE		BIOME			
			TYPE[1]	FREQ.[2]	TYPE[1]	FREQ.[2]	TYPE[1]	FREQ.[2]	TYPE[1]	FREQ.[2]	TYPE[1]	FREQ.[2]	FREQ.[2]	
1	**Site history and disturbance: Freq., seasonal timing and intensity of:**													
1.1	Fire	10%			d	m	d	m	d	d	d	m	e	TSBF
1.2	Cultivation(inc.crop type)	10%	d	d	d	m			d	y			e	?
1.3	Fertilisation	10%	d	d	d	m			d	m			e	FAO
1.4	Pesticide input	10%	d	d									e	?
1.5	Flooding & irrigation	10%	d	d	d	m			d	d			e	?
1.6	Harvest (Yield C, N, P)	5%	v	s	d/v	m	d	m	d	y			e	FAO/TSBF
1.7	Planting (sp.,density,date)	10%	d	d	d	m	d	m	d	m			e	?
1.8	Pest outbreak (sp.)		d	d			d	m	d	d			e	?
1.9	Herbivory	20%			d	m							m	?
1.10	Pollution (SO_2,O_3,HF etc)	20%							d	d			d	UN-ECE
1.11	Cyclone/severe storm etc				d	m			d	y			e	?
2	**Climate**													
2.1	Rainfall	10%	d	d	d	m	d	m	d	d	d	m	d	TSBF, WMO

2.2	Snowfall	10%			d	m	d	m	d	d			d	WMO
2.3	Photosynthetic active *radiation*	5%	d	d			d	d/m			d	m	d	WMO
2.4	Wind run	10%	d	d									d	WMO
2.5	Humidity	5%	d	d									d	WMO
2.6	Air temperature (1.5m)	0.1°C	d	d	d	m					d	m	d	WMO
2.7	Soil temperature (20 cm)	0.1°C	d	d	v	m					d	m	d	WMO
3	**Soils** (by unique horizon)													
3.1	Organic carbon	5%	p	ø	v/p	10							y/5	TSBF
3.2	Soil litter (>0.25 mm)	5%			v	ø							y/5	TSBF
3.3	Total N	5%			v/p	10							y/5	TSBF
3.4	Major cations (Ca^{++}, Mg^{++}, K^+, Na^+)	2% 0.1%	p	ø	p	ø			p	ø			y/5	TSBF, ASA2
3.5	pH in water 1:2.5	0.1%			v	ø/y							y/5	
3.6	CEC ° pH 7.0	2%			v	ø/y							y/5	
3.7	Exchangeable acidity												y/5	
4	**Groundwater**													
4.1	Depth to water table	0.01m			p	ø			v	d			d	?
4.2	Soil water content		v	d	v	m			v	d			d	ASA1, TSBF
4.3	Nitrogen chemistry (NO_3^-, NH_4^+)	10%			v	m			v	w			w	UN-ECE
5	**Streamflow**													
5.1	Discharge	5%							v	d			d	UN-ECE
5.2	Nitrogen chemistry	10%							v	d			w	UN-ECE
5.3	Other ionic chemistry	10%							v	d			w	UN-ECE
5.4	Sediment load	10%							v	d			w	UN-ECE

Variable		Accuracy[3]	Model type[5] CROP TYPE[1]	CROP FREQ.[2]	CNPS CYCLE TYPE[1]	CNPS CYCLE FREQ.[2]	STAND TYPE[1]	STAND FREQ.[2]	LANDSCAPE TYPE[1]	LANDSCAPE FREQ.[2]	BIOME TYPE[1]	BIOME FREQ.[2]	Monitor Change FREQ.[2]	Method Source[4]
6	Nutrient inputs and outputs													
6.1	Wet deposition: (NO_3^-, NO_4^+, other ions)	10%				d	m						w	UN-ECE
7	**Vegetation: Canopy parameters**													
7.1	PAR(z)/PAR(o) by 0.1z increments	10%												?
7.2	LAI	10%	v	w	d/v	w/m			v	w			w	?
7.3	% projected cover	10%							v	y			-	?
	Leaf parameters: by spp													
7.4	% Lignin (at litterfall)	10%			p	ø							y	TSBF
7.5	% Lignin (newly expanded leaf)	10%											y	TSBF
7.6	% N,P (at litterfall)	10%			p	ø							y	TSBF
7.7	%N,P(newly expanded leaf)	10%			p	ø							y	TSBF
	Composition: by spp													
7.8	Density	10%					p/v	y					y	
7.9	Functional type										v	ø	y	?
	Vegetation demography: by spp													
7.10	Size category: DBH, height, cover	10%					d/v	y					y	TSBF
	Phenology: by spp													
7.11	Leaf bud break	day							v	d			d	?

7.12	Flowering	day							v	d			d	?
7.13	Phenological stages	day	p	d	d	m							d	?
	Function: by dominant functional type													
7.14	Peak above-ground biomass	15%			v	y							y	TSBF
7.15	Necromass (standing dead)	15%			v	m							y	TSBF
8	**Animals. Mammalian herbivores: by class**													
8.1	Stocking density by time		p	ø	d	m							w	?
8.2	Secondary production		v	m									y	?
	Birds: by spp													
8.3	Presence, breeding												m	?
9	**Gaseous fluxes**													
9.1	CO_2 flux above canopy	10%	v	h/d	v								m	?
9.2	CO_2 flux from soil	10%			v	w/m							m	TSBF
10	**Landscape composition**													
10.1	Patch proportions						d/v	y					y	UN-ECE
10.2	Mean patch size, etc						d/v	y					y	UN-ECE

TABLE 3. PROPOSED GTOS VARIABLES: ADDITIONAL MEASUREMENTS

The Additional measurements are those which would be beneficial for models and for monitoring change but are optional. See Footnote to Table 1 for definition of the accuracy, type of measurement, frequency and source.

	Variable	Accuracy[3]	Model type[5]										Monitor Change	Method Source[4]
			CROP		CNPS CYCLE		STAND		LANDSCAPE		BIOME			
			TYPE[1]	FREQ.[2]	TYPE[1]	FREQ.[2]	TYPE[1]	FREQ.[2]	TYPE[1]	FREQ.[2]	TYPE[1]	FREQ.[3]	FREQ.[3]	
1	**Climate**													
1.1	Other(irrigation, mist, etc.)	10%	d	d					d	d			d	WMO
1.2	Net radiation	10%											d	WMO
1.3	Shortwave incoming radiation	5%									d	m	d	WMO
2	**Soils** (by unique horizon)													
2.1	N mineralization potential	5%			v/p	10							y/5	TSBF
2.2	Total and organic P	5%			v	m							y/5	TSBF
2.3	Extractable P (resin)	0.1 ml							p	ø			y/5	TSBF, ASA2
2.4	δ^{13}C in soil C, by fraction		p	ø					p	ø			5	TSBF, ASA2
2.5	δ^{15}N in soil N, by fraction												5	
3	**Groundwater**													
3.1	Other ionic chemistry	10%							v	w			w	UN-ECE
4	Nutrient inputs and outputs													
4.1	Dry deposition: N chemistry (NO_3^-, NH_4^+) and other ions & aerosols	10%			d	m							w	?

4.2	N_2 fixation	15%			d	m							m	TSBF
4.3	NH_3, volatilization from urine and fertilizer	15%			d/v	m							w/m	?
4.4	N gaseous loss NO_3, N_2O				v	w/m							w/m	?
5	**Vegetation: Canopy parameters**													
5.1	Leaf angle	5@	p	ø										?
	Leaf parameters: by spp													
5.2	Specific leaf area & major dimension	10%	p	ø							v	ø		?
5.3	Transmittance	10%	p	ø										?
5.4	Succulescence (IFW-DW/DW)	10%									v	ø		?
5.5	A-Ci Curve (newly expanded leaf)	10%	p	ø										?
5.6	Secondary compounds (Tannins, alkaloids)	10%			p	ø								TSBF
	Composition: by spp													
5.7	% contribution to above-ground biomass	10%											y	TSBF
5.8	% contribution to FPAR	10%											y	?
	Demography: by spp													
5.9	Growth rate: by size, class & density	10%					p	ø					y	?
5.10	Mortality rate:by size class	10%					p	ø					y	?
5.11	Establishment class:by density	20%					p	ø					y	?
	Function: by dominant functional type													
5.12	Peak below-ground biomass	15%			v	y							y	TSBF
5.13	Above-ground NPP	20%			v	m			v	w			m	TSBF
5.14	Below-ground NPP	20%			v	m							m	TSBF

	Variable	Accuracy[3]	Model type[5]										Monitor Change	Method Source[4]
			CROP		CNPS CYCLE		STAND		LANDSCAPE		BIOME			
			TYPE[1]	FREQ.[2]	TYPE[1]	FREQ.[2]	TYPE[1]	FREQ.[2]	TYPE[1]	FREQ.[2]	TYPE[1]	FREQ.[2]	FREQ.[2]	
5.15	Litterfall	10%			v	m							m	TSBF
5.16	Allocation ratios:by size class	10%	p	ø	p	ø	p	ø						?
6	**Animals: Soil fauna by functional type**													
6.1	Density	20%											y	TSBF
6.2	Biomass	20%			p	ø							y	TSBF
	Insects by key spp													
6.3	Outbreaks:date & intensity												m	?
6.4	% herbivory												s	?
7	**Gaseous fluxes**													
7.1	CH_4 flux canopy/soil	10%											m	TSBF
7.2	N_2O flux canopy/soil	10%											m	?
7.3	Non-methane hydrocarbons	10%											m	?

Agroecosystems[1]

Agroecosystems (including production forests) have been the subject of intensive research and monitoring for at least a century. Considerable data already exist at national, regional and global levels of long-term changes in crop production and its relation to climate, management and genotype variability. Thus crop performance from experimental plots and production statistics from annual surveys provide both intensive and extensive data. Additionally change in the spatial distribution of agroecosystems can be readily monitored by remote sensing. Agroecosystems therefore provide a particularly strong base for detecting responses to global climate change and for discriminating between effects of climate, pollution and land use.

The purposes of monitoring in agroecosystems are to detect and quantify change, and the causes and consequences thereof. The question of whether these are global or local effects could be determined by comparisons within the network.

Driving variables

With respect to the effect of change in climate and atmospheric composition on agroecosystems, it should be noted that temperature change is expected to be most marked at high latitudes, and that rainfall changes could have devastating effects where water supply is already limiting. The effects of increased CO_2 concentration in the atmosphere are expected to be a general fertilizing effect on vegetation, and an effect due to improvement in water use efficiency in particular situations. However, long-term responses of vegetation and crops are still uncertain. The changes in competition within plant communities due to changes in temperature, UVB-radiation, CO_2 concentration and water supply are of minor importance in intensively managed systems but may influence more natural systems like grasslands and forests.

In the context of agroecosystems, changes in land use are particularly important. It is expected that in the immediate future, there will be increasing intensification of land use in parts of the developed countries, but in other parts large areas of land may come out of agriculture altogether. In many developing countries, land use is likely to be driven by increasing demand for food and fibre, based on the increase in population numbers and on increased economic expectations. This is likely to lead to increased use of marginal land, which will often cause serious land degradation, so that little or no increase in output results from the expanded land area. It will also lead to much greater intensification of existing utilized areas; this may cause serious problems of pollution and other forms

1. Contribution by F. Beese, H. Narjisse, P.B. Tinker, W. Sombroek and Workshop participants.

of degradation. Nevertheless, more intensive but sustainable forms of land use are essential if the needs of developing countries are to be met. These varied changes and problems will need careful monitoring in all the main types of agroecosystems so that problems can be identified at an early stage when they occur.

It is essential to monitor land cover on a global scale at regular intervals by remote sensing techniques. This must be done according to a statistically based, widely accepted and georeferenced system.

Characteristics of agroecosystems and measured variables

Do agroecosystems have characteristics that differ from those of less intensively used systems? Such differences would be important in establishing selection criteria for sites, the site characteristics that need to be recorded, and the variables that need to be monitored regularly. The essential difference is that agroecosystems have much larger inputs and outputs, relative to the size of the internal pools, than do natural systems. These inputs and outputs include agrochemicals, nutrients, and economic yields, and all are important ones requiring monitoring.

Agroecosystems have special characteristics with regard to hydrology and to the production of greenhouse gases - these are of interest to the IGBP core projects BAHC, IGAC and GCTE. Irrigation systems can alter surface and ground water hydrology (and water quality) over large areas, and hydrological factors determine to a large extent the forms of farming that can be practised. The greenhouse gases methane and nitrous oxide are produced in soils under reducing conditions. Methane is produced from paddy rice farming, and also from cattle, whereas nitrous oxide production is affected by the level of nitrogen fertilizer.

Considering variables listed in a number of monitoring networks, particular attention needs to be given to materials that can act as pollutants, such as pesticides, and to variables that can indicate land degradation, such as erosion or loss of organic carbon. Such site-specific measurements need to be integrated with broader measures obtained from agricultural statistics and regulations, such as economic yields, areas planted to different crops, fertilizer and agrochemical use rates.

Site selection criteria

With particular reference to agroecosystems, the following criteria should be incorporated into site selection procedures.

- **Size.** Field, patch, catchment and landscape scales need to be considered as in Figure 3. Basically, the repeating unit of the landscape should be identified, with proper representation of different types of managed and unmanaged vegetation. Measurements need to be taken at representative points within this unit, and extended by ground survey and remote sensing to cover the whole of it.

▼ **Location.** Sites need to be placed with consideration of climatic, soils and socio-economic factors (as indicated on pages 30-34). It should be borne in mind that climate can no longer be considered to be a constant. It is desirable to locate sites along a gradient of environment (e.g. Figure 4) or land-use. The concept of agroecological zones (FAO) can be valuable in locating sites. Security of sites is important as monitoring will last for 50 years or more.

▼ **Farming Systems.** All forms of agroecosystem, from intensive arable systems to open range grazing, should be considered. Within this, there are annual and perennial forms of vegetation, tree-crops and forests, and systems including animals. It is important that all types are represented with the final set of sites, in proportion to their relative importance.

Rotation	Intensification ··➔
Annual	Traditional .... Intensive arable
Mixed	Agroforestry ...... Agroforestry
	Rangelands .... Intensive pasture
Perennial	Natural forest ..... Plantation forest

A draft list of the farming systems is included in Table 4.

▼ **Development.** There may be local or national issues concerning development or conservation that need to be taken into account. Sites may help to resolve such issues, but should not become foci for disputes.

▼ **Networks.** The position of each site should be considered in relation to other sites in existing networks. Supporting data from nearby sites will be valuable at a local level.

▼ **Existing data.** Wherever possible, the sites selected should possess long-term data sets of relevant variables. Agricultural research stations often have such data sets. They may be national stations in industrial or developing countries: for the latter the ISNAR organization in The Hague may be instrumental in suggesting choices and initial contacts. Some of the large-scale early natural resources inventories in a number of developing countries as carried out by UNDP/FAO and by various bilateral development cooperation units (e.g. ORSTOM-France, German University Units, CSIRO-Australia) can provide a wealth of information on the situation 20-30 years ago, which would serve as retrospective long-term ecological research data if sites can be located in such areas. In addition some of the international agricultural research sites of the CGIAR system (IRRI, ICRISAT, CIAT, IITA, ICRAF, etc.) offer possibilities for site monitoring.

The value of each site depends upon the efficiency and quality of the network as a whole. The network provides coordination, assessment and aggregation of data; dissemination of data; continuity of operational support; and quality control. A central unit or group of full-time professional staff will be needed to implement these functions, and the group should include staff with experience of different agroecosystems.

Biodiversity: the Relationship between *Diversitas* and GCTE and the Special Concern with Fauna[1]

The workshop addressed the similarities and commonalities of the two programmes. *Diversitas* is an IUBS/SCOPE/UNESCO programme with three subprogrammes (page 17). GCTE is an IGBP programme also with three subprogrammes (Foci) and a fourth one on complexity (diversity) being developed (page 14). The two programmes have strong relationships with each other. For example, the subprogramme on the functional role of biodiversity of *Diversitas* can evolve and feed into the Focus 4 programme currently being developed by GCTE. *Diversitas* and GCTE have complementary strengths. *Diversitas*' primary interest is in monitoring groups of organisms (plants, animals, microorganisms), while GCTE's focus is on global change, impacts on the diversity/function relationship, and its feedback to further change. Thus, development of appropriate landscape evaluation and monitoring schemes could be part of common methodological efforts by the two programmes. Topics of mutual interest include: definition of vegetation or land cover types; investigation of the full range of ecosystems, from pristine to intensively managed; application of GIS to analysis of landscape patch proportions, mean patch sizes, corridors, etc.; the common importance and need to study and monitor keystone species; access to remote sensing facilities. Therefore, close collaboration of activities of GCTE and *Diversitas* is highly desirable.

The proposed list of variables to be measured (Tables 1-3) is directly relevant to the interest of both programmes in biodiversity but requires some modification in order to provide a comprehensive system for detecting change in terrestrial ecosystems. Further consideration of the importance of animals as a component of biodiversity and of ecosystem function is necessary. An outline rationale for the selection of fauna variables follows.

Fauna - Biodiversity, indicators and feedback effects

Biodiversity is a major issue of global concern. In the short-term, 'permanent' changes in land use, particularly from natural to arable systems, are likely to be the major contributory factor to extinctions, amplified by major droughts and

1. Based on contribution by J.M. Anderson, J. Robertson, E. Fuentes, W. D'Oleire and Workshop participants.

TABLE 4. PROVISIONAL SHORT LIST OF MAIN FARMING TYPES TO BE INCLUDED IN GTOS

1. Shifting cultivation: humid tropical forest

2. Small-holder mixed farming:
- humid tropical forest
- mountain ecosystem
- mediterranean climate
- temperate climate
- semi-arid sub-tropics

3. Large-scale arable cropping:
- rain-fed
- irrigated

4. Plantation farming of perennials

5. Extensive grazing in open savanna:
- subtropics
- temperate
- cold-arid

6. Extensive grazing in tree savanna:
- subtropics
- temperate
- cold-arid

7. Intensive grazing

8. High input horticulture/ornamentals

natural disasters which threaten isolated species populations. Intensification of land use also disrupts the corridors between isolated habitats, increasing the probability of local extinctions. The long-term effect of climatic shifts on communities at high altitudes and latitudes is still controversial. Current models, however, suggest that the rate of extinction may not be as high as through anthropogenic effects because the time scale may allow for adaptation, genetic selection and/or dispersal.

With a few important exceptions animal activities do not have major feedback effects on global change and are therefore not central to the remit of GCTE. Other programmes (e.g. *Diversitas*) have biodiversity, inventories and monitoring as a central focus and will provide important, complementary data and information on the effects of climate and land use change on biota. Conversely, GCTE monitoring will provide a broad geographic framework of ecosystem functioning as a context for biodiversity studies.

Certain groups of animals are relevant to the remit of GCTE and justify monitoring as a site dynamic. These include anomalous events indicative of direct effects on community organization, pest species of major economic importance, and feedbacks on ecosystem processes.

Indicator species and anomalous events. The value of indicator species such as birds and butterflies can be debated because of the difficulty in defining the area and the communities which they represent. As a result, it may be difficult to relate indicator species to more spatially targeted GCTE activities. In addition, indicator species often require specialist expertise which may not be locally available. However, anomalous events or those involving few species are comparatively simple to record. For example:

- ▼ Changes in routes and densities of migrating animals (caribou/reindeer) in tundra; ungulates in the African savanna; mass hibernation of insects (monarch butterfly in Mexico/California, ladybirds in Himalaya);
- ▼ Populations of insectivores (bats, cave swifts, etc.);
- ▼ Casting rate of earthworms and the abundance of humivorous termite-mounds are sensitive indicators of environmental change in rain forest/savanna regions. Humivorous termites are particularly good indicators of changes in rain forest habitats, with abundance related to intensity of cultivation.

Pest species. Records of mass outbreaks of insect pests (and fungal pathogens) provide a valuable long-term data base for analysis of environmental (and economic) effects of climate change. Long-term records are available for locusts and armyworms (*Spodoptera*), for analysis of environmental control of population dynamics. Termite (*Macrotermitinae*) damage to farm crops in Africa and Asia is also closely linked to periods of drought stress.

Animal populations affecting feedbacks on global change. Certain key groups of animals can have major influences on ecosystem functioning and trace gas emissions and hence justify closer monitoring within GCTE. Four examples follow.

First, grazing and browsing effect on vegetation dynamics: Intensive mammalian grazing/browsing influences the composition of vegetation, particularly the balance between grass and trees, ecological succession in sub-climax communities, and nutrient cycling. In boreal and savanna regions, these activities are key elements of system functioning. Overgrazing also affects erodability of slopes and exposed surfaces by wind and rain, surface albedo, etc.

Second, grazing ungulates and methanogenesis: Domestic animals (and to a lesser extent wild ungulates) are estimated to contribute 15-20% of the terrestrial methane efflux. Methanogenesis in the rumen is influenced by the quality of forage and increases with C/N ratio of feeds. The fluxes are therefore potentially linked to changes in soil nutrient (N availability) status and $C0_2$ fertilization effects.

Third, termites and carbon dynamics: The contribution of termite gut fermentation to methanogenesis is controversial because of inadequate data on species populations and gut physiology. The potential magnitude of this flux, equivalent to that attributed to ruminants, merits attention as termite biomass is one to ten times above-ground animal biomass in many semi-arid regions. The wood and litter-feeding termites (*Macrotermitinae*) of Africa and Asia can potentially exploit almost all above-ground plant detrital inputs (which are metabolized in fungus gardens). As a consequence, soil carbon pools are lower in landscapes dominated by this group of termites and carbon turnover between plant and atmospheric pools is accelerated in the absence of intermediate stabilized humus pools. In areas of overgrazing by wild and domestic mammals, grass-harvesting termites may be in direct competition for food resources. This can result in the total depletion of grass cover and increased erodability of soils in these regions.

Fourth, termites and soil physical effects: The depletion of soil organic matter by litter removed may affect CEC (cation exchange capacity), soil structural properties and associated plant growth parameters. During foraging activities, surface deposition of clay/silt rich materials (with high mineral nutrient status) can occur together with the formation of macropore channels which influence surface water infiltration. The balance between sediment sources and sinks is an important dynamic in semi-arid regions. Changes in water balance associated with termite activities have been shown to affect competitive balances between grasses and woody vegetation in arid regions. Earthworm and termite activities are generally measured in both wet and dry seasons. The influence of their activities on soil surface hydrology, sediment entrainment in surface wash, and hence the patchiness of nutrient losses and redistribution in disturbed habitats, should not be underestimated and requires study.

Data Acquisition, Management and Dissemination[1]

Defining and initiating a global terrestrial monitoring system requires guidance on variables to be monitored, the structure of the monitoring system in space and time, an implementation programme, site selection/management, measurement protocols, funding and other operational requirements, and linkages to other networks. All of these needs have data-handling implications, and a well-designed information management strategy will lie at the heart of the network. To a large extent, the data definition and management protocols will define the structure of the network itself.

1. Contribution by M. Collins, B. Murray and Workshop participants.

To identify the key basic structural design for the network, based on information and data flow, three important considerations must be borne in mind throughout:

- **Form must follow function.** Hardware and software decisions should not be accepted until the systems functionality has been defined.
- **Technology availability and transfer.** Sites in the network will vary widely in their accessibility, amenities (electricity, water, communications) and staffing levels. All data management decisions must take account of this variability and present a range of suitable options.
- **Data mobilization.** The network is for data dissemination as well as data-gathering. Data must flow freely in all directions within the network and between the network and collaborating organizations. Communication is a vital factor in developing a network rather than a collection of sites.

Data acquisition

A chart of variables and likely users of data should be developed, based on the Tables 1-3. This will focus attention on the essential purposes of the network, and in particular help to define the variables to be measured, including formats, and sampling frequency, resolution and distribution.

Data quality objectives (DQOs):

- DQOs must be defined in advance of operational sampling, monitored and regularly reviewed.
- Failure to comply with DQOs may invalidate data-sets and/or preclude intercomparisons.

Units of measurement:

- Every variable must be expressed in standardized units of measurement.

Methodology harmonization:

- Methods of sampling must be harmonized across the network, making use of standard techniques and technology as far as possible.

Manuals and protocols:

- The adoption of common sampling regimes, units and methods implies the provision of clear guidance to the network in the form of a Network Manual. This would be regularly reviewed and updated.

Core data:

- Members of the network will bear responsibility for gathering specified core data. This minimum data-set outlined in Tables 1 and 2 is yet to be finalized, but will certainly include basic site descriptions and land cover for GCTE evaluation;
- Sites will not be constrained on the data they choose to gather. Harmonization within the network will always be encouraged, but the obligation to gather and supply data is limited to the core data set. Extended data

sets may be defined for particular types of site (e.g. particular biomes, selected intensive research sites).

Spatial data:
- ▼ Spatially related data must, wherever possible, be attributed at the point of collection, i.e. a precise latitude and longitude. This is the most flexible system, allowing for aggregation into rasterized grid cells or polygons.
- ▼ It is recognized that certain parameters relating to highly mobile subjects or extensively spread subjects will be difficult to locate precisely in space.
- ▼ Use of artificial points for data attribution, such as the summit of a mountainous site, or the centre-point of a site, is discouraged.

Data Flow Recommendations

Data input:
- ▼ Core data (as a minimum) should be entered into databases using a common data entry template (available in digital and hard-copy format).

Interchange formats:
- ▼ Interchange of digital data between suppliers and users will only be through agreed interchange formats.

Archiving:
- ▼ Archives of core data (as a minimum) should be held at regional or thematic data centres. These will not be duplicated at a global centre (see below), but the centres will be directly linked with each other. (All data can be accessed via one centre).

Data transfer to users:
- ▼ Data must be available on-line, off-line and as hard copy.
- ▼ The objective is to make all data available to users on-line.

Data sharing:
- ▼ 'Membership' of the network should be subject to an agreement on common data-sharing, attribution procedures and commercial use. The ECN network agreement is recognized as a useful model.

Data Management

A proposed model for infrastructure is shown in Figure 5. The roles of the three levels are as follows:

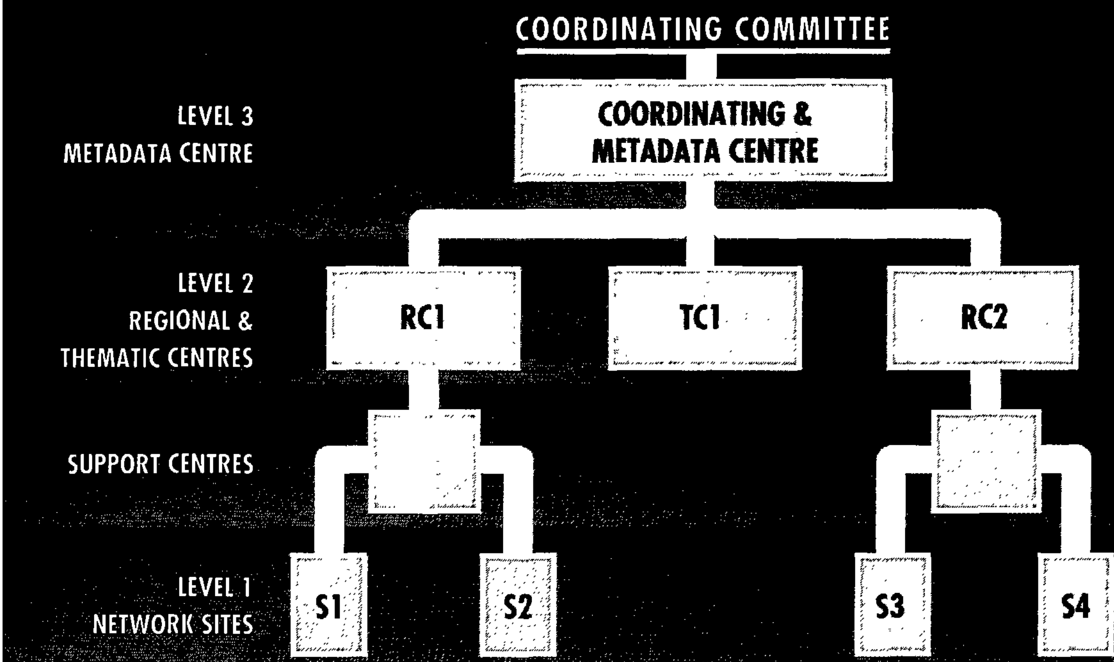


Fig.5 Outline model of GTOS infrastructure in relation to data management.

Level 1: Network sites. Individual sites are responsible for:
- ▼ Research
- ▼ Data collection
- ▼ Data input
- ▼ Quality control

Level 2: Regional and Thematic Centres. Regional Centres (RC), of which 5-10 may be needed, are responsible for:
- ▼ Archiving of data
- ▼ Compiling reports
- ▼ Quality assessment (including training courses, QA (quality assessment) exercises, data flagging)
- ▼ Coordinating technical support
- ▼ Monitoring data use, including proposals for analysis and expansion by non-network users
- ▼ Collaboration with non-network data sites; access to non-network data
- ▼ Provision of data-sets to users

Regional centres will each hold archive copies of all core data-sets for the sites under their responsibility, and will be networked for this purpose. In particular circumstances the regional centres may delegate their responsibilities:

- Where specialist Thematic Centres (TC) exist, management of particular variables may be delegated to them (e.g. WCMC for biodiversity).
- In regions where technology and infrastructure are less developed, support centres may be established or commissioned for data preparation prior to archiving.
- Support centres may be commissioned to carry out specialist laboratory investigations, including analyzes of samples for groups of sites in the network (e.g. chemical analysis of water or organic materials).

Level 3: Global Coordination and Metadata Centre. A single metadata centre will be responsible to a central coordinating committee. The centre will be responsible for:

- Maintaining a catalogue or index of all available data sets, including details of format, access and availability.
- Maintaining a catalogue of people and prospects using the data.
- Ensuring that information flows both up and down through the network, utilizing mechanisms such as newsletters and electronic bulletin boards to maintain morale and cohesion.
- Ensuring global coordination of quality control and assessment.
- Maintaining an operational calendar for logistical purposes.
- Forging links with internal and external collaborators and data users.

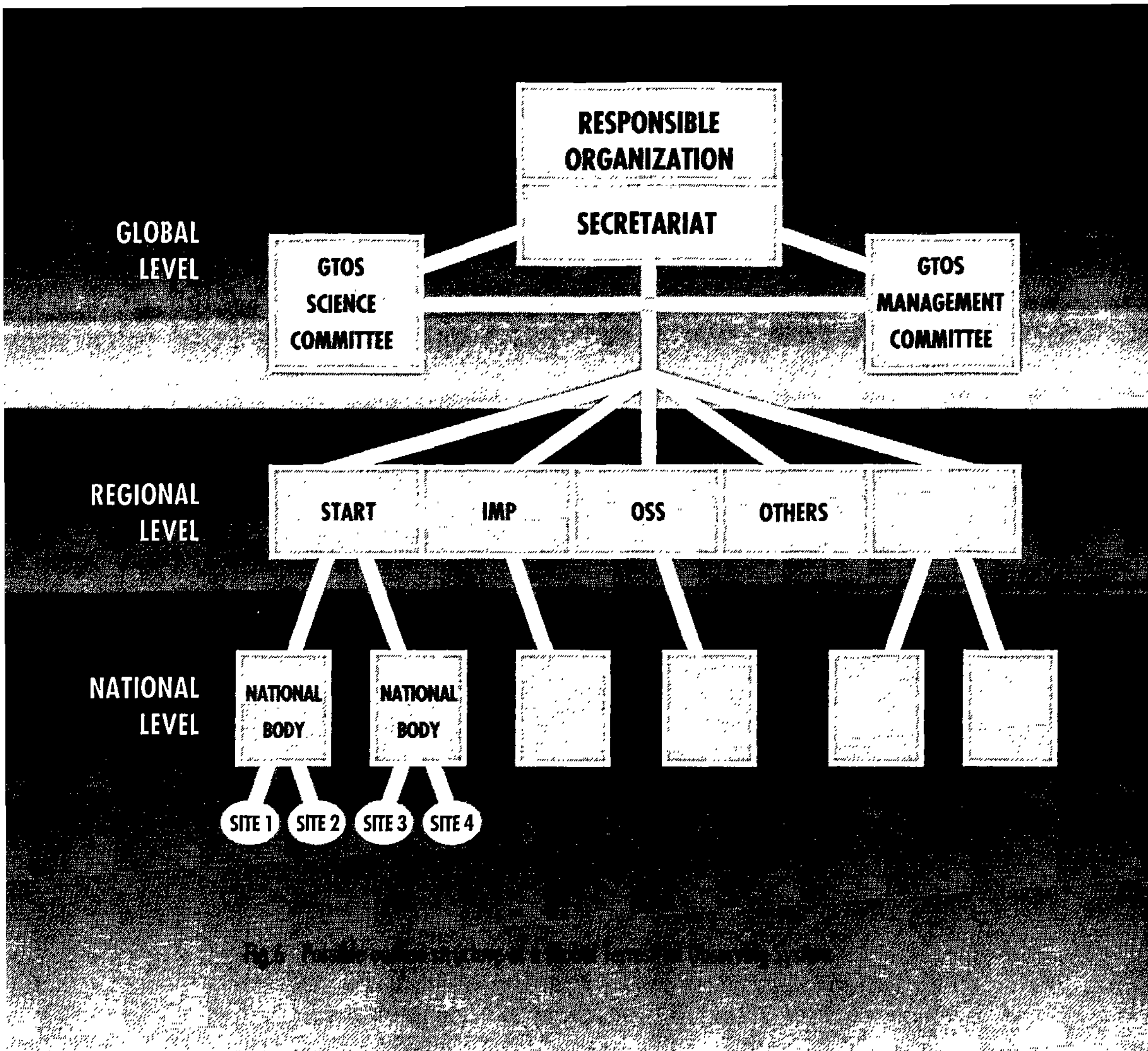
Conclusions

The network's data management systems will not be established in a vacuum. There are a number of organizations and initiatives already in place, sharing some of the network's objectives and practices. The network should collaborate and communicate widely in order to benefit from existing experience and infrastructure. Help is available at all levels: site, region, theme and global.

The Organization of a Global Terrestrial Observing System (GTOS)[1]

The operation of the GTOS ground-based sites must be considered at three basic levels: global, regional and national. It must also serve the information and data needs of both government and the scientific community, and, particularly where developing countries are concerned, national development and resource management requirements. An outline structure of the proposed GTOS, shown in Figure 6, is described below.

1. Based on contributions by M. Gwynne, O.W. Heal, P.B. Tinker, J. Robertson and Workshop participants.



Global level

Within the UN System, UNEP has the mandate to co-ordinate all activities related to the environment. UN General Assembly Decision Oct 44/224 has called upon the UN System to strengthen its monitoring and assessment capabilities (given the name 'Earthwatch') and to develop a system for providing governments and the world community with early warnings of significant environmental problems. UNEP was asked to take the lead in moving Earthwatch forward. This was further confirmed at the UN Conference on Environment and Development in Rio de Janeiro in June 1992.

Consequently, UNEP has begun to compile an inventory of sites at which activities relevant to GTOS are already being carried out. As of late 1992, fifty-three had expressed interest in being part of a co-ordinated network - Global Integrated Monitoring (GIM) - including a number of designated biosphere reserves.

To guide the long-term scientific programme of the GIM network, UNEP has established an independent Scientific Advisory Committee for Terrestrial Ecosystems Monitoring and Assessment (SACTEMA) which first met in September 1992. The composition of SACTEMA reflects the main scientific interests in the detection of global change, with IGBP-GCTE providing a major input. Members are, however, appointed by UNEP on a personal basis. The interests and concerns of relevant UN agencies (e.g. UNESCO, WMO, FAO, etc.) and other organizations will be served by a GIM Management Committee on which they would be represented. SACTEMA and the GIM Management Committee will be served by an office to be established within UNEP which would also co-ordinate the work programme on a routine basis and ensure that it ran as a functional network system. Data and information would be managed as a distributed system to maximize interaction and use of facilities. Quality assurance and control will be an important responsibility of the GIM Office.

The future of GIM and SACTEMA may need to be revised in the light of the proposed GTOS. The development of GTOS also needs to be articulated with the concerns and operations of other global observing systems, more particularly the Global Climate Observing System (GCOS) and the Global Ocean Observing Systems (GOOS) (Figure 7).

Regional level

Coordination of activities at the regional level is critical to gather sufficient high quality data to properly serve the information and data requirements of both the scientific research community and the development and resource management needs of national governments.

The global change research community thus takes a practical interest in the development of GTOS as a regionally based network with adequate quality control to ensure that good quality, reliable data became available for its modelling and other research needs.

The development and routine operational coordination of regional network elements within GTOS would be perhaps best achieved through existing and planned regional networks (e.g. START, UN-ECE-IMP, OSS, ...). These bodies provide the regional infrastructure which would ensure that stations at selected sites within the region contributed properly to GTOS according to previously agreed terms of cooperation with the operators of each site station. This would include routine measurement of variables, application of quality control procedures and transmission of data from the sites to designated data repositories. In developing country regions, the START or appropriate regional bodies, in cooperation with the central global coordination office, could develop a funding strategy for that region utilizing appropriate funding mechanisms (e.g. GEF, Regional Development Banks, Foundation grants, etc.). It is envisaged that

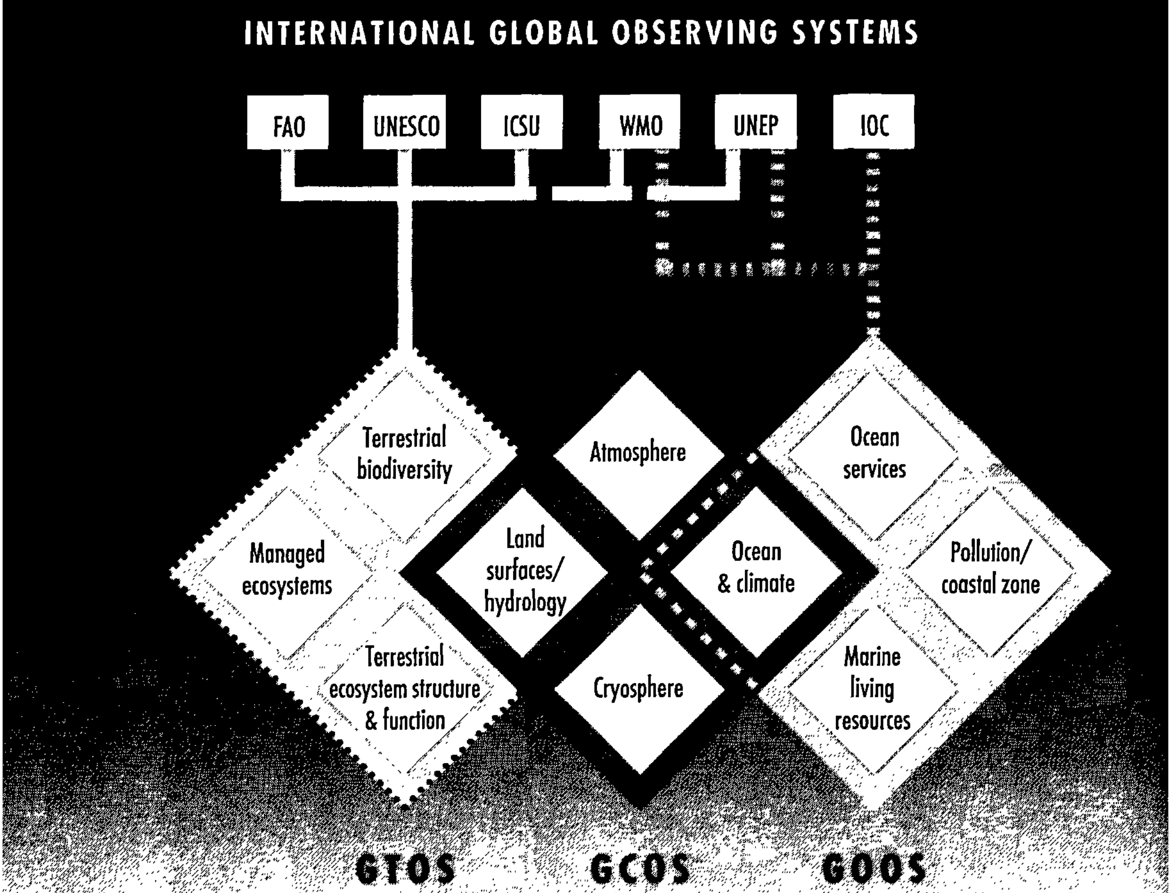


Figure 7. One perception of the relationships between the Global Terrestrial Observing System (GTOS), the Global Climate Observing System (GCOS) and the Global Ocean Observing System (GOOS). Figure based on documentation associated with the 25th session of the Executive Council of the Intergovernmental Oceanographic Commission (document IOC/EC-XXV/8, Annex 1), extended by J. Gauntlett and colleagues in the Australian Bureau of Meteorology to include GTOS and to update appropriate organizational linkages.

bilateral arrangements between developed and developing countries would be an important element in establishing the GTOS infrastructure, particularly with regard to training aspects.

In developed country regions, funding may be less of a problem so that routine network development and coordination might best be achieved by the global GTOS coordinating office working closely with GCTE and the START headquarters and with other regional networks (in Europe, North America, etc.).

National level

Many relevant field stations and sites are already in operation as part of national or international networks. These provide the critical nuclei for GTOS. From among these and from new field stations, a network of sites will be selected according to defined criteria. To ensure that the GTOS network operates as a network and not as a loose collection of stations, it will be necessary to enter into an agreement with those responsible for each station concerning the participation of that station in the GTOS network, with particular attention to the quality, availability and access of data generated by that station. These agreements may vary according to the circumstances of particular stations and could take the form, for example, of exchange of letters, memoranda of understanding, memoranda of cooperation, etc. Such agreements may be with operating agencies or with governments, or both, according to the circumstances.

Many national sites on which relevant measurements and background information exist are already active in the subject and provide the base from which the global network can be drawn. For example, the Long-Term Ecological Research (LTER) programme in USA and the Chinese Ecological Research Network (CERN) contain sites with comprehensive analysis of managed and unmanaged ecosystems. The biosphere reserves of UNESCO-MAB provide a potential suite of relatively natural systems contrasting with agricultural, rangeland and forestry systems in which potential sites are managed by national agencies. These reserves are of particular importance to GTOS because they already have a commitment to the international network of MAB and participate in international exchange. Many of the sites within national networks such as LTER and CERN are biosphere reserves.

GTOS should not be a one-way system of information generated from national field sites flowing to regional and global databases. An essential feature will be feedback of global and regional data which will allow the information generated by individual sites and national networks to be placed in a wider context and compared with more general trends. Additional data from other sources, such as satellite imagery and model output, will be made available at national level to assist governmental and scientific assessment of the effects of global change, the planning of sustainable development, and the maintenance of biodiversity. Important local benefits will include training in monitoring and data management techniques and, where necessary, enhanced facilities and staffing.

Financial implications

Substantial financial support for GTOS is essential to ensure the establishment and maintenance of an effective network of sites integrated into a regional and global information system on global change. Significant resources are already committed nationally, especially in developed countries, but these will have to be enhanced to ensure that the network conforms to a statistically valid design and measurements are fully compatible. Whilst enhanced funding will also be sought from appropriate national sources, international funding will be necessary particularly where new sites are required in developing countries.

A preliminary assessment is that, for each site, a minimum of $100k is required for initial site instrumentation and $100k for annual running costs. The cost at each site will depend mainly on the degree of replication and the range of ecosystems examined. For 50 sites a capital input of $5m and annual support of $5m is a basic requirement.

The requirements for Regional Research Centres (RRCs) have been explored within the START initiative. The five functions of the START RRCs are research (including documentation of environmental change), training, data management, synthesis and modelling, and communications. Funding of $5-10m for each RRC when fully operational was projected. As the functions of these RRCs extend beyond those of GTOS regional centres, the annual costs relevant to GTOS are likely to be of the order of $1-3m per centre. A minimum of five regional centres would be required. Additionally, central funding of the order of $2-4 per annum will be necessary for global coordination and synthesis.

Thus the total annual cost is of the order of $12-24m. Some of this funding is already being provided through national agencies mainly for site and network support. Support for some regional networks, particularly START, is planned, and GTOS activities would constitute a specific part of such centres. With the existing and planned national and international developments, an initial estimate of the additional annual funding requirement is $10m. The Global Environment Facility is considered to be the most appropriate funding agency.

CONCLUSIONS

The UN Conference on Environment and Development articulated the concerns on global change, including the need both to understand and to monitor the mechanisms of change and response. A key element which is missing in the global armoury of information is consistent data on ecosystems from across the range of terrestrial environments. Whilst programmes to measure and analyze the global climate and ocean systems have been developed, the need for a terrestrial programme remains. Satellites provide one component with extensive information on land cover and physico-chemical characteristics. However, ground-based measurements are essential to calibrate satellite imagery and, more importantly, to amplify this information in terms of the biological structure, diversity and function. The need for information from a ground-based network of sites is required by GCOS; it is a prime requirement to develop and test models in the GCTE programme; UNEP has given priority to development of a field network in its Earthwatch programme and UNESCO-MAB has identified the need to assess change in biodiversity focused through the new *Diversitas* programme, using wherever possible, the international network of biosphere reserves.

The needs of the different organizations vary in detail but contain many common features. Cooperation in establishing a global network would be cost-effective. It would also be scientifically valuable in providing integrated information on driving and response variables and allow model predictions to be systematically tested against long-term observations. The multiple-objectives of a network would thus provide short-term products to enhance the function of long-term monitoring. The challenge here is in combining the flexible requirements of research with the consistency demanded of monitoring.

The essential components of a Global Terrestrial Observing System exist in the form of international organizations with relevant responsibilities and with appropriate data handling and communication systems and in a variety of intensively studied field sites in natural and managed ecosystems. The field sites have been developed for a variety of mainly national objectives and are supported from national funds. An important stage in the development of GTOS will therefore be to obtain the commitment of nations and sites. Existing commitments to international networks such as biosphere reserves provided a valuable basis for development.

The proposals outlined in this report for the selection of sites are designed to place practical considerations within the scientific framework of 'environmental space'. It is expected that 50-100 existing well documented sites could constitute the initial GTOS network. This would provide a sparse but realistic cover of the major climatic variation and of the range of ecosystems from 'pristine' to intensively managed. Although the coverage of sites in the initial network is severely limited, they are not functioning in isolation. In practice many of the sites will be associated with existing local or regional networks, from which information can be drawn to improve definition of spatial variation. Further, integration with remote sensing programmes provides the basis for extrapolation to larger spatial scales.

Consistent observations across the network will be an essential requirement to meet the twin objectives of short-term modelling of dynamics and long-term detection of change. The variables listed in the report constitute a first approximation directly related to the objectives. It is a demanding schedule and will need to be refined and amplified.

The objectives of the Fontainebleau workshop (page 12) were wide ranging. This report details the rationale and outlines the components of GTOS. The next step is to establish a Task Force, under the auspices of the major international organizations, to implement the proposal to form a Global Terrestrial Observing System.

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ANNEX 1
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ANNEX 2
Glossary of acronyms

ABRACOS	Anglo-Brazilian Climate Observational Study
APAR	Absorbed Photosynthetically Active Radiation
AVHRR	Advanced Very High Resolution Radar
BAHC	Biospheric Aspects of the Hydrological Cycle (IGBP)
BAPMoN	Background Air Pollution Monitoring Network
BOREAS	Boreal Ecosystem Atmosphere Study
BRIM	Biosphere Reserve Integrated Monitoring (Euro-MAB)
CERN	Chinese Ecological Research Network
CGIAR	Consultative Group on International Agricultural Research
CIAT	Centro Internacional de Agricultura Tropical (CGIAR)
CORINE	Coordination of Information on the Environment
CSIRO	Commonwealth Scientific and Industrial Research Organization (Australia)
DIS	Data and Information System (IGBP)
DQOs	Data Quality Objectives
ECN	Environmental Change Network (UK)
EEA	European Environment Agency
EMEP	Environment Monitoring and Evaluation Programme
EOS	Earth Observation System
FAO	Food and Agriculture Organization (UN)
FIFE	First ISLSCP Field Experiment
GAIM	Global Analysis, Interpretation and Modelling (IGBP)
GAW	Global Atmosphere Watch
GCOS	Global Climate Observing System
GCTE	Global Change and Terrestrial Ecosystems (IGBP)
GEF	Global Environment Facility
GEMS	Global Environment Monitoring System (UNEP)
GIM	Global Integrated Monitoring (UNEP)
GIS	Geographic Information System
GLOSS	Global Oberving System for Sea

GOOS	Global Ocean Observing System
GRID	Global Resource Information Database
GTMS	Global Terrestrial Monitoring System
GTOS	Global Terrestrial Observing System
HAPEX	Hydrological Atmosphere Pilot Experiment
HEM	Harmonization of Environmental Measurement
ICRAF	International Centre for Research on Agroforestry (CGIAR)
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics (CGIAR)
ICSU	International Council of Scientific Unions
IGAC	International Global Atmospheric Chemistry Programme (IGBP)
IGBP	International Geosphere-Biosphere Programme (ICSU)
IGOSS	Integrated Global Ocean Service Systems
IITA	International Institute for Tropical Agriculture (CGIAR)
IMP	Integrated Monitoring Programme
IOC	Intergovernmental Oceanographic Commission
IRRI	International Rice Research Institute (CGIAR)
ISLSCP	International Satellite Land Surface Climatology Project
ISNAR	International Service for National Agricultural Research
ITEX	International Tundra Experiment
IUBS	International Union of Biological Sciences (ICSU)
LOICZ	Land-Ocean Interactions at the Coastal Zone (IGBP)
LTER	US Long Term Ecological Research
LTERNET	US Long Term Ecological Research Computer Network
MAB	Man and the Biosphere Progeramme of UNESCO
MSS	Multispectral Scanner System
ORSTOM	Institut Français de Recherche Scientifique pour le Développement en Coopération (France)
OSS	Observatoire du Sahara et du Sahel
QA	Quality Assurance
RRCs	Regional Research Centres
RSSD	Responses of Savannas to Stress and Disturbance (IUBS-MAB)
SACTEMA	Scientific Advisory Committee for Terrestrial Ecosystems Monitoring and Assessment (UNEP)
SCOPE	Scientific Committee on Problems of the Environment (ICSU)
START	Global Change System for Analysis, Research and Training (IGBP)
TM	Thematic Mapper
TSBF	Tropical Soil Biology and Fertility (IUBS-MAB)
UN	United Nations
UN-ECE-IMP	United Nations Economic Commission for Europe - Integrated Monitoring Programme
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme

UNESCO-MAB	UNESCO-Man and the Biosphere Programme
WCMC	World Conservation Monitoring Centre (IUCN-WWF-UNEP)
WMO	World Meteorological Organization (UN)
WWW	World Weather Watch