EARTHWATCH

GLOBAL ENVIRONMENT MONITORING SYSTEM

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Report of the Scientific Advisory Committee for Terrestrial Ecosystems Monitoring and Assessment

Prague, Czechoslovakia, 9 - 11 September 1992

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1 OPENING OF THE MEETING AND INTRODUCTION

The meeting was opened at 9.00 a.m. on the 9th of September 1992 by Dr Michael Gwynne, Assistant Executive Director, Earthwatch Co-ordination and Environmental Assessment.

Dr. Gwynne welcomed the participants to the meeting after which introductions were made of all in attendance. Participants included members of SACTEMA, invited consultants, representatives of UNEP and other UN agencies and national/international organizations.

Dr Gwynne briefly outlined the role of UNEP, Earthwatch and GEMS and the new requirements placed on the programmes as a result of Agenda 21 and the UN Conference on Environment and Development. He gave a brief history of integrated monitoring activities since 1978, referring also to the three meetings held at Hindas, Sweden in 1990, Maine, USA in 1990 and Nairobi, Kenya in 1991, precursors to the present SACTEMA meeting. He noted that in response to priority issues of global environmental concern (e.g the green house effect, the ultraviolet radiation increase, the conservation of biodiversity etc) UNEP had recently identified an initial 54 sites where relevant multidisciplinary observations are being conducted (Annex IV). A database of these monitoring sites is being set up at GEMS/PAC-UNEP, comprising information on location, affiliation, geographical detail and nature and extent of observational activities. This database will continue to be enlarged as new site information becomes available.Once criteria for site selection and necessary observational programmes for a global terrestrial monitoring network have been decided upon, it is intended to use the database as a source of information from which sites will be selected for the actual monitoring network.

The database as it stands shows considerable imbalance with regard to the geographical distribution of sites and representation of the range of terrestrial ecosystems of the Earth. These imbalances will be rectified as the database is expanded through the addition of more sites from other localities.

The need for independent scientific advice to address all technical aspects of terrestrial ecosystem monitoring and assessment, led UNEP to establish a "Scientific Advisory Committee for Terrestrial Ecosystem Monitoring and Assessment" - SACTEMA. This Committee has the following responsibilities:

a) Provision of advice to UNEP and (upon request) to other national, international, non-governmental agencies and organizations on all relevant aspects of terrestrial ecosystem monitoring and assessment, including:

- The development and operation of a global terrestrial monitoring network;

- Modification and extension of the monitoring programme in response to emerging new environmental threats (e.g. climate change, ultraviolet-B radiation increase, pollution, acid deposition, etc.);

- Consideration of emerging structural and functional problems on terrestrial ecosystems as a result of global environmental changes;

- Development of mechanisms for required data and information exchange and technology transfer;

- Furtherance of ways and means of improving international cooperation between ongoing terrestrial ecosystem monitoring activities;

- Identification of current and future requirements for improved methods, including the use of Remote Sensing and GIS Technology, for the monitoring and assessment of terrestrial ecosystems;

- Integration between terrestrial ecosystem monitoring and modelling including the development of further models as required; and

- Consideration of any other topic-specific issue as requested.

b) Establishment of links between UNEP and other national and international scientific advisory bodies (SAB) and the research community with regard to terrestrial ecosystem monitoring issues, including:

  - new requirements for the observational programme network and for method and assessment procedures proposed by SABs and the research community;

  - promotion of integrated monitoring data usage by national and international programmes and research project implementation; and

  - Any other issues as they may consider appropriate.

c) Provide a platform for the coordination of:

  - reports on the state of terrestrial ecosystems, their responses to global environmental changes and emerging issues associated with terrestrial ecosystems.

Dr. Gwynne also briefed the meeting on the ongoing discussions, between various agencies and international organizations like IGBP, about the need for establishing a comprehensive Global Terrestrial Observing System (GTOS) on a par with those being established for climate (Global Climate Observing System - GCOS) and for oceans (Global Oceans Observing System - GOOS). He pointed out that in the future SACTEMA could play a major role in advising the international community on the technical aspects for the establishment of such a GTOS.

2 ELECTION OF CHAIRMAN AND VICE-CHAIRMAN

Dr M. Baumgardner was elected chairman and Dr J. Serey vice-chairman of the meeting.

A list of participants is given in Annex I of the report.

3 ADOPTION OF AGENDA

The agenda of the meeting was accepted, adding a new item: land use. (Annex II).

4 WORKING PROCEDURES FOR SACTEMA

The secretariat presented guideline procedures for SACTEMA. See Annex III. Participants took note.

5 POINTS ARISING FROM DISCUSSIONS OF BACKGROUND PAPERS

During the meeting detailed and thorough discussions were carried out on all relevant issues to terrestrial monitoring and assessment. This report is only a summary of the discussions.

This meeting had before it a number of background papers relevant to the agenda items and prepared by Dr Holten, Dr Semenov Prof. Izrael, Prof. Velichko, Dr Hultberg, Prof. Rovinsky, Dr Egorov, Dr Zelikson and Prof. Nechaen (see Annex V).

These papers provided a good basis for a common understanding of the size and complexity of the task of representative sampling and monitoring of global terrestrial ecosystems. They also gave specific examples of the results of monitoring and assessment of different components and processes of specific ecosystems in different areas of the world.

A background paper on the basic concept and new requirements for the monitoring and assessment of the global anthropogenic impacts and terrestrial ecosystems responses was discussed. Major deficiencies and weak points with respect to terrestrial issues were identified as: - Observational activity, - Environmental forecasting and - Assessment methodologies.

5.1 General Issues:

The papers showed a number of common issues:

- Research is being conducted around the world in a wide variety of terrestrial ecosystems and disciplines in an attempt to measure, monitor and model the effects of global change on terrestrial ecosystems as well as the impacts of ecosystems on global change.

- The many national and international efforts in terrestrial ecosystem monitoring and assessment need to be better linked and related to each other to improve mutual effectiveness.

- There is a critical need for research to identify the most appropriate indicators (flora, fauna processes, etc) of environmental change in each ecosystem.

- Adequate characterization and modeling of terrestrial ecosystems for global change studies require coordinated sampling and measurements of both intensive (relatively small areas, great detail) and extensive (large areas, less detail, extrapolation) sites.

- Biodiversity estimates should be included in any observational programme. The rate of extinction of species and the environmental consequences of the process should be looked at.

- There is little, if any, international agreement on spatial and temporal resolution of data and on criteria for data quality.

- Both natural and managed ecosystems must be included within any international terrestrial ecosystem monitoring network.

- Special problems may require monitoring of specific variables which will have to added at some sites.

5.2 Site Selection:

Much discussion centered around the most appropriate sampling approach to provide credible, objective global representation of the entire range of terrestrial ecosystems of the Earth.

It was perceived that two sets of data were required. A very extensive one, based on a regular grid sampling procedure to describe the state of the globe; and a set of detailed data based on intensive sampling sites. These two types of data would together be used to address the effects of environmental change on ecosystems (pollution problems, climate change, UV-B) as well as local, national or regional issues.

How to sub-divide the world to cover the major ecosystems was discussed. Two approaches were reviewed: the one proposed by B. Walker (Australia)based exclusively on climatic variables (see annex VII for background paper) and that outlined by H. Nix (Australia) based on both climatic and biological variables (see Annex VII).

The Group recommended:

- an approach be adopted which takes into consideration biological as well as climatic variables.
- a grid based sample frame design be adopted for global sampling of data on terrestrial ecosystems.
- a working group should be set up to look into global sampling design to allow for subsequent site selection.

5.3 Selection of parameters:

A basic question in the monitoring and assessment of any ecosystem is: "what are the parameters and variables to be observed and measured?". The meeting considered the reports on data requirements for terrestrial ecosystem monitoring which have been compiled by various symposia and workshops held in recent years. Some of the conclusions which resulted from the present discussion were:

- It is essential that studies on the effects of global change on terrestrial ecosystems include chemical, physical and biological observations and measurements.
- The identification of species and biological processes that are particularly sensitive and therefore good indicators of the effects of induced change is an essential component of all ecosystem studies.
- Data sets which are assembled for global change studies must be selected for their utility in modeling specific ecosystem processes and predicting effects of change.
- A list of terrestrial ecosystem data requirements for global change studies should include a "core" set of parameters to be measured in all ecosystems.

- An additional set of parameters should be identified as unique to specific ecosystems, geographic locations and/or for specific problems.

- It is essential to have sufficient, accurate "meta" data (catalogues) in support of all biological, chemical and physical measurements obtained in terrestrial ecosystem monitoring. These meta databases should include as a minimum the following: type of data; name of person(s) collecting the data; why the data were collected; time (s) of data collection; how the data were obtained; conditions under which measurements were made; any quality control procedures used; etc.

- In the acquisition of terrestrial ecosystem data for global change studies, it is difficult to finalize the data requirements without knowing the specifications of the sampling design and without considering the technologies and methodologies to be used.

- A working group needs to be set up to look into priority parameters for intensive and extensive monitoring sites.

5.4 Future Activities:

Taking into consideration the recommendations on the need to develop a sampling design and define priority parameters and methodologies for monitoring, the Group agreed on the establishment of two working groups to operate during the intersessional period from September 1992 until the next annual meeting of SACTEMA, proposed for June 1993.

A description of their objectives and the tasks to be addressed by these Working Groups is given below.

SACTEMA Working Group 1: Priority Parameters and Methodologies for Intensive and Extensive Monitoring of Selected Sample Sites. Chair: Dr. Jarle I. Holten, Norway

Objectives of Working Group 1:

Working Group 1 will consider and further develop and elaborate the terrestrial ecosystem observational programme recommended by SACTEMA. See Annex VIII.

Priority areas to be addressed by Working Group 1 include:

PARAMETERS

- specification of requirements for measurements of those variables SACTEMA has designated as priorities, including considerations of frequency of sampling in time and space, and data accuracy;

- review ecosystem processes previously identified as being important for terrestrial ecosystem monitoring;

- identification and provision of rationale for monitoring and additional variables which may subsequently be thought important to monitor;

- identification of both mandatory and optional variables for intrazonal and marginal monitoring sites;

- identification of types of organisms, communities and ecosystems which are thought to be the most sensitive to processes of global change;

- identification of appropriate methodologies and specification of equipment types for each of the various observation and measurement categories;

- development and harmonization of guidelines and protocols for each category of observations and measurements; and

- recommend research priorities to support global monitoring and assessment of terrestrial ecosystems.

Timetable for Working Group 1:

A Propose a detailed draft provisional agenda for Working Group 1 based on the objectives of the Working Group, with specific questions to be answered by the Working Group (GEMS PAC and WG 1 Chair).

B Decision on necessary background papers for dealing with the agenda of Working Group 1; these papers to be commissioned, assembled and distributed to members of SACTEMA prior to the meeting (Responsible: GEMS/PAC).

C Identification of experts to prepare background material (GEMS/PAC).

D Preparation of a provisional final agenda (taking into account the result from the background paper presentations) for an Intersessional Workshop of Working Group 1 (GEMS/PAC and experts).

E Distribute documents to SACTEMA members and relevant support staff not less than one month before the Working Group Meeting.

F Intersessional Workshop in March 1993, to be held back-to-back with a Workshop of Working Group 2 in Trondheim, Norway.

G Preparation of the Report of the Working Group 1 Meeting (March 1993) for presentation to SACTEMA at its Annual Meeting in June 1993.

Members of Working Group 1:

Members of Working Group 1, consisting of 5-7 persons, will be selected from the membership of SACTEMA through consultation with the UNEP/GEMS Secretariat, the Chair of SACTEMA and the Chair of Working Group 1. This group will also select a few specialist consultants to work with Working Group 1.

SACTEMA Working Group 2: Global Sampling Design for Monitoring Terrestrial Ecosystems. Chair: Prof. Henry Nix, Australia.

Objectives of Working Group 2:

Working Group 2 will explore possible sampling designs for obtaining good estimates of identified variables over a range of spatial and temporal scales, with emphasis on characterizing the ecosystems of small scale extended areas.

The variables to be sampled are those arising from intersessional Working Group 1. The ultimate reporting scale should be global with the objective of extending the results obtained from studies on intensive study sites, and related research efforts to obtain reliable global estimates. It was recommended by SACTEMA that the working group considers as one possible point of departure, the continental scale sampling frame developed by the U.S. Environmental Protection Agency (EPA) for its Environmental Monitoring and Assessment Program (EMAP).

Timetable for Working Group 2:

A Propose a detailed draft provisional agenda for Working Group 2 based on the activities of the Working Group, with specific questions to be answered by the Working Group (GEMS PAC and Working Group Chair).

B Decision on necessary background papers for dealing with the draft provisional agenda of Working Group 2; these papers to be commissioned, assembled and distributed to members of SACTEMA prior to the meeting (Responsible: GEMS/PAC).

C Identification of experts to prepare background material (GEMS/PAC).

D Preparation of a provisional final agenda (taking into account the results from the background paper presentations and the recommendations of WG 1) for Intersessional Workshop of Working Group 2 (GEMS/PAC and experts).

E Distribute documents to SACTEMA members and relevant support staff not less than one month before the Working Group 2 Meeting.

F Intersessional Workshop in March 1993, to be held back-to-back with a Workshop of Working Group 1 in Trondheim, Norway.

G Preparation of the Report of the Working Group 2 Meeting (March 1993) for presentation to SACTEMA at its Annual Meeting in June 1993.

Members of Working Group 2:

Members of Working Group 2, consisting of 5-7 persons, will be selected from the membership of SACTEMA through consultation of the UNEP/GEMS Secretariat with the Chair of SACTEMA and the Chair of Working Group 2. This group will select a few specialist consultants to work with Working Group 2.

1993 ANNUAL MEETING OF SACTEMA

It was proposed that the 1993 annual meeting of SACTEMA be scheduled for June to be held in Europe - possibly in Munich or Paris.

ANNEX 1

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1st Session of SACTEMA
9-11 September 1992, Prague,
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ANNEX II

Agenda of the First Session

1. **Opening of the Meeting**

The meeting will be opened by UNEP

1.1 UNEP will present the main objectives and goals of SACTEMA.

1.2 UNEP will introduce the members of SACTEMA.

1.3 Participants will elect Chairman and Vice-Chairman for the 1st session.

2. **Adoption of Agenda**

The agenda, prepared by UNEP, will be submitted for discussion and adoption.

3. **Working Procedures**

A draft paper prepared by UNEP on the modus operandi of SACTEMA will be discussed. The paper includes proposals for establishment of ad hoc expert groups, designation of experts, publications, reporting, etc).

4. **Pollution Related Monitoring of Terrestrial Ecosystems**

The following points are to be considered:

4.1 Global Integrated Monitoring (GTEM) : basic concept and new requirements.

4.2 Information on GTEM Sites Database maintained at GEMS/PAC-UNEP.

4.3 GTEM Sites Database review carried out by GEMS/PAC-UNEP.

4.4 Conclusions

5. Issues Related to Climate Change and Ultraviolet Radiation Increase

The following points are to be considered:

5.1 Global climate change, ultraviolet radiation increase and their ecological consequences: processes to study and variables to monitor

5.2 Basic requirements for monitoring programmes and networks to detect ecological consequences of climate change and allowing **early warning**.

5.3 Review of climate-related observations being carried out at the GTEM sites and estimation of their relevance.

5.4 Conclusions

6. Recommended Actions

6.1 Establishment of an overall programme:

T E R G A I - Terrestrial Ecosystem Responses to the Global Anthropogenic Impacts

The following items are to be considered:

6.1.1 Selection Criteria for GTEM sites to be incorporated into GTEM Network in the light of new requirements.

6.1.2 Observational programme for GTEM network to monitor the global man-made impacts and their ecological consequences.

6.1.3 Establishment of Regional Programme Centres.

6.2 Co-ordination on terrestrial ecosystem monitoring under EARTHWATCH

6.3 Conclusions

7. **Work Plan for Intersessional Activity**

Outline priority problems and propose a work plan for intersessional activity.

8. **Session Report**

Discussion of draft report.

9. **Next meeting**

10. **Closure of the Session**

<The background papers on items 3, 4.1, 4.3, 5.3 and 6.1 of the agenda are provided by GEMS PAC/UNEP and discussion papers on items 5.1 and 5.2 of the agenda are requested from designated experts>

Note: Terrestrial ecosystems, including those associated with freshwater resources, are considered to comprise all the biota and associated non-living components of the environment (soils, water, atmosphere, etc.) and their interactions. Ecosystems associated with coastal areas will also be considered when required. However, in view of the fact that other groups exist which deal with marine ecosystems, efforts will be made to avoid duplication and to achieve close co-operation with those groups.

ANNEX III

Guideline Procedures for Sactema

The following procedural guidelines for conducting SACTEMA are proposed to implement its terms of reference:

Secretariat

UNEP, through GEMS PAC, will act as the Secretariat.

Membership of the Group (SACTEMA)

UNEP will nominate the members according to its interest in the substantive work of the session. Members appointed to the Group should act in their individual capacities. Members are nominated to serve for a period of up to four years to provide a continuing nucleus.

In addition to SACTEMA members, experts can be appointed as occasion demands, having in mind the particular subjects to be considered at each session of the Group.

Sessions

The Group normally meets once a year. The date and place of the session will be decided by UNEP after consultation with the Chairman. Prospective experts should be informed of this decision as soon as possible by the Secretariat.

The Secretariat should also invite:

(a) Such other organizations of the UN system as may so wish to participate in any session of the Group; and

(b) Any other intergovernmental organization with official relations or consultative status with UNEP to send an observer.

Agenda

The Agenda for each session of the Group should include:

(a) Any item which has been requested for inclusion by UNEP;

(b) Items considered at the previous session and not yet concluded; and

(c) Any items proposed by other organizations of the UN system, subject to agreement of UNEP and to such preliminary consultations as may be necessary.

The provisional agenda should be prepared by the Secretariat after consultation with the Chairman and, if necessary, other organizations of the UN system that have proposed items for inclusion.

When adopting the Agenda, the Group should not delete or substantially alter any items except with the agreement of UNEP and, should another UN organization propose items, with their agreement.

Chairman and Vice-Chairman

At the end of each session the Group elects from among its experts a chairman and a vice-chairman who will hold office for the intersessional period and for the following session. The candidates are to be proposed to the Group by the Secretariat. Incumbents are eligible for reelection, normally once.

Documents

Documents, papers and notes related to any Agenda item of any session should be prepared by UNEP or particular items by any UN organization that has proposed them for inclusion. UNEP will reproduce each document and circulate them as follows:

(a) One copy each to the experts of the Group as far as they are known;

(b) To other organizations invited to the session;

Every effort should be made for the documents to be circulated well in advance of the session.

Languages

The official language of the Group is English.

Intersessional work

The Working Groups established by the Group should consist of:

(a) Member(s) selected from the members of SACTEMA; and

(b) Additional member(s) selected from experts outside SACTEMA.

The terms of reference for the Working Groups will be proposed by UNEP and should be approved by the Group.

The Group will nominate the Chairman of the Working Group and the member(s) of the Working Group selected from the members of SACTEMA. The recommendations for these nominations will be made by UNEP after prior consultation with the Chairman of SACTEMA and, in the case of the member(s) of the Working Group, with the proposed Chairman of the Working Group.

Additional member(s) of the Working Group selected from experts outside SACTEMA will be nominated by UNEP in consultation with the Chairman of the Working Group and other Co-operating Agencies.

Reports of sessions

The draft report of each session should be prepared by the Secretariat. The Secretariat is responsible for drafting the relevant sections of the draft report, with assistance, as necessary, from the members of the Group.

The Secretariat is responsible for the compilation of the drafts and the presentation of the draft report to the meeting, as early as possible so as to leave adequate time for its consideration and approval by the Group.

No changes, except editorial ones, should be made to the report of the session after it is approved by the Group. After the session, the Secretariat should circulate to the Chairman a copy of the report in its edited form for clearance before. Subsequently, the report of the session is distributed.

Substantive reports and studies

Reports of the intersessional Working Groups are submitted for approval of the Group. No changes, except editorial ones, should be made in these reports after the Group has agreed to publish them as SACTEMA studies or reports.

The publication of studies and reports should be undertaken by UNEP.

SACTEMA publications

The reports of the sessions as well as the studies and reports resulting from the Working Groups which were approved by the Group will be published in the SACTEMA Reports and Studies series, with serial number assigned by UNEP.

All such publications shall contain a standard outline, including the definition of terrestrial ecosystems by SACTEMA and other explanatory notes together with standard disclaimer as follows:

> "This (Report/Study) contains views expressed by experts acting in their individual capacities, and may not necessarily correspond with the views of UNEP".

Studies or reports resulting from the Working Groups which were not approved by the Group cannot be published in the SACTEMA Reports and Studies series and cannot be referred to as SACTEMA publications.

UNEP will bear the expenses incurred by the members it nominates for their attendance at any sessions of the Group. Should any other agency send attendees, the cost will be borne by them.

The costs for the session will be borne by UNEP.

The costs for reproduction of reports, studies and documents will be borne by UNEP unless other UN organizations have proposed items that require documentation.

The costs for intersessional activities of the Working Groups should be borne by UNEP or, should a UN agency require advice from SACTEMA on a particular item, by the concerned agency.

ANNEX IV

Global Terrestrial Ecosystem Monitoring Sites Database Review

Introduction

Since the 1970's, a series of multidisciplinary projects have been carried out within the framework of the Global Environment Monitoring System to improve our understanding of air pollution and climate change and their ecological implications.

The emergence of new priority issues in the global environmental scene (e.g. the greenhouse effect, ultraviolet radiation increase, biodiversity, etc) with their possible associated impacts on terrestrial ecosystems has made it clear that there is a need for the establishment of a global terrestrial ecosystem monitoring programme.

In response to this, GEMS/PAC-UNEP has recently convened several expert meetings that looked at the necessary requirements for setting up a global terrestrial ecosystem monitoring programme. They were as follows:

- Expert Meeting on Global Integrated Monitoring (31 May - 1 June 1990, Hindas, Sweden);
- Meeting of an Ad Hoc Group of Experts on Terrestrial Ecosystem Monitoring and Assessment (3-7 December 1990, Maine, USA);
- Working Group Meeting on Integrated Monitoring of Terrestrial Ecosystems (8-11 October 1991, Nairobi, Kenya).

One of the ideas that emerged from these meetings, was to identify existing and proposed monitoring programmes/networks and to estimate their suitability for being included into a global terrestrial monitoring network.

As a first step towards achieving this goal, GEMS/PAC-UNEP has recently undertaken a review of terrestrial sites where multidisciplinary observations are being conducted (Global Terrestrial Ecosystem Monitoring, GTEM sites). Observations include long-term biological observations within an ecological reference area, and physical, chemical and climatological measurements at the co-located monitoring station carried out in an integrated manner on a permanent basis.

These sites were initially selected from several existing continental/regional integrated monitoring networks, such as:

- Network of "Pilot Programme on Integrated Monitoring of Air Pollution Effects on Ecosystems" (Economic Commission for Europe, UN);

- Background Integrated Monitoring (BIM) Network in Eastern Europe;
- GEMS/UNEP;
- PARKNET and LTER in the USA and;
- Association of Ecosystem Research Centres in the USA.

The criteria used for selecting these sites (terrestrial ecosystem monitoring sites) were as follows:

i) Biological as well as non-biological measurements are carried out in an integrated fashion at the same time;

ii) The site is operated on a long-term basis;

iii) The site is located in regions where the pollutant sources are relatively far away, i.e no known local sources;

iv) Pollutant fluxes are measured and estimated at the site;

v) Attempts are made at the site to estimate the impact or response of natural systems to anthropogenic influences;

vi) The site constitutes a discrete land area such as a watershed, national park, experimental forest or biosphere reserve.

Information on these monitoring sites is gathered through a questionnaire and stored in a database (GTEM Sites Database). This database is being set up at GEMS/PAC-UNEP and comprises information on location, affiliation, geographical details and observational activities. At present, data on fifty three sites in North and South America, Europe and Asia are stored in the database.

Once criteria for site selection and the necessary observational programme required for a global terrestrial monitoring network have been decided upon, it is intended to use the database as a source of information for candidate sites for the network.

SUMMARY

GEMS/PAC-UNEP has recently undertaken a review of (potential) Global Terrestrial Ecosystem Monitoring (GTEM) sites. Data from these sites were gathered by means of a questionnaire and stored in an environmental database (GTEM Sites Database). The following working definition of GTEM site was used:

GTEM site = *ecological reference area with a co-located monitoring station, where biological observations as well as multimedia chemical and physical measurements are implemented in the integrated manner on a long-term basis for the purpose of assessing human impact on natural and managed ecosystems.*

GTEM Sites Database Questionnaire

The disseminated Questionnaire consists of three parts.

1 Administrative Information

1.1 Country, region, coordinates of the monitoring station, name, address (mail, phone, fax, telex, e-mail, etc); contact person, key staff members and their professions; name of co-located monitoring station (if any).

1.2 Institution responsible for station's programme operations, address, contact person and his/her profession.

1.3 National Agency or Organization responsible for station's administration, address; contact person.

1.4 Monitoring Programme or Network of which the GTEM site is part, address; contact person.

1.5 Data Storage Facility of the GTEM site, address; contact person.

2 Basic Environmental Information

This information concerns site coordinates (which are not always equal to the monitoring station coordinates), type of biome etc (see next page)

3 Observational Programme Implemented at the GTEM Site

The respondents were requested to indicate for each type of observation (see below) the following details:

- the beginning and the end (if any) of time series;
- whether observations are regular or occasional;
- data storage facility used;
- data availability on request (yes, no, restricted).

Terrestrial Ecosystem Monitoring Sites Database

Part II - Basic Environmental Information

N/S ° ' "; E/W ° ' " ____________________
Site Coordinates — Biome

Atmospheric Monitoring Station: __________ Mean Annual Temperature (°C) __________ Total Annual Precipitation (mm) __________ Altitude (m above sea level)

Mean Monthly Temp. (°C):				**Total Monthly Precip. (mm)**			
J	______	J	______	J	______	J	______
F	______	A	______	F	______	A	______
M	______	S	______	M	______	S	______
A	______	O	______	A	______	O	______
M	______	N	______	M	______	N	______
J	______	D	______	J	______	D	______

__________ Prevailing Wind Direction(s)

__________ Number of snow days per year __________ Hours of sunshine per year

Reference Area:

__________ Size (sq.km) __________ Min. Altitude (m) __________ Max. Altitude (m)

Geology: ____________________

Orography: ____________________

Pedology: ____________________

Hydrology: ____________________

Is Area a Watershed (Y/N) : ____________________

Land Use/Cover Information	**% of total**	% of type
Forest	______	
deciduous (list)		
______		______
______		______
______		______
coniferous (list)		
______		______
______		______
______		______
Grassland (list)	______	
______		______
______		______
______		______
Other (list)	______	
______		______
______		______
______		______
Agriculture	______	
Built	______	
Water	______	

Subjects of Observation (selected in accordance with recommendations of Nairobi Meeting).

SURFACE AIR
Air Temperature
Aldebo (above canopy)

Ultraviolet radiation-B
Radionuclides
Precipitation, bulk
Precipitation chemistry:
- NO_3
- NH_4
- SO_4
- PO_4
- Ca
- Cl
- K
- Mg
- Na
- P
- PH
- Conductivity
- Organics
- Heavy metals
- Others

Gaseous *components:*
- CO_2
- O_3
- HNO_3
- SO_2
- NO_2
- NH_3
- Others

Clouds and Fog
- pH
- N deposition
- S deposition
- Others

VEGETATION
Radiation:
- Photosynthetically active radiation
- Leaf/needle fluorescence
- Red/far-red radiation
- Others

Radionuclides
Through-fall, bulk
Through-fall chemistry:
- NO_3
- NH_4
- SO_4
- PO_4
- Ca
- Cl
- K
- Mg
- Na
- P
- pH
- Conductivity
- Organics
- Heavy Metals
- Others

Stemflow, bulk

VEGETATION(continued)
Stemflow Chemistry:
- NO_3
- NH_4
- SO_4
- PO_4
- Ca
- Cl
- K
- Mg
- Na
- P
- pH
- Conductivity
- Organics
- Heavy metals
- Others

Leaf/needle chemistry:
- N
- P
- S
- C
- Others

Litterfall chemistry:
- N
- P
- S
- C
- Others

Heavy metals in epigeal mosses
Heavy metals in epiphytic lichens

VEGETATION (continued)

Gaseous flures for ecosystems:
- CO_2
- NO_2
- Methane
- Others

Epiphytic lichenoflora:
- Species composition
- Species occurrence
- Species density
- Others

Epigeal vegetation:
- Species composition
- Species occurrence
- Species density
- Others

Trees:
- Age
- Height
- Diameter
- Radial growth
- Others

Phenology of higher plants:
- Vegetative period (begin/end)
- Leaf/needle growth (begin/end)
- Flowering period (begin/end)
- Others

Plant pathology:
- Needle loss (conifers)
- Diseases
- Pest outbreaks
- Others

Net primary production

Decomp. rate of dead org. matter

SOIL:

Soil temperature:
- 0-10 cm layer
- Below 10 cm

pH:
- 0-10 cm layer
- Below 10 cm

Chemical compounds, *0-10 cm layer:*
- N
- P
- S
- C
- Hg
- Cd
- Pb
- Others

Chemical compounds, below 10 cm:
- N
- P
- S
- C
- Hg
- Cd
- Pb
- Others

Radionuclides

WATER:

Water temperature

Water budget

Surface water chemistry:
- pH
- O_2
- CO_2
- Organics
- Heavy metals
- Others

Surface water biology:
- Bioindicators
- Net primary production
- Decomp. rate of dead org. matter
- Others

Radionuclides

A short Questionnaire Guide was attached to assist the respondents in completing the forms (however, in spite of the guide, some misunderstandings still occurred).

SUMMARY

The GTEM Sites Database Questionnaire consists of three parts - "Administrative Information", "Basic Environmental Information" and "Observational Programme Implemented at the site". The latter requests information on observations related to pollution of environment, climate change, radiation (solar and biologically caused) and the potential ecological consequences. Fifty-four responses have been received. The results of the analysis are outlined below.

GTEM Site Staff, Affiliation, Participation to the Monitoring Programme/Network/System, Data Storage Facilities

The review showed that the GTEM sites are operated by national environmental agencies/organisations, both governmental (eg Swedish Environmental Protection Agency) and non-governmental (eg National Science Foundation, USA). Thus, the observational activity is sponsored by countries through either governmental or nongovernmental funds; additional support through international programmes occasionally occurs.

The observational programme at a site is carried out by local staff. This staff normally consists of environmentalists - ecologists, chemists, physicists, meteorologists, environmental managers etc.

Usually a GTEM site (even independently from its formal administrative affiliation) is supervised by a scientific institution responsible for the implementation of the observational programme implementation. These institutions (universities, hydrometeorological institutes, research centres, scientific units of the governmental bodies etc) serve as methodological, consulting and training centres. They often also take responsibility for carrying out the most difficult types of measurements.

Having been requested to complete the GTEM Sites Database Questionnaire the respondents were asked whether their sites participate in a national/international monitoring programme/system/network. Respondents participate in twenty three such activities, namely:

- Four global international activities: the network of the Biosphere Reserves/UNESCO-MAB, GEMS - the Global Environment Monitoring System/UNEP, BAPMoN - the Background Air Pollution Monitoring Network/WMO & UNEP, GAW - the Global Atmosphere Watch/WMO;

- Four regional international activities: IMP - Pilot Programme on Integrated Monitoring of Air Pollution Effects on Ecosystems/UN-ECE, EMEP - European Monitoring and Evaluation Programme/UN-ECE, EUROTRAC - European Experiment on Transport and Transformation of Environmentally Relevant Trace Constituents in the Troposphere over Europe, ENCORE - European Network of Catchments Organized for Research on Ecosystems/UN-ECE;

- Fifteen national activities*, including large-scale activities such as the National Atmospheric Deposition Programme/ USA, PMK - National Monitoring Programme/Sweden, National System of Background Monitoring/Russia, GEOMON - Geological Survey/Czech and Slovak Federal Republic, etc.

The responses showed that normally a GTEM site participates in several monitoring programmes/systems/networks at various levels (national and international). This apparently reflects a tendency to utilize existing monitoring activities, whenever a new monitoring programme is established.

As far as Data Storage Facilities are concerned, they are mainly established at the national level (except UN-ECE Environmental Data Centre in Helsinki (EDC) and the IGCE Computer Data Bank in Moscow). Thirty specialized data storage facilities were mentioned by respondents. The supervising institution's facilities are used in the majority of cases. The observational data are very rarely kept directly on magnetic tapes or in diaries on site.

SUMMARY

The GTEM sites are operated by national governmental or nongovernmental agencies/organizations.

Observational activities at GTEM sites are implemented by a local staff of environmentalists and/or by a collaborating scientific institution. These activities are sponsored in the majority of cases by host countries through governmental and/or non-governmental funds. International support is also occasionally received.

The monitoring activities at the GTEM sites are, in many cases, coordinated by leading national or international environmental agencies/organizations (UNESCO, WMO, UN-ECE, UNEP etc). Many GTEM sites participate in several networks.

The monitoring data obtained at GTEM sites are most often stored in national data storage facilities (at the supervising scientific institution etc), but international data centres are also used.

Thus, the monitoring data are available and currently used for assessments of the state of the environment and its anthropogenic changes.

**Two unrecognized activities (given by abbreviations only) are conventionally identified as national.*

PROGRAMME OR NETWORK

Code:	Name ':
USA-LTER	Long-Term Ecological Research Network
USA-EPA-NDDN	National Dry Deposition Network
USA-NADP	National Atmospheric Deposition Programme
USA-NPS	Gaseous Pollutant Network
USA-AERC	Association of Ecosystem Research Centres
USA- NMSCN	New Mexico State Climate Network
USA-CMDL	Climate Monitoring & Diagnosis Lab.
UNESCO-MAB	Man and the Biosphere Programme, The Network of Biosphere Reserves
SWD-EPA-PMK	Swedish Environmental Protection Agency Monitoring Programme
ECE/UN-IMP	Integrated Monitoring Programme (Pilot Programme on Integrated Monitoring and Air Pollution Effects on Ecosystems)
RUS- NSBM	Russia, National System of Background Monitoring
UNEP-GEMS	Global Environment Monitoring System

WMO- BAPMoN	World Meteorological Organization, Background Air Pollution Monitoring Network
CRO- NN	Croatia, National Network
ECE-EMEP	European Monitoring and Evaluation Programme
WMO-GAW	World Meteorological Organization, Global Atmosphere Watch
CSFR-CHI	Czech and Slovak Federal Republic, Czech Hydrometeorological Institute
CSFR-GEOMON	Czech and Slovak Federal Republic, Geological Survey
CSFR-TOCOEN	Czech and Slovak Federal Republic
EUREKA	
EUROTRAC	European Experiment on Transport and Transformation of Environmentally Relevant Trace Constituents in the Troposphere over Europe
TOR	
ECE-ENCORE	European Network of Catchments Organized for Research on Ecosystems

DATA STORAGE FACILITIES

Code:	Name ':
USA-EPA-CERL	US, Environmental Protection Agency
USA-EPA-AREA	
USA-NADP	National Atmosphere Deposition Programme
USA-NPS	Gaseous Pollutant Network
USA-UNM-DB	University of New Mexico, Department of Biology
USA-SDSU-DG	San Diego State University, Department of Geography
USA-INSTAAR	
USA-CL-UWM	Centre for Limnology, University of Wisconsin-Madison
USA-RDPR	Rugers Division of Pinelands Research
USA-SIMS	Sevilleta Information Management System
USA-SmERC	Smithsonian Environmental Research Centre
USA-VCR-LTER	Department of Environmental Sciences Long-Term Ecological Research Network

USA-SERC	Sawyer Environmental Research Centre, University of Maine
ECE-EDC	UN-ECE, Environmental Data Centre
ECE-EMEP	European Monitoring and Evaluation Programme
WMO-GAW	World Meteorological Organization, Global Atmosphere Watch
SWD-IVL	Environmental Research Institute, Sweden
SWD-EPAEIAD	Environmental Protection Agency, Sweden, Environmental Impact Assessment Department
SWD-EPARD	Environmental Protection Agency, Sweden, Research Department
SWD-MHI	Meteorological and Hydrological Institute, Sweden
RUS-IGCE	Institute of Global Climate and Ecology, Russia
ICDB	IGCE Computer Data Bank on IBM PC (Russia, Byelorussia, Ukraine, Hungary, Kazakhstan, Uzbekistan,Turkmenistan and Kirghizstan)
RUS-ASPOD	Data Centre ASPOD, Russia

CSFR-CHINMS	Czech and Slovak Federal Republic, Czech Hydrometeorological Institute Network of Meteorological Stations
CSFR-GEOMON	Czech and Slovak Federal Republic, Geological Survey
CSFR-TOCOEN	Czech and Slovak Federal Republic,
POL-IEP	Institute of Environmental Protection, Poland
RUS-RINCR	Research Institute of Nature Conservation and Reserves, Russia
OS-MC	On Site-Magnetic Carriers
OS-D	On Site-Diaries

'The national activities are named basically as they were presented by respondents.

Spatial Distribution of GTEM Sites

At present, the GTEM Sites Database holds information on fifty-four sites located in North America (28), South America (1), Europe (20)* and Asia (5). Fifty-three of these sites are situated in the Northern Hemisphere.

North America is represented by twenty eight sites. They cover a wide range of latitudes from 18°18'N to 68°38'N, but the latitudinal distribution is non-homogeneous; the majority of sites are in temperate latitudes while low and high latitudes are relatively poorly represented. The longitudinal range (149°34'W - 65° 47'W) and the altitudinal range (2-2925 m above sea level) seem to characterize the continent comprehensively. However, the density of sites in the most westerly part of North America is relatively low.

The European GTEM sites (20) are situated mostly in Central Europe (6), within the Nordic Area (3) and in Eastern Europe (11). The latitudinal range (41°08'N - 66°40'N), characterizes Europe quite well, however, there is an obvious lack of sites in the Mediterranean Area. The longitudinal distribution is non-homogeneous; the most western part of the continent is not represented at all and the most easterly part is poorly represented (North-East is not covered). The altitudinal range (-24 - 2000 m above sea level) seems to be quite typical for Europe and the altitudinal distribution is quite homogeneous.

Asia is represented by 5 sites, situated in Kazakhstan (1), in Middle Asia (3) and in Siberia (1). The latitudinal range is 41°06'N - 54°20'N, the longitudinal one is 62°12'E - 109°32'E and the altitudes vary from 120 m to 1360 m above sea level. Thus, the northern and the southern parts of the continent as well as Far East are not represented. The lowlands are not represented and the highlands are characterized poorly.

South America is represented by 1 site situated in Chile (Torres del Paine). Information on other South American sites is forthcoming.

As far as specific matters are concerned the permafrost areas in Euro-Asia and North America are so poorly represented that a spatial distribution of GTEM sites can not be estimated.

More detailed information concerning spatial distribution of GTEM sites can be found in Form 1 and in the continental maps (see next chapter) for North America, Europe and Asia respectively.

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* When the location of the sites was being identified, complications emerged with respect to two sites - Juga Massif and Caucasus Biosphere Reserve, since they are situated at the very boundary of Europe and Asia. They are included conventionally in the list of European sites.

GLOBAL TERRESTRIAL ECOSYSTEM MONITORING SITES REVIEW

Form 1
Sheet 1

Region: North America
Subject: List of GTEM Sites

N	Site name	Country	Altitude m	Latitude	Longitude
1	ARCTIC TUNDRA/ TOOLIC LAKE	USA	760	68°38'N	149°34'W
2	BEUR BROOKS WATERSHED IN MAINE	USA	265-410	44°52'N	68°06'W
3	BONANZA CREEK EXPERIMENTAL STATION	USA	600-1800	64°45'N	148°00'W
4	CEDAR CREEK NATURAL HISTORY AREA	USA	175-288	45°74'N	93°12'W
5	CENTRAL PLAIN EXPERIMENTAL RANGE	USA	1650	40°49'N	104°46'W
6	COWEETA HYDROLOGIC LABORATORY	USA	679-1595	35° N	83°30'W
7	GOTHIC.,CO	USA	2925	38°57'N	106°59'W
8	GRAND CANYON,AZ	USA	2073	36°04'N	112°11'W
9	HARVARD FOREST	USA	220-410	42°37'N	72°10'W
10	HOWLAND INTEGRATED FOREST STUDY	USA	60	45°10'N	68°40'W
11	HUBBARD BROOK,NH	USA	258	43°57'N	71°42'W
12	HUBBARD BROOK EXPERIMENTAL FOREST	USA	229-1015	43°56'N	71°45'W
13	HJ ANDREWS EXPERIMENTAL FOREST	USA	412-1630	44°14'N	122°11'W
14	JORNADA	USA	1332	32°30'N	106°45'W
15	KONZA PRARIE RESEARCH NATURAL AREA	USA	366	39°05'N	96°35'W
16	LUQUILLO EXPERIMENTAL FOREST	USA	100-1070	18°18'N	65°47'W
17	NIWOT RIDGE	USA	3743	40°03'N	105°37'W

GLOBAL TERRESTRIAL ECOSYSTEM MONITORING SITES REVIEW Form 1 Sheet 2

Region: North America
Subject: List of GTEM Sites

N	Site name	Country	Altitude m	Latitude	Longitude
18	NORTH TEMPERATE LAKES (TROUT LAKE STATION)	USA	500	46°00'N	89°40'W
19	NORTHINLET MARSH-ESTUARINE SYSTEM	USA	2	33°30'N	79°13'W
20	PENNSYLVANIA STATE UNIVERSITY	USA	393	40°44'N	77°57'W
21	RUTGERS DIVISION OF PINELAND RESEARCH	USA	30	39°57'N	74°36'W
22	REYNOLDS CREEK,ID	USA	1198	43°13'N	116°45'W
23	SHENNANDOAH NATIONAL PARK	USA	1073	38°31'N	78°26'W
24	SEVILETTA NATIONAL WILDLIFE REFUGE	USA	1553	34°21'N	106°54'W
25	SMITHSONIAN ENVIRONMENTAL RESEARCH CENTER	USA	15	38°51'N	76°32'W
26	VIRGINIA COAST RESERVE	USA	5	37°27'N	75°40'W
27	WHITEFACE MOUNTAIN,NY	USA	570	44°24'N	73°51'W
28	W.K.KELLOGG BIOLOGICAL STATION	USA	288	47°74'N	85°74'W

GLOBAL TERRESTRIAL ECOSYSTEM MONITORING SITES REVIEW

Form 1
Sheet 1

Region: Europe
Subject: List of GTEM Sites

N	Site name	Country	Altitude m	Latitude	Longitude
1	ASTRAKHANSKY BIOSPHERE RESERVE	Russia	-24	46°00′N	48°30′E
2	BEREZINSKY BIOSPHERE RESERVE	Belorus	175	54°42′N	28°24′E
3	CAUCASUS BIOSPHERE RESERVE	Russia	575	43°41′N	40°17′E
4	CENTRAL FOREST BIOSPHERE RESERVE	Russia	250	56°29′N	32°58′E
5	IVAN SEDLO	Yugoslavia	970	43°46′N	18°02′E
6	JUGA MASSIF	Russia	2000	43°53′N	40°28′E
7	KARA-DAG	Ukraine	200	44°54′N	35°12′E
8	KOSETICE	Czech Republic	534	49°35′N	15°05′E
9	K-PUSTA	Hungary	125	48°58′N	19°33′E
10	LAKE GARDSJON	Sweden	113	58°04′N	12°01′E
11	LAZAROPOLE	Yugoslavia	1320	41°32′N	20°42′E
12	NEUGLOBSOW	Germany	65	53°10′N	13°02′E
13	PRIOKSKO-TERRASNY BIOSPHERE RESERVE	Russia	150	54°50′N	37°50′E
14	PUSZCZA BORECKA (DIABLA GORA)	Poland	157	54°09′N	22°04′E
15	REIVO	Sweden	550	65°47′N	19°06′E
16	ROGEN	Bulgaria	1750	41°08′N	24°08′E
17	TIVEDEN	Sweden	210	58°41′N	14°38′E

GLOBAL TERRESTRIAL ECOSYSTEM MONITORING SITES REVIEW

Form 1
Sheet 2

Region: Europe
Subject: List of GTEM Sites

N	Site name	Country	Altitude m	Latitude	Longitude
18	VALDAI	Russia	208	57°51'N	32°21'E
19	VELIKIY	Russia	15	66°40'N	33°00'E
20	VORONEZHSKY BIOSPHERE RESERVE	Russia	155	51°54'N	39°36'E

GLOBAL TERRESTRIAL ECOSYSTEM MONITORING SITES REVIEW

Form 1
Sheet 1

Region: Asia
Subject: List of GTEM sites

N	Site name	Country	Altitude m	Latitude	Longitude
1	BARGUZINSKY BIOSPHERE RESERVE	Russia	470	54°20'N	109°32'E
2	BOROVOYE	Kazakhstan	340	53°00'N	70°15'E
3	CHATKALSKY BIOSPHERE RESERVE	Uzbekistan	1250	41°06'N	69°30'E
4	REPETEKSKY BIOSPHERE RESERVE	Turkmenistan	120	38°30'N	62°12'E
5	SARY-CHELEKSKY BIOSPHERE RESERVE	Kyrgyzstan	1360	41°36'N	71°54'E

SUMMARY

The spatial distribution of the fifty-four GTEM sites is uneven. North America and Europe are represented satisfactorily, however some gaps exist. Asia and South America are poorly covered . Some important specific areas of the Northern Hemisphere (eg permafrost areas) are insufficiently represented. The altitudinal distribution characterizes North America and Europe satisfactorily but is not sufficient for Asia and South America.

Consequently, to provide an adequate basis for the Global Terrestrial Ecosystem Monitoring Network the essential geographical expansion of terrestrial ecosystem monitoring activities is clearly required.

Distribution of GTEM Sites by World Biomes

Since the response of terrestrial ecosystems to equal abiotic impacts (loads) can vary widely due to the particular characteristics of the site, the proposed Global Terrestrial Ecosystem Monitoring Network should be representative of the existing variety of biogeocenotic conditions, thus enabling the monitoring system to give a global picture of probable changes. The World Biomes (by Mikos Udvardy) has been chosen as a generally accepted classification system (the world biomes are listed on the next page), since it is a system of zonation that adequately describes the variety of biogeocenotic conditions.

The following attributes were used for each site classification:

- "biome" to identify the location of a given site on the map of world biomes*;

- "site type":

INTRAZONAL	(for the sites situated reasonably far from a biome boundary) or
MARGINAL	(for the sites situated near the boundary of two biomes or close to the seashore) or
COASTAL	(for the sites situated directly at a sea coast).

The latter classification is not generally accepted. It was used because information regarding site closeness to biome boundary appears to be important for climate-related monitoring issues.

The classification results are presented in Form 2. It should be underlined that these results depend to a large extent on the accuracy of site coordinates indicated by respondents and on the accuracy of the world biomes map used.

Diagrams on the distribution of the reviewed GTEM sites by world biomes are given below. These diagrams show that GTEM sites are unevenly distributed by biomes.

The biomes "Temperate Needleleaf Forests or Woodlands" and "Temperate Broadleaf Forests or Woodlands and Sub-Polar Deciduous Thickets" in North America are over-represented by GTEM sites, while sub-tropical and tropical biomes are not represented at all.

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*The Map of the Biosphere Reserves (UNESCO-MAB) was used.

WORLD BIOMES

TROPICAL HUMID FORESTS **THF**

SUB-TROPICAL AND TEMPERATE RAIN FORESTS **STTRF**

TEMPERATE BROADLEAF FORESTS OR WOODLANDS AND SUB-POLAR DECIDUOUS THICKETS **TBFWSPT**

TEMPERATE NEEDLELEAF FORESTS OR WOODLANDS TNFW

EVERGREEN SCLEROPHYLLOUS FORESTS, SCRUB OR WOODLANDS **ESFSW**

TROPICAL DRY OR DECIDUOUS FORESTS (INCLUDING MONSOON FORESTS) OR WOODLANDS **TDDFW**

TROPICAL GRASSLANDS AND SAVANNA **TGS**

TEMPERATE GRASSLANDS **TG**

WARM DESERTS AND SEMI-DESERTS **WDSD**

COLD WINTER (CONTINENTAL) DESERTS AND SEMI-DESERTS **CWDSD**

TUNDRA COMMUNITIES AND BARREN ARTIC DESERTS TCBAD

GLOBAL TERRESTRIAL ECOSYSTEM MONITORING SITES REVIEW

Form 2
Sheet 1

Region: North America
Subject: Distribution by World Biomes

NUMBER	NAME	BIOME	SITE TYPE
1	Artic Tundra Tollik Lake	Tundra Communities and Barren Artic Deserts	Marginal
2	Bear Brooks Watershed in Maine	Temperate Needleleaf Forests or Woodlands	Marginal
3	Bonanza Creek Experimental Station	Temperate Needleleaf Forests or Woodlands	Intrazonal
4	Cedar Creek History Area	Temperate Grasslands	Marginal
5	Central Plains Experimental Range	Temperate Grasslands	Intrazonal
6	Coweeta Hydrological Laboratory	Temperate Broadleaf Forests or Woodlands and Sub-Polar Deciduous Thickets	Intrazonal
7	Gothic, CO	Mixed Mountain and Highland Systems with Complex Zonation	Intrazonal
8	Grand Canyon AZ	Mixed Mountain and Highland Systems with Complex Zonation	Intrazonal
9	Harvard Forest	Temperate Broadleaf Forests or Woodlands and Sub-Polar Deciduous Thickets	Intrazonal
10	Howland Integrated Forest Study	Temperate Needleleaf Forests or Woodlands	Intrazonal

GLOBAL TERRESTRIAL ECOSYSTEM MONITORING SITES REVIEW

Form 2
Sheet 2

Region: North America
Subject: Distribution by World Biomes

NUMBER	NAME	BIOME	SITE TYPES
11	Hubbard Brook	Temperate Needleleaf Forests or Woodlands	Marginal
12	Hubbard Brook Experimental Forest	Temperate Needleleaf Forests or Woodlands	Marginal
13	HJ Andrews Experimental	Cold Winter (Continental) Deserts and Semi-Deserts	Marginal
14	Jornada	Warm Deserts and Semi-Deserts	Intrazonal
15	Konza Prairie Research Natural Area	Temperate Grasslands	Marginal
16	Luquillo Experimental Forest	Mixed Island Systems	Intrazonal
17	Niwot Ridge	Mixed Mountain and Highland Systems with Complex Zonation	Intrazonal
18	North Temperate Lakes -Trout Lake Station	Temperate Broadleaf Forests or Woodlands and Sub-Polar Deciduous Thickets	Marginal
19	North-Inlet Marsh Estuarine System	Temperate Broadleaf Forests or Woodlands and Sub-Polar Deciduous Thickets	Coastal

GLOBAL TERRESTRIAL ECOSYSTEM MONITORING SITES REVIEW
Form 2
Sheet 3

Region: North America
Subject: Distribution by World Biomes

NUMBER	NAME	BIOME	SITE TYPE
20	Pennsylvania State University	Temperate Broadleaf Forests or Woodlands and Sub-Polar Deciduous Thickets	Intrazonal
21	Rutgers Division of Pineland Research	Temperate Broadleaf Forests or Woodlands and Sub-Polar Deciduous Thickets	Marginal
22	Reynolds Creek, ID	Cold Winter (Continental) Deserts and Semi-Deserts	Intrazonal
23	Shenandoah National Park	Temperate Broadleaf Forests or Woodlands and Sub-Polar Deciduous Thickets	Intrazonal
24	Sevilleta National Wildlife Refuge	Warm Deserts and Semi-Deserts	Marginal
25	Smithsonian Environment. Research Centre	Temperate Broadleaf Forests or Woodlands and Sub-Polar Deciduous Thickets	Marginal
26	Virginia Coast Reserve	Temperate Broadleaf Forests or Woodlands and Sub-Polar Deciduous Thickets	Coastal
27	White Face Mountain	Temperate Needleleaf Forests or Woodlands	Intrazonal
28	W.K.Kellogg Biological Station	Temperate Needleleaf Forests or Woodlands	Marginal

GLOBAL TERRESTRIAL ECOSYSTEM MONITORING SITES REVIEW

Form 2
Sheet 1

Region: Europe
Subject: Distribution by World Biomes

NUMBER	NAME	BIOME	SITE TYPE
1	Astrakhansky Biosphere Reserve (RUS)	Cold Winter (Continental) Deserts and Semi-Deserts	Marginal
2	Berezinsky Biosphere Reserve (RUS)	Temperate Broadleaf Forests or Woodlands and Sub-Polar Deciduous Thickets	Intrazonal
3	Caucasus Biosphere Reserve (RUS)	Mixed Mountain and Highland Systems with Complex Zonation	Marginal
4	Central Forest Biosphere Reserve (RUS)	Temperate Broadleaf Forests or Woodlands and Sub-Polar Deciduous Thickets	Marginal
5	Ivan Sedlo (YUG)	Mixed Mountain and Highland Systems with Complex Zonation	Marginal
6	Juga Massif (RUS)	Mixed Mountain and Highland Systems with Complex Zonation	Intrazonal
7	Kara-Dag(UKR)	Temperate Grasslands	Marginal
8	Kosetice (CSFR)	Temperate Broadleaf Forests or Woodlands and Sub-Polar Deciduous Thickets	Intrazonal
9	K-Putszta (HUN)	Temperate Broadleaf forests or Woodlands and Sub-Polar Deciduous Thickets	Intrazonal
10	Lake Gardsjon (SWE)	Temperate Broadleaf Forests or Woodlands and Sub-Polar Deciduous Thickets	Marginal

GLOBAL TERRESTRIAL ECOSYSTEM MONITORING SITES REVIEW
Form 2
Sheet 2

Region: Europe
Subject: Distribution by World Biomes

NUMBER	NAME	BIOME	SITE TYPES
11	Lazaropole (YUG)	Mixed Mountain and Highland Systems with Complex Zonation	Intrazonal
12	Neuglobsow (GER)	Temperate Broadleaf Forests or Woodlands and Sub-Polar Deciduous Thickets	Intrazonal
13	Prioksko-Terrasny Biosphere Reserve(RUS)	Temperate Broadleaf Forests or Woodlands and Sub-Polar Deciduous Thickets	Intrazonal
14	Puzscza Borecka (Diabla Gora) (POL)	Temperate Broadleaf Forests or Woodlands and Sub-Polar Deciduous Thickets	Intrazonal
15	Reivo (SWE)	Temperate Needleleaf Forests or Woodlands	Marginal
16	Rogen (BUL)	Mixed Mountain and Highland Systems with Complex Zonation	Intrazonal
17	Tiveden(SWE)	Temperate Broadleaf Forests or Woodlands and Sub-Polar Deciduous Thickets	Intrazonal
18	Valdai (RUS)	Temperate Broadleaf Forests or Woodlands and Sub-Polar Deciduous Thickets	Marginal
19	Velikiy, N16 (RUS)	Temperate Needleleaf Forests or Woodlands	Coastal
20	Voronzehsky Biosphere Reserve (RUS)	Temperate Broadleaf Forests or Woodlands and Sub-Polar Deciduous Thickets	Marginal

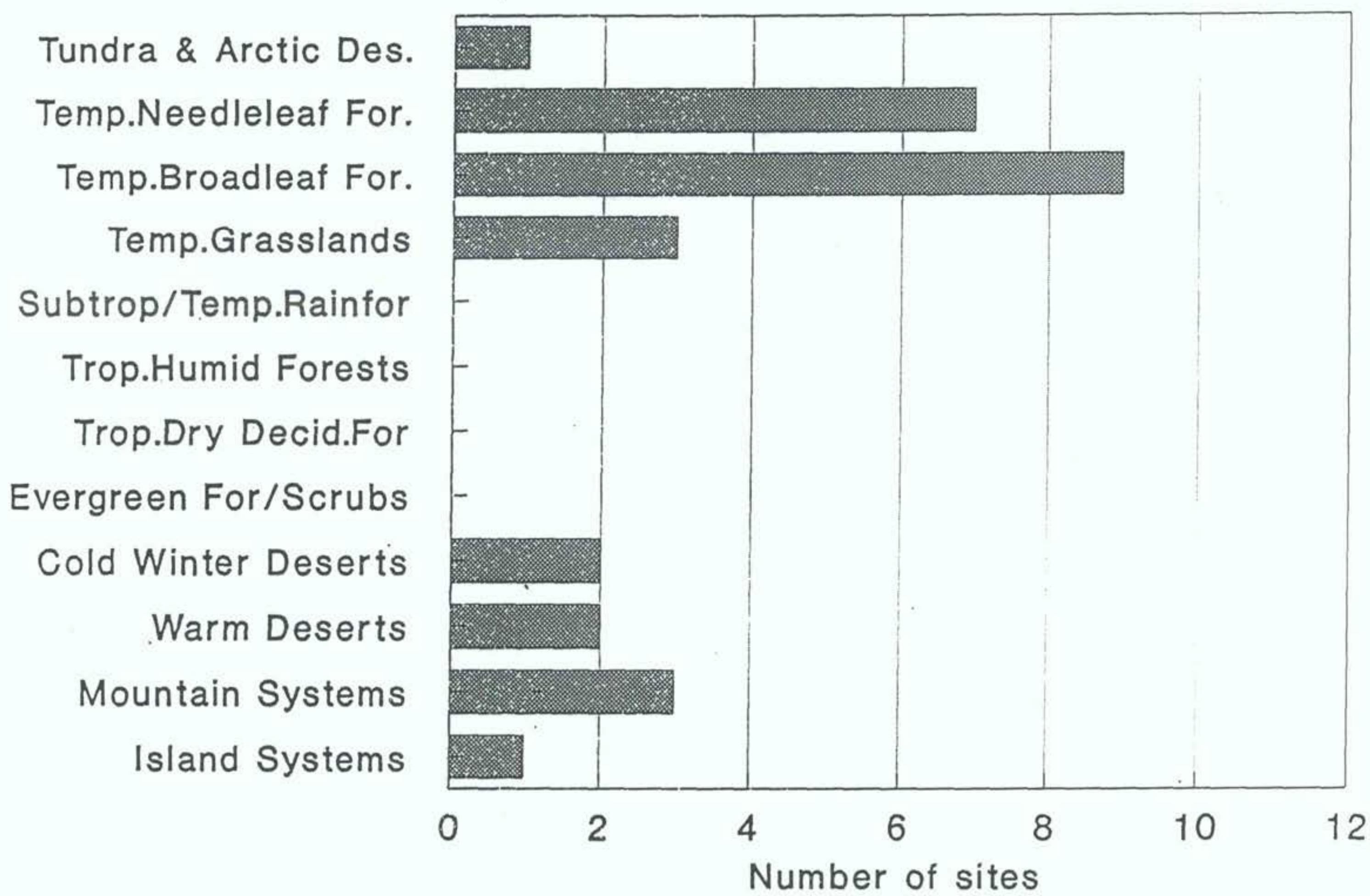
GLOBAL TERRESTRIAL ECOSYSTEM MONITORING SITES REVIEW

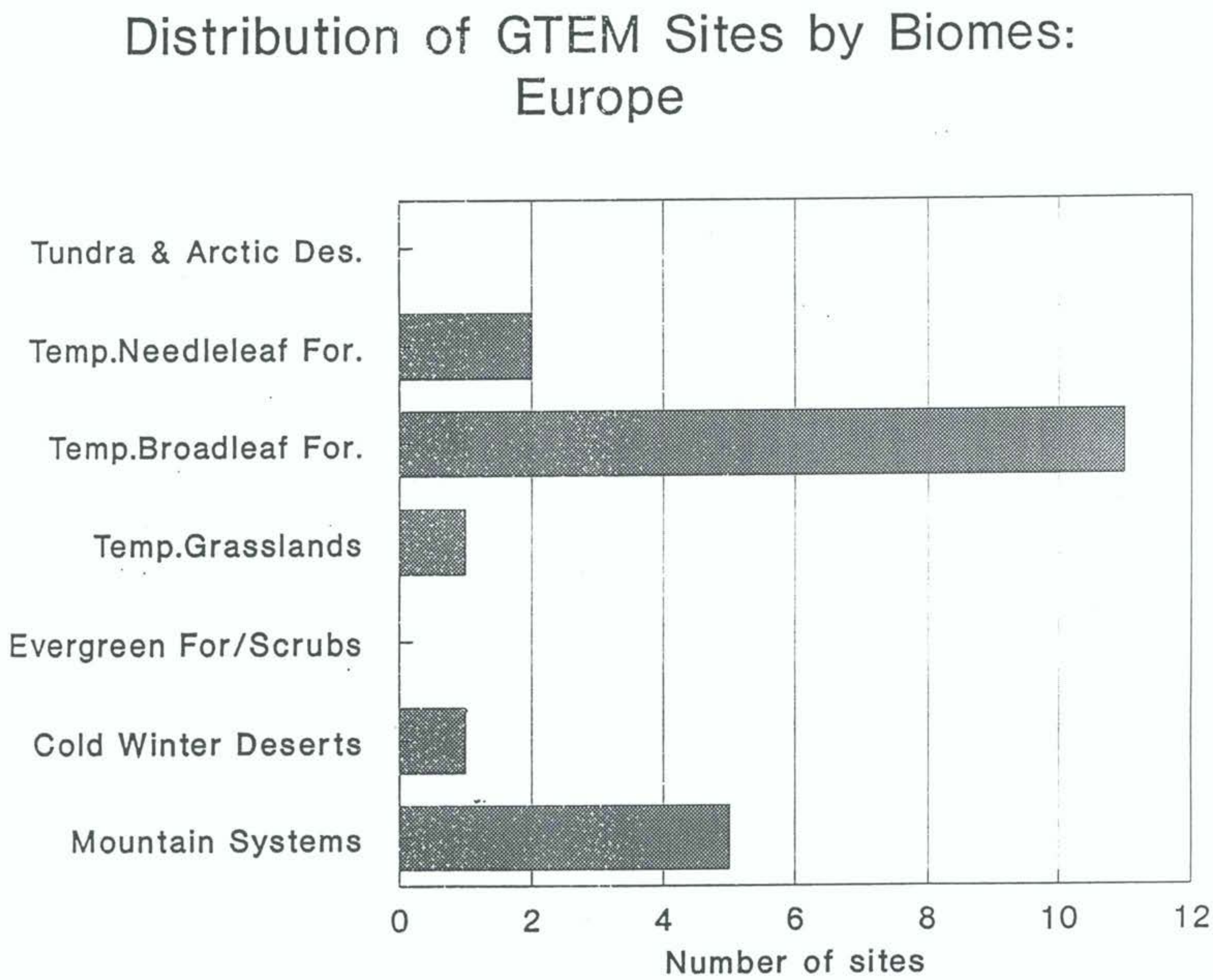
Form 2
Sheet 1

Region: Asia
Subject: Distribution by World Biomes

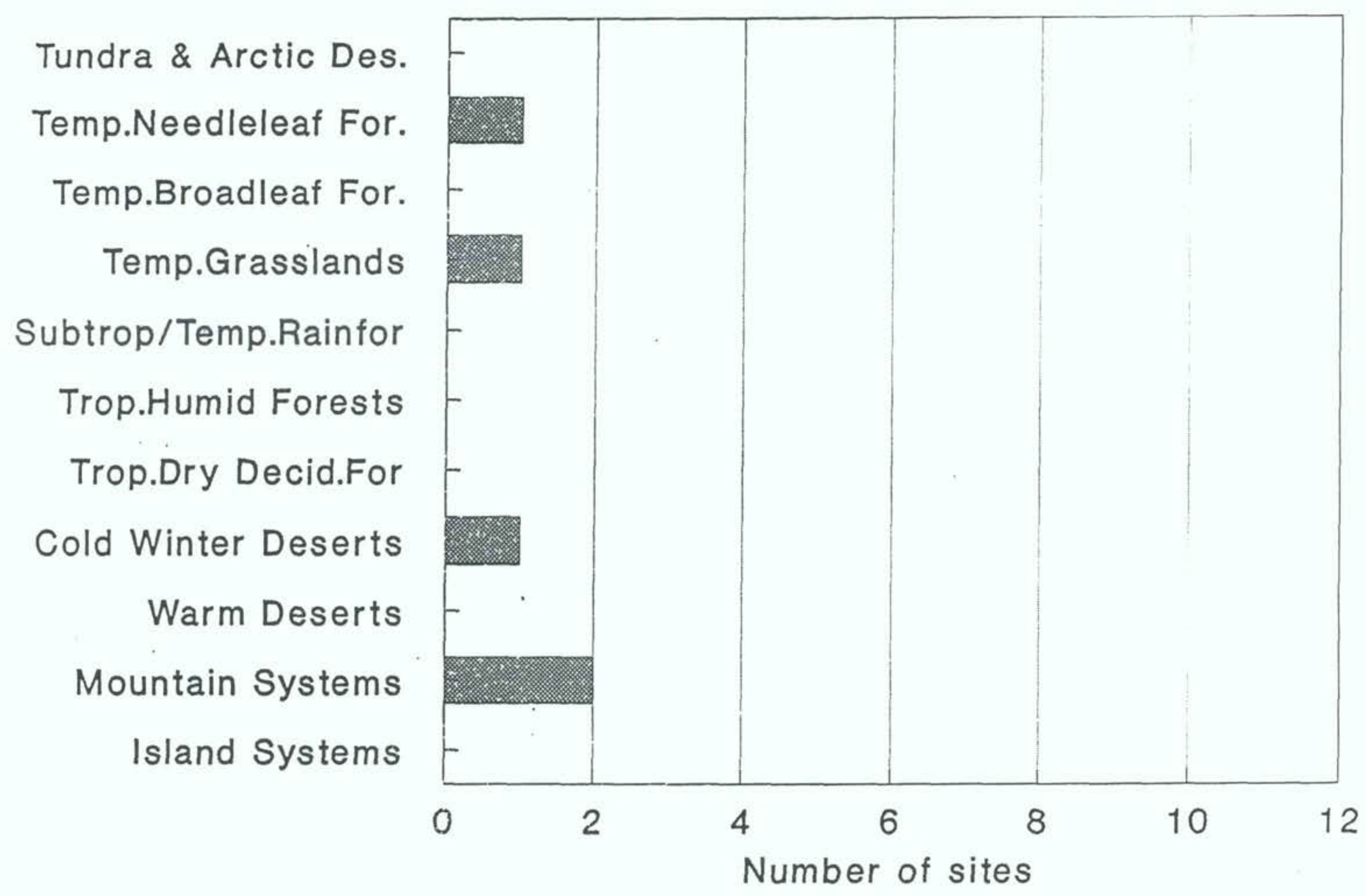
NUMBER	NAME	BIOME	SITE TYPE
1	Barguzinsky Biosphere Reserve(RUS)	Temperate Needleleaf Forests or Woodlands	Intrazonal
2	Borovoye (KZK)	Temperate Grasslands	Intrazonal
3	Chatkalsky Biosphere Reserve (UBK)	Mixed Mountain and Highland Systems with Complex Zonation	Marginal
4	Repeteksky Biosphere Reserve (TKM)	Cold Winter (Continental) Deserts and Semi-Deserts	Intrazonal
5	Sary-Cheleksky Biosphere Reserve (KGT)	Mixed Mountain and Highland Systems with Complex Zonation	Intrazonal

Distribution of GTEM Sites by Biomes: North America

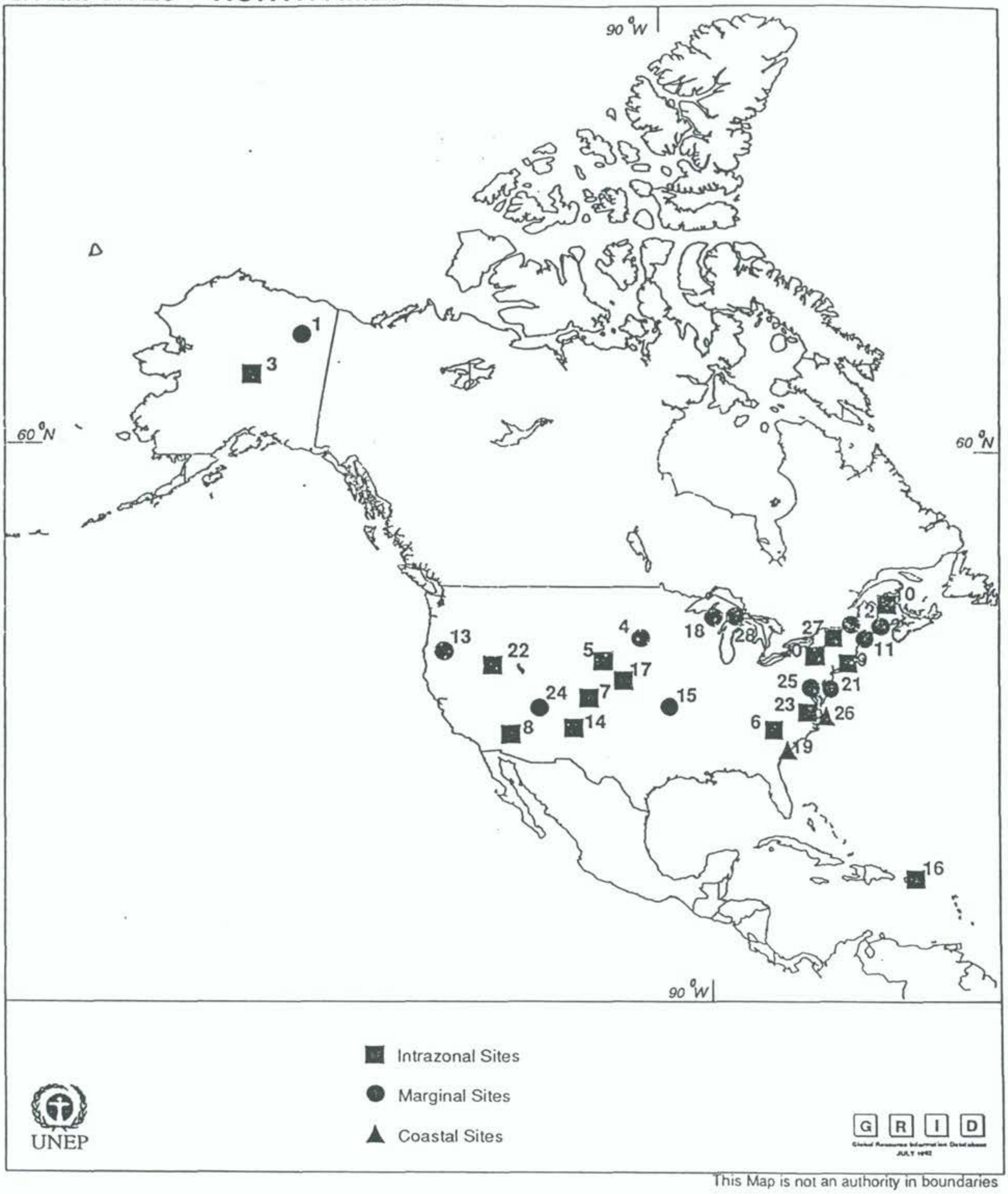



Distribution of GTEM Sites by Biomes:
Europe
Tundra & Arctic Des.
Temp.Needleleaf For.
Temp.Broadleaf For.
Temp.Grasslands
Evergreen For/Scrubs
Cold Winter Deserts
Mountain Systems
0
2
4
6
8
10
12
Number of sites

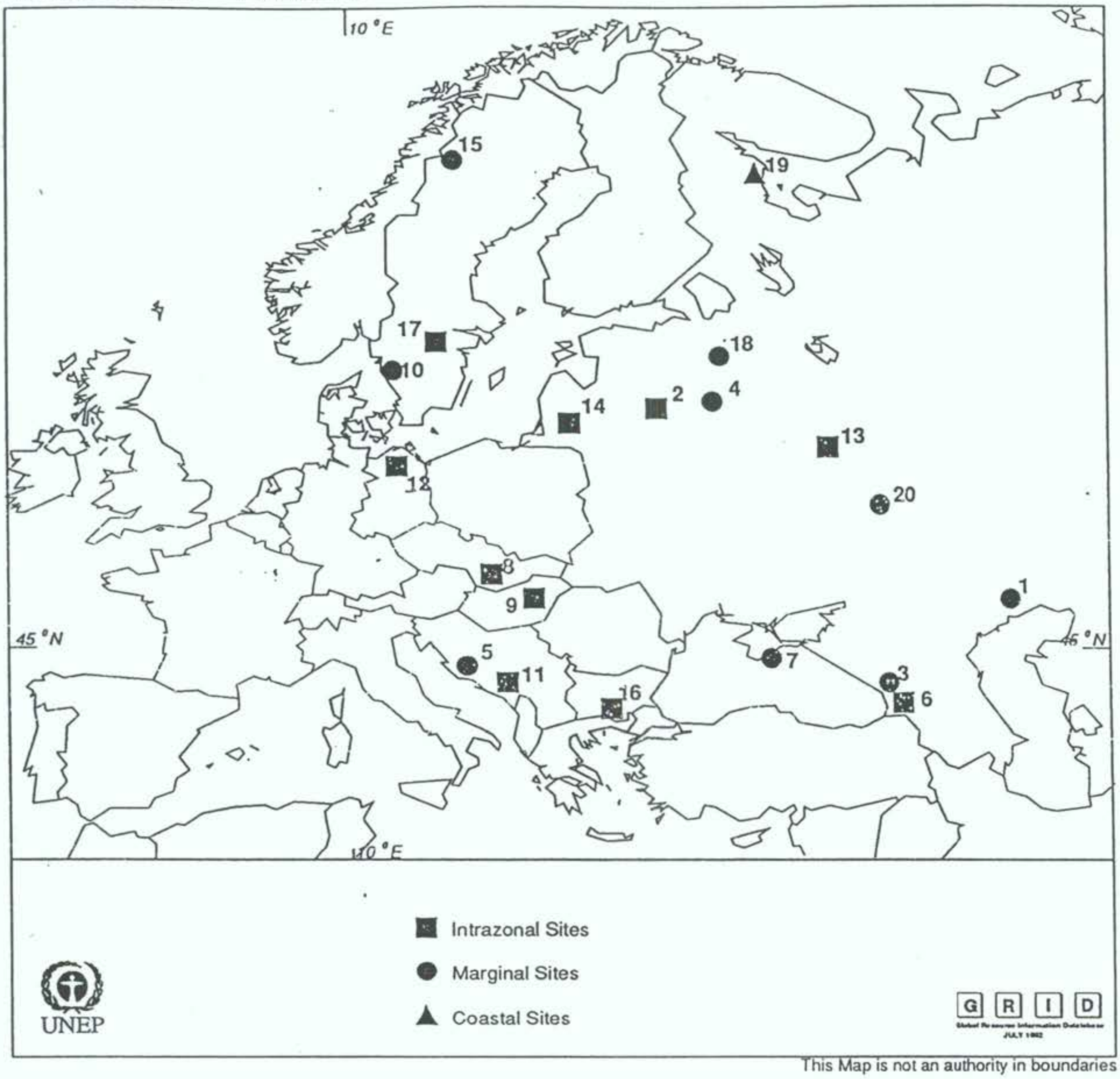
Distribution of GTEM Sites by Biomes: Asia



GTEM SITES - NORTH AMERICA

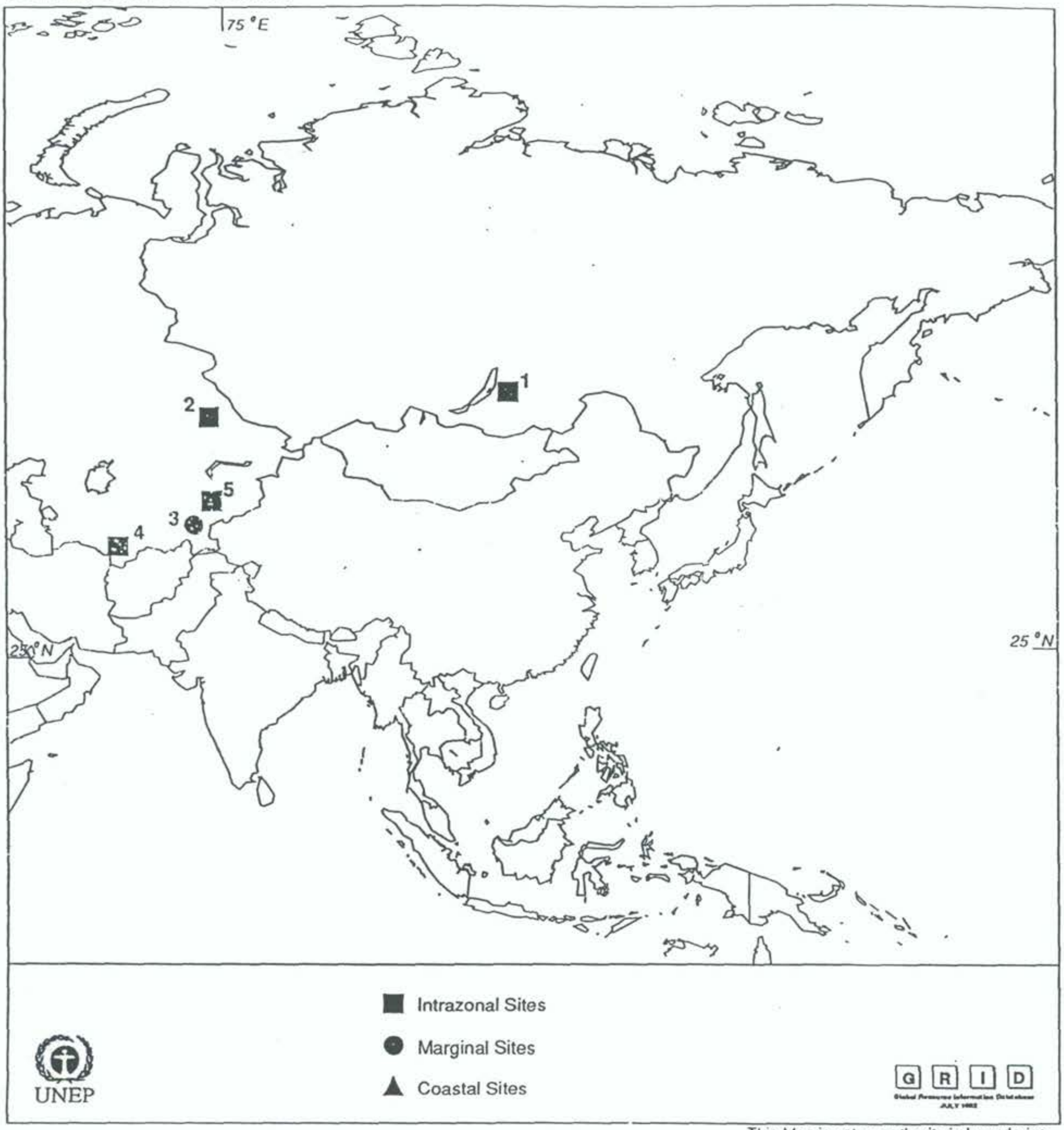


GTEM SITES - EUROPE



This Map is not an authority in boundaries

GTEM SITES - ASIA



This Map is not an authority in boundaries

The situation in Europe is quite similar. There are too many sites within the "Temperate Broadleaf Forests or Woodlands and Sub-Polar Deciduous Thickets", while, "Tundra communities and Barren Arctic Deserts" and "Evergreen Sclerophyllous Forests, Scrub or Woodlands" are not represented.

Only four of the existing eleven biomes are represented in Asia, namely "Temperate Needleleaf Forests or Woodlands", "Temperate Grasslands and Savanna", "Cold Winter (Continental) Deserts and Semi-deserts" and "Warm Deserts and Semi-deserts".

The results of a classification of the sites with respect to their closeness to a boundary of a biome or to a sea shore are displayed in the maps above. The analysis showed that a substantial number of the sites are marginal. This site location may be useful for monitoring the ecological consequences of eventual global climate change, since they seem to appear first at the biome boundaries.

SUMMARY

Since the response of terrestrial ecosystems to equal abiotic impacts (loads) can vary widely due to the particular characteristics of the site, the proposed GTEM Network should include, at least, the major world biomes. The analysis of GTEM sites distribution by World Biomes shows that a majority of the occurring biomes are represented by GTEM sites in North America and in Europe. However, four of the twelve North American biomes, two of the seven European biomes, and four of the eleven Asian biomes are represented in their respective areas and only one of the nine South American biomes is represented in South America. Some biomes (eg "Temperate Broadleaf Forests or Woodlands and Sub-Polar Deciduous Thickets" in North America and in Europe, and "Temperate Needleleaf Forests or Woodlands" in North America) are over-represented. Many sites are situated near the boundary of two biomes which may be useful for climate-related monitoring.

Monitoring Activities at GTEM Sites

The questionnaire forms completed by respondents (namely, Part III - see the chapter "GTEM Sites Database Questionnaire") were also analysed with respect to observational activities .

To implement this analysis Form 3 was used. Two types of items are presented in the column "type of observation" of this form. The item could be either an environmental variable extracted directly from the questionnaire (eg "Ultraviolet-B") or an aggregate of variables like "Precipitation Chemistry".

To complete Form 3 the following approach was used:

- the environmental variable is considered as active at a given monitoring site if it is (or was)* monitored; and

- the aggregate is considered as an active item at a given monitoring site if at least one variable of the group is (or was)* active.

Form 3 shows that the observational activity at the monitoring sites under consideration concerns various media: surface air, vegetation, soil and water. The various observations are carried out, in the majority of cases, on a permanent basis. Amongst environmental variables being measured, there are pollution-related, climate-related and radiation-related variables (biologically caused and solar radiation including ultraviolet).

North America

Surface air is monitored at 100% of the sites in North America. Vegetation is monitored at twenty-five sites, and soil and water both at fifteen sites as well.

Amongst surface air items "Albedo, above canopy" and "Clouds and fog" are rarely monitored (at six and three sites respectively)."Ultraviolet-B" is measured at eleven sites. Other items are implemented at twelve to twenty-seven sites. Radionuclides are not measured at all, neither in surface air nor in other media. They will, therefore, not be considered hereafter.

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*The review ~~showed~~ that, in an overwhelming majority of cases, once the observations

Vegetation is quite comprehensively studied but some gaps exist. Unlike in Europe, "Heavy metals in epigeal mosses" and "Heavy metals in epiphytic lichens" are not measured at all. "Epiphytic lichenoflora" and "Plant pathology" are poorly monitored (at three sites each).

Soil and water items are implemented at 25-50% of sites in North America.

Europe

Surface air is monitored at nineteen sites, vegetation at sixteen sites, soil at fifteen sites and water at twelve sites in Europe.

The surface air items are unequally measured at different sites. "Albedo, above canopy" and "Ultraviolet-B" are not under study at all and "Clouds and fog" (ie pH of and N & S deposition by clouds and fog) are monitored at one site only. Other surface air items are measured at thirteen to eighteen sites.

Vegetation-related observations are not very well represented. "Leaf/needle chemistry", "Heavy metals in epiphytic lichens" and "Epiphytic lichenoflora" are monitored at nine to eleven sites, while "Stemflow bulk", "Heavy metals in epiphytic lichens", "Gaseous fluxes from ecosystems", "Higher plant phenology" and "Net primary production" are each under study at only one site.

Soil items are measured at five to fourteen sites and water items are measured at five to eleven sites. Soil and water chemistry observations prevail within the European monitoring activity.

Asia

The following types of observations are carried out at each site under consideration.

Surface air: air temperature; precipitation bulk; precipitation chemistry; gaseous components.

Vegetation: leaf/needle chemistry; heavy metals in epigeal mosses; epiphytic lichenoflora.

Soil: chemical compounds (0-10 cm layer); chemical compounds (below 10 cm layer).

Water: surface water chemistry.

BAL TERRESTRIAL ECOSYSTEM MONITORING SITES REVIEW
Region : North America
Subject: Monitoring Activities

Form 3
Sheet 1.1

e of ob- vation	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
FACE AIR	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
tempe- ure	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓		▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	
edo,above opy						▓			▓	▓		▓				▓								▓					
roviolet .-B	▓		▓			▓						▓	▓		▓		▓		▓					▓	▓			▓	
ionucli- .																													
cipita- n, bulk	▓	▓	▓	▓	▓	▓			▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓		▓			▓	▓	▓		▓	
cipita- n che- try		▓		▓		▓	▓	▓		▓	▓	▓	▓					▓	▓	▓	▓	▓	▓	▓	▓	▓	▓		
eous com- ents				▓			▓	▓		▓	▓			▓						▓		▓	▓	▓	▓		▓		
uds and		▓															▓										▓		
ETATION		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*		*	*		*	*	*	*	*	*	*	
iation'			▓				▓	▓		▓	▓			▓			▓			▓			▓		▓		▓	▓	
ionucli-																													
oufall, k		▓								▓	▓		▓			▓									▓				
oufall mistry		▓								▓	▓			▓	▓										▓				
mflow, k		▓								▓	▓			▓											▓				
mflow mistry		▓								▓	▓			▓											▓				
f/needle mistry					▓				▓	▓	▓	▓		▓											▓				

LOBAL TERRESTRIAL ECOSYSTEM MONITORING SITES REVIEW — Form 3
Region : North America — Sheet 2.1
Subject: Monitoring Activities

ype of ob- ervation	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
itterfall hemistry			■	■		■			■	■	■	■			■									■	■				
eavy metals n epigeal osses																													
eavy metals n epiphytic ichens																													
aseous luxes from cosystem					■				■	■			■	■										■	■			■	
piphytic ichenoflora												■	■															■	
pigeal egetation				■	■							■			■	■	■		■									■	
rees			■	■		■	■	■	■	■		■	■			■								■	■	■			
igher plant henology			■	■	■	■	■	■			■		■	■	■		■			■		■	■	■	■		■	■	
lant patho- ogy					■				■																			■	
et primary roduction					■						■			■	■									■	■	■		■	
ecomposi- ion rate of ead organic atter			■						■		■		■	■	■									■	■	■			
OIL	*	*	*	*	*					*	*	*	*	*			*					*		*	*			*	
oil tempe- ature	■	■	■	■	■					■		■	■	■								■		■	■			■	
H				■	■					■		■	■	■			■							■	■			■	
hemical ompounds, -10 cm ayer			■	■	■					■	■	■		■			■							■	■			■	

ɪAL TERRESTRIAL ECOSYSTEM MONITORING SITES REVIEW — Form 3
Region : North America — Sheet 3.1
Subject: Monitoring Activities

Type of observation	Site number 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
Chemical compounds, below 10 cm layer			▓									▓		░			░							░	░			░	
Radionuclides																													
WATER	*	*				*					*	*	*	*		*	*	*	*			*		*	*	*		*	
Water temperature	▓	▓										▓	░					░	░						░	▓		▓	
Water budget	▓	▓									▓	▓							░			░		▓	░				
Surface water chemistry	▓	▓				░					░	▓	▓	▓		▓	░	░	░					▓	░	▓			
Surface water biology	░					░					▓		░			▓	░	░	▓						░				
Radionuclides																													

' Solar radiation and biologically caused radiation

Legend:

▓ - at least one parameter under the item is being monitored regularly, data storage facility is known and data are available on request

░ -at least one parameter under the item is measured, but some gaps in time series or/and in data storage attributes exist or/and there are restrictions in data availability on request

* - (for major items-SURFACE AIR, VEGETATION, SOIL, WATER)
at least one type of observations under the item is active

.OBAL TERRESTRIAL ECOSYSTEM MONITORING SITES REVIEW Form 3

Region : Europe Sheet 1.1
Subject: Monitoring Activities

Type of observation	Site number																												
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
SURFACE AIR	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*		*									
Air temperature	▒	▒	▒	▒	▒	▒	▒	▒		▒	▒	▒	▒	▒	▒		▒	▒		▒									
Albedo, above canopy																													
Ultroviolet rad.-B																													
Radionuclides																													
Precipitation, bulk	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒		▒	▒		▒									
Precipitation chemistry	▒	▒	▒	▒	▒	▒		▒	▒	▒	▒		▒	▒	▒	▒	▒	▒		▒									
Gaseous components	▒	▒	▒	▒	▒			▒	▒	▒	▒		▒	▒			▒			▒									
Clouds and fog										▒																			
VEGETATION	*	*	*	*		*	*	*		*			*	*	*	*	*	*	*	*									
Radiation'								▒		▒																			
Radionuclides																													
Throufall, bulk						▒		▒		▒				▒	▒	▒	▒	▒											
Throufall chemistry						▒		▒		▒				▒	▒	▒	▒	▒											
Stemflow, bulk										▒																			
Stemflow chemistry										▒								▒											
Leaf/needle chemistry	▒	▒	▒	▒				▒		▒				▒					▒	▒									

'Solar radiation and biologically caused radiation

GLOBAL TERRESTRIAL ECOSYSTEM MONITORING SITES REVIEW Form 3

Region : Europe Sheet 2.1
Subject: Monitoring Activities

Type of observation	Site number																												
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
Litterfall chemistry										■				■	■		■												
Heavy metals in epigeal mosses		■		■				■		■			■	■	■		■	■	■										
Heavy metals in epiphytic lichens														■															
Gaseous fluxes from ecosystem										■																			
Epiphytic lichenoflora	■	■	■			■		■		■				■	■		■	■	■										
Epigeal vegetation						■				■				■	■		■	■	■										
Trees						■	■	■		■			■	■	■		■	■	■										
Higher plant phenology								■																					
Plant pathology								■		■				■	■		■	■	■										
Net primary production														■															
Decomposition rate of dead organic matter										■				■	■		■												
SOIL	*	*	*	*			*	*		*			*	*	*	*	*	*	*	*									
Soil temperature							■	■		■								■											
PH								■		■				■	■		■												
Chemical compounds, 0-10 cm layer	■	■	■	■				■		■			■	■	■	■	■	■	■	■									

GLOBAL TERRESTRIAL ECOSYSTEM MONITORING SITES REVIEW Form 3

Region : Europe Sheet 3.1
Subject: Monitoring Activities

Type of observation	Site number 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
Chemical compounds, below 10 cm layer	░	░	░	░				▓		░			▓	▓	▓	░	▓	░	▓	░									
Radionuclides																													
WATER	*	*	*	*				*		*				*	*	*	*	*		*									
Water temperature								▓		▓				▓		░		░											
Water budget								▓		▓					▓		▓	░											
Surface water chemistry	░	░	░	░				▓		▓				▓	▓		▓	░		░									
Surface water biology										▓				▓	▓	░	▓												
Radionuclides																													

Legend:

▓ - at least one parameter under the item is being monitored regularly, data storage facility is known and data are available on request

░ -at least one parameter under the item is measured, but some gaps in time series or/and in data storage attributes exist or/and there are restrictions in data availability on request

* - (for major items-SURFACE AIR, VEGETATION, SOIL, WATER) at least one type of observations under the item is active

AL TERRESTRIAL ECOSYSTEM MONITORING SITES REVIEW — Form 3

Region : Asia — Sheet 1.1
Subject: Monitoring Activities

Type of observation	Site number																												
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
SURFACE AIR	*	*	*	*	*																								
Air temperature	▒	▒	▒	▒	▒																								
Albedo, above canopy																													
Ultroviolet rad.-B																													
Radionuclides																													
Precipitation, bulk	▒	▒	▒	▒	▒																								
Precipitation chemistry	▒	▒	▒	▒	▒																								
Gaseous components	▒	▒	▒	▒	▒																								
Clouds and fog																													
VEGETATION	*	*	*	*	*																								
Radiation'																													
Radionuclides																													
Throufall, bulk																													
Throufall chemistry																													
Stemflow, bulk																													
Stemflow chemistry																													
Leaf/needle chemistry		▒	▒		▒																								

'Solar radiation and biologically caused radiation

GLOBAL TERRESTRIAL ECOSYSTEM MONITORING SITES REVIEW Form 3

Region : Asia Sheet 2.1
Subject: Monitoring Activities

Type of observation	Site number																												
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
Litterfall chemistry																													
Heavy metals in epigeal mosses																													
Heavy metals in epiphytic lichens																													
Gaseous fluxes from ecosystem																													
Epiphytic lichenoflora																													
Epigeal vegetation																													
Trees																													
Higher plant phenology																													
Plant pathology																													
Net primary production																													
Decomposition rate of dead organic matter																													
SOIL	*	*	*	*	*																								
Soil temperature																													
PH																													
Chemical compounds, 0-10 cm layer																													

GLOBAL TERRESTRIAL ECOSYSTEM MONITORING SITES REVIEW Form 3

Region : Asia Sheet 3.1
Subject: Monitoring Activities

Type of observation	Site number																												
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
Chemical compounds, below 10 cm layer																													
Radionuclides																													
WATER	*	*	*		*																								
Water temperature																													
Water budget																													
Surface water chemistry																													
Surface water biology																													
Radionuclides																													

Legend:

- at least one parameter under the item is being monitored regularly, data storage facility is known and data are available on request

-at least one parameter under the item is measured, but some gaps in time series or/and in data storage attributes exist or/and there are restrictions in data availability on request

* - (for major items-SURFACE AIR, VEGETATION, SOIL, WATER)
at least one type of observations under the item is active

The observational programmes carried out at the monitoring sites are not of a constant character. New variables are incorporated once their importance becomes generally accepted or even probable.

SUMMARY

The observations at the monitoring sites under consideration are carried out on a permanent basis. They concern various media: surface air, vegetation, soil and water. Important types of environmental variables (pollution-related, climate-related and radiation-related) are being monitored to some extent in North America, Europe and Asia.

The observational activities being implemented in North America are similar to the European and Asian activities but some differences exist. Heavy metals monitoring and "Lichenoflora" observations are advanced in Europe, but less developed in North America. "Albedo, above canopy", "Ultraviolet-B", "Clouds and fog" (ie pH of, and S & N deposition by, clouds and fog), "Radiation" (ie solar radiation and biologically caused radiation), "Gaseous fluxes from ecosystems" are widely monitored in North America and poorly monitored in Europe, Asia and South America. However, inspite of these differences, the observational programmes being implemented at GTEM sites under consideration are unified to a certain extent.

Thus, the ongoing activities at the GTEM sites could render them suitable (<u>after appropriate selection</u>) to act as the core of a global terrestrial ecosystem monitoring network to monitor global anthropogenic impacts and terrestrial ecosystem responses.

Ecological Observations

Selection of climate-related environmental variables from a set of the variables listed in GTEM Sites Database Questionnaire was carried out (see column "Type of observation", Form 4). Since a generally accepted definition of a climate-related variable has not yet been worked out, the "common-sense approach" was used. The following types of observations have been selected:

1 Variables characterizing the primary man-made impact on the climate system, namely greenhouse gases (GHG) concentrations: CO_2, methane and O_3.

2 Variables characterizing the climate change impact on terrestrial ecosystems - "Surface air temperatures", "Precipitation", "Soil temperature", "Water temperature", "Water budget".

3 Variables that may characterize terrestrial ecosystem response to climate change - "Higher plant phenology" (ie higher plants phenological dates), "Tree radial growth", "Needle loss (for coniferous)", "Net primary production" and "Decomposition of dead organic matter" (for terrestrial and freshwater ecosystems), "Bioindicators (epiphytic lichens)".

4 Variables that characterize a secondary influence (by feedbacks) on climate: CO_2 and methane flows from terrestrial ecosystems to the atmosphere.

The above variables, arranged by media (surface air, vegetation, soil, water), are presented in form 4.

North America

"Air temperature", "Precipitation", "Soil temperature", "Higher plant phenology" and "Tree radial growth" are measured at thirteen to twenty-seven sites of the total twenty-eight sites in North America.

The key ecosystem processes - primary productivity and decomposition of dead organic matter, are measured at eight to nine sites of the total twenty-eight. Bioindicators (epiphytic lichens) are poorly monitored (at three sites only). Water variables are measured relatively often. The vegetation items, "Decomposition of dead organic matter" and "Needleloss (for coniferous)" are, however, monitored at one site only.

CO_2, methane and O_3 concentrations, as well as CO_2 and methane fluxes from ecosystems to the atmosphere, are measured at three to seven sites. Thus it is encouraging that the nucleus of this important (but very difficult) flux measurement exists.

GLOBAL TERRESTRIAL ECOSYTEM MONITORING SITES REVIEW Form 4

Region: North America Sheet 1
Subject: Climate-related observations

Type of observation	Site number																												
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
SURFACE AIR	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
Air temperature	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒		▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	
Precipitation, bulk	▒	▒	▒	▒	▒	▒			▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒		▒			▒	▒	▒		▒	
Concentrations:																													
CO2										▒														▒	▒				
Methane										▒				▒										▒					
O3							▒			▒	▒											▒	▒		▒		▒		
VEGETATION			*	*	*	*	*	*	*	*	*	*	*	*	*	*	*					*	*	*	*	*	*	*	
Gaseous fluxes (from ecosystem to the atmosphere):																													
CO2					▒				▒	▒			▒											▒	▒			▒	
Methane					▒				▒					▒											▒				
Higher plant phenology			▒	▒	▒	▒	▒	▒			▒		▒	▒	▒		▒					▒	▒	▒	▒		▒	▒	
Tree radial growth			▒	▒		▒	▒		▒	▒	▒	▒	▒			▒							▒	▒	▒	▒			
Needle loss (for conifers)																												▒	
Net primary production					▒						▒			▒	▒									▒	▒	▒		▒	

GLOBAL TERRESTRIAL ECOSYSTEM MONITORING SITES REVIEW Form 4

Region : North America Sheet 2
Subject: Climate-related observations

Type of observation	Site number																												
	1		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
Decomposition of dead organic matter			░						░		░		░	░	░									░	░	░			
Biondicators (epiphytic lichens)												░	░															▓	
SOIL	*	*	*	*	*					*		*	*	*								*		*	*			*	
Soil temperature	▓	▓	▓	▓	▓					░		▓	▓	▓								░		▓	░			░	
WATER	*	*									*	*	*					*	*			*		*	*	*		*	
Water temperature	▓	▓										▓	░					░	░						░	▓			
Water budget	▓	▓									▓	▓							░			░		▓	░			▓	
Net primary production	▓										▓							░	▓						░				
Decomposition of dead organic matter											▓		░																

Legend:

▓ - at least one parameter under the item is being monitored regularly, data storage facility is known and data are available on request

░ -at least one parameter under the item is measured, but some gaps in time series or/and in data storage attributes exist or/and there are restrictions in data availability on request

* - (for major items-SURFACE AIR, VEGETATION, SOIL, WATER) at least one type of observations under the item is active

GLOBAL TERRESTRIAL ECOSYSTEM MONITORING SITES REVIEW   Form 4

Region: Europe   Sheet 1
Subject: Climate-related observations

Type of observation	Site number																												
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
SURFACE AIR	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*		*	*		*									
Air temperature	▒	▒	▒	▒	▒	▒	▒	▒		▒	▒	▒	▒	▒	▒		▒	▒		▒									
Precipitation, bulk	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒		▒	▒	▒		▒	▒		▒									
Concentrations:																													
CO2									▒			▒																	
Methane																													
O3		▒						▒	▒			▒																	
VEGETATION						*	*	*		*				*	*		*	*	*										
Gaseous fluxes (from ecosystem to the atmosphere):																													
CO2																													
Methane										▒																			
Higher plant phenology								▒																					
Tree radial growth						▒	▒	▒		▒				▒	▒		▒	▒	▒										
Needle loss (for conifers)								▒		▒				▒	▒		▒		▒										
Net primary production														▒															

GLOBAL TERRESTRIAL ECOSYSTEM MONITORING SITES REVIEW — Form 4

Region : Europe — Sheet 2

Subject: Climate-related observations

Type of observation	Site number																												
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
Decomposition of dead organic matter										▓				░	▓		▓												
Biondicators (epiphytic lichens)						░		▓		░				░	▓		▓	░	▓										
SOIL							*	*		*								*											
Soil temperature							▓	▓		░								░											
WATER								*		*				*	*	*	*	*											
Water temperature								▓		▓				▓		░		░											
Water budget								░		▓					▓		▓	░											
Net primary production										▓				░															
Decomposition of dead organic matter										░																			

Legend:

▓ - at least one parameter under the item is being monitored regularly, data storage facility is known and data are available on request

░ -at least one parameter under the item is measured, but some gaps in time series or/and in data storage attributes exist or/and there are restrictions in data availability on request

* - (for major items-SURFACE AIR, VEGETATION, SOIL, WATER) at least one type of observations under the item is active

GLOBAL TERRESTRIAL ECOSYSTEM MONITORING SITES REVIEW Form 4

Region: Asia Sheet 1
Subject: Climate-related observations

Type of observation	Site number																												
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
SURFACE AIR	*	*	*	*	*																								
Air temperature																													
Precipitation, bulk																													
Concentrations:																													
CO2																													
Methane																													
O3																													
VEGETATION	*	*	*	*	*																								
Gaseous fluxes (from ecosystem to the atmosphere):																													
CO2																													
Methane																													
Higher plant phenology																													
Tree radial growth																													
Needle loss (for conifers)																													
Net primary production																													

GLOBAL TERRESTRIAL ECOSYSTEM MONIOTRING SITES REVIEW — Form 4

Region : Asia — Sheet 2

Subject: Climate-related observations

Type of observation	Site number																												
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
Decomposition of dead organic matter																													
Biondicators (epiphytic lichens)	▓	▓	▓	▓	▓																								
SOIL																													
Soil temperature																													
WATER																													
Water temperature																													
Water budget																													
Net primary production																													
Decomposition of dead organic matter																													

Legend:

▓ - at least one parameter under the item is being monitored regularly, data storage facility is known and data are available on request

░ -at least one parameter under the item is measured, but some gaps in time series or/and in data storage attributes exist or/and there are restrictions in data availability on request

* - (for major items-SURFACE AIR, VEGETATION, SOIL, WATER) at least one type of observations under the item is active

Europe

"Air temperature", "Precipitation" and "Tree radial growth" are measured often (nine to seventeen monitoring sites of the total twenty), which is quite similar to the situation in North America. However, "Net primary production" (terrestrial) and "Higher plant phenology" are monitored at one site each only. "Needle loss (for coniferous)" and "Bioindicators (epiphytic lichens)" are measured widely (at six to eight sites) as compared with the situation in North America.

CO_2 and methane (either concentrations or fluxes) are very rarely measured ; O_3 is monitored at four sites.

"Water temperature" and "Water budget" are under study at five sites of the total twenty. This is similar to the occurrence of these observations in North America.

Asia

"Air temperature" and "Precipitation" are measured in all five sites; epiphytic lichens are under study at four sites. Other variables in the list (Form 4) are not monitored.

SUMMARY

The review of climate-related observations being carried out at GTEM sites shows that traditional variables (temperature of air, soil and water; tree radial growth) as well as "greenhouse effect-related" variables (ozone; CO_2 and methane concentrations and fluxes from ecosystems to the atmosphere) are measured to a certain extent in North America and in Europe. The key environmental processes (net primary productivity, decomposition of dead organic matter) and bioindicators (epiphytic lichens) which might be affected by climate change, are also monitored at some sites but implemented to a different extent in North America and Europe. The climate-related variables at Asian sites are very poorly monitored.

Thus, the existing climate-related observational activities at the GTEM sites under consideration in Europe and in North America could serve as a nucleus of a full-scale climate-related monitoring subprogramme. As far as Asian sites are concerned, the climate-related observations are to begin there.

OVERALL SUMMARY

GEMS/PAC-UNEP has recently undertaken a review of (potential) Global Terrestrial Ecosystem Monitoring (GTEM) sites. Data from individual sites is gathered by means of a special questionnaire and stored in an environmental database (the GTEM Sites Database). The following working definition of a GTEM site was used:

GTEM site = ecological reference area with a co-located monitoring station, where biological observations as well as multimedia chemical and physical measurements are implemented in an integrated manner on a long-term basis with the purpose of assessing human impact on natural and managed ecosystems.

The GTEM Sites Database Questionnaire consists of three parts - "Administrative Information", "Basic Environmental Information" and "Observational Programme Implemented at the GTEM site". The Observational Programme requests information on observations related to pollution of environment, climate change, radiation (solar and biologically caused) and the potential ecological consequences. Fifty-four responses have been received. The results of the analysis are outlined below.

The GTEM sites are operated by national governmental or non-governmental agencies/organizations.

Observational activities at GTEM sites are implemented by a local staff of environmentalists and/or by a collaborating scientific institution. These activities are sponsored in the majority of the cases by host countries through governmental and/or non-governmental funds. International support is also occasionally received.

The monitoring activities at the GTEM sites are, in many cases, coordinated by leading national or international environmental agencies/organizations (UNESCO, WMO, UN-ECE, UNEP etc). Many GTEM sites participate in several networks.

The monitoring data obtained at the GTEM sites are most often stored in national data storage facilities (at the supervising scientific institution etc), but international data centres are also used.

Thus, the monitoring data are available and currently being used for the assessments of the state of the environment and its anthropogenic changes.

The spatial distribution of fifty-four GTEM sites (information held in the GTEM Sites Database) is significantly uneven. North America and Europe are represented satisfactorily; however some gaps exist. Asia and South America are poorly covered . Some important specific areas of the Northern Hemisphere (eg permafrost areas) are insufficiently represented. The altitudinal distribution characterizes North America and Europe satisfactorily but is not sufficient for Asia and South America.

Consequently, to provide an adequate basis for the Global Terrestrial Ecosystem Monitoring Network the essential geographical expansion of terrestrial ecosystem monitoring activities is clearly required.

Since the response of terrestrial ecosystems to equal abiotic impacts (loads) can vary widely due to the particular characteristics of the site, the proposed GTEM Network should be representative, at least of the major World Biomes. The analysis of GTEM sites distribution by World Biomes shows that the majority of occurring biomes are represented by GTEM sites in North America and in Europe. However, four of the twelve North American biomes, two of the seven European biomes, and only four of the eleven Asian biomes are represented. Only one of the nine South American biomes is represented in South America. Some biomes (eg "Temperate Broadleaf Forests or Woodlands and Sub-Polar Deciduous Thickets" in North America and in Europe, and "Temperate Needleleaf Forests or Woodlands" in North America) are over-represented. Many sites are situated near the boundary of two biomes which may be useful for climate-related monitoring.

The observations at the monitoring sites under consideration are carried out on a permanent basis. They concern various media: surface air, vegetation, soil and water. The important types of environmental variables (pollution-related, climate-related and radiation-related) are being monitored to some extent in North America, Europe and Asia.

The observational activities being implemented in North America are similar to the European and Asian activities but some differences exist. Heavy metals monitoring and "Lichenoflora" observations are advanced in Europe, but less developed in North America. "Albedo, above canopy", "Ultraviolet-B", "Clouds and fog" (ie pH of and S & N deposition by clouds and fog), "Radiation" (ie solar radiation and biologically caused radiation), "Gaseous fluxes from ecosystems" are widely monitored in North America and poorly monitored in Europe,Asia and South America. However, inspite of these differences, the observational programmes being implemented at GTEM sites under consideration are comparable to a certain extent.

Thus, the ongoing activities at GTEM sites could render them suitable (after appropriate selection) to act as the core of a global integrated monitoring network to monitor global anthropogenic impacts and terrestrial ecosystem responses.

The review of climate-related observations being carried out at GTEM sites shows that traditional variables (temperature of air, soil and water, tree radial growth), as well as "greenhouse effect-related" variables (ozone; CO_2 and methane concentrations and fluxes from ecosystems to the atmosphere), are measured to a certain extent in North America and in Europe. The key environmental processes (net primary productivity, decomposition of dead organic matter) and bioindicators (epiphytic lichens) which may be affected by climate change, are also monitored at some sites but implemented to a different extent in North America and Europe. The climate-related variables at Asian sites are very poorly monitored.

Thus, the existing climate-related observational activity at GTEM sites under consideration in Europe and in North America can serve as a nucleus of a full-scale climate-related monitoring subprogramme. As far as Asian and South American sites are concerned, the climate-related observations are to begin there.

RECOMMENDATIONS ON THE ASSESSMENT OF HIGH AND MIDDLE LATITUDE ECOSYSTEM REACTION TO THE GLOBAL CLIMATE CHANGE (vegetation, permafrost)

General Methodological Approaches

Among the important consequences of climate changes due to the green house effect expected by the end of the 20th and in the 21st century, reaction of natural ecosystems to these changes should be mentioned. Acuteness of this reaction will depend on the amplitude and the type of climate transformations in a certain region. Climatic scenarios testify that significant qualitative transformations should be expect in particular in the easily disturbed ecosystems such as desert, semi desert, tundra.

With the help of complex researches (see YPCC issue "Climate change", 1990, "Prospects of changing climate," USA, 1991,"Anthropogenic climate change", USSR, 1987, etc.) by the present time a series of global, subglobal, and regional scenarios of climate state under the condition of the increase of the average global temperature by 1° (the beginning of the 21st century), by 2° (the first half of the 21st century)(basing mainly on palaeogeographical data), and by 3-4° (basing mainly on numerical simulation, and also on palaeogeographical data), has been worked out. Till recently it was considered that doubling of CO_2 in the atmosphere causes increase of the average global temperature by 3-4° and more. However, recent results testify to the lower warming.

In any case, taking into account the succession and supposed dates of the average global temperature increase, study of the ecosystem reactions at the initial and middle levels of the average global temperature increase, should be recommended.

It is worth noting, that all climatic scenarios (obtained both from the method of numerical simulation and from the method of palaeo-analogues) show that most significant changes of hydrothermal regime, first of all, temperature increase, will occur in the high latitudes and partly in the middle latitudes including northern part of the temperate forest belt and tundra ecosystems. In this connection, the recommendations consider, first of all, the problems of the ecosyste reaction in the regions mentioned. Two leading components: vegetatio and permafrost are the main points. However, it is also necessary to analyse the reaction of other components: soil, geomorphological processes, animal population, etc.

In its general way the analysis of ecosystem reaction should be made in two main fields:

1) study of trends and changes in the present conformity (structu of the ecosystem components; revealing of the parameters controlled the global climate change; this result may be obtained by a system o comprehensive monitoring.

2) reconstruction of spatial scenarios of the status of ecosystem components and the ecosystems as a whole under the expected new leve of hydrothermal regime. Such scenarios can be obtained both fro numerical simulation and from models – analogues. Non of these two types models can substitute for the other. Numerical models are based on the know patterns of functioning of an ecosystem or its components, but they can hardly be controlled. While the scenarios obtained with the help of palaeo/geographical analogues make it possible to reveal the real situations (dislocation of zones, state of formations), which occurr in the past under the levels of hydrothermal regime similar to the regimes expected in the future.

Obviously, more realistic scenarios may be worked out on the ba of the synthesis of the models of both types: numerical simulation and palaeoreconstructions.

These scenarios should be based on the two classes of models: a) balanced models, and b) unbalanced models.

Balanced models simulate the situations which correspond to the conditions, when an ecosystem has reached quasi-equilibrium with the actual hydrothermal regime. Such models provide the possibility to assess maximum possible changes, i.e. to assess as it were a gene result to which the transformation of the ecosystem will go. However to reach this result, a long time period, no shorter than several centures, is required. Realization of these models does not correspo to the extremely close dates of expected climate changes due to the green house effect (several tens of years).

Unbalanced models are aimed to assess the state of an ecosyste taking into account real time interval of the hydrothermal regime change. This class of models contains a variety of rates of possil reactions for different ecosystem components, takes into account the inertia mechanizms, dynamics of interaction of different eleme of the system, including, from one side, the role of introduced species and, from the other side, the role of loss of certain elem which can not survive under the new regime. Even the first researc have shown that mankind is going to face new ecosystem types as th transformation of different components will occur with different r i.e. asynchronously.

Finally, in perspective it is necessary to provide realizatio of the task of continuous correction of the ecosystem under transf mation due to unstable hydrothermal regime under the conditions of successive increase of the average global temperature.

Further on, as the first stage of the general methodological approaches, the main aspects of the high latitude and middle latitu system reaction are considered for two components: vegetation and permafrost.

Vegetation

1. Monitoring

For the purpose of revealing vegetation successions caused by the predicted climate warming there are the following informative indices:

- loss or decrease in frequency with certain plant species, first of all, with the components of zonal plant formation
- increase in frequency with certain plant species;
- change in the rythm of flowering and fruiting, in the number o sprouts;
- introduction of pioneer species and anthropophytes into the natural coenosis;
- introduction of immigrants into the natural coenosis;
- change in the rythm of recurrency of epidemic diseases, fungous diseases and attacks of insects-vermins;
- change in the frequency of arboreous species drying up periods in those regions where this phenomenon reours with regular interval

In order to reveal the trend of the climatogenic plant succession it is necessary to fix both plant species for which any of the indic have been revealed, and belonging of these species to certain eco-coenotic groups. Monitoring program should be long-term, as the abov mentioned indices require different periods of time to be revealed: from a few years to the period equal to life duration of 2 or 3 generations of the species. It should be also taken into account that we do not know now the rate of the predicted climate changes ‹ vegetation successions caused by them.

II. Assessment of Vegetation Cover Changes Caused by the Coming Climate Changes. Spatial scenarios and models.

Assessment of the supposed vegetation changes in different reg: may be done in two ways: basing on numerical simulation (this appr‹ is being developed in detail by a number of researchers) and using palaeo — analogues. The latter method being rather effective in itself, may be also useful for verification of the numerical simulation results. The value of this method is that the obtained results show total impact of a combination of natural factors whicl determine character of vegetation cover and its geographical diffe1 tiation.

Researches made in the Laboratory of Evolutional Geography, Institute of Geography, R.A.S. allowed us to make the analysis of climate conditions attended by the analysis of vegetation status f‹ the ages corresponding to the increase of the average global tempe1 ture by 1°C (palaeo-analogue - Holocene optimum, 5.5 thou years ag‹ and by 2°C (palaeo-analogue - optimum of Mikulino-Eomian Interglaci 125 thou years ago). Reconstruction of vegetation in the Northern Hemisphere made by V.P.Grichuk /1992/ shows that in high and middl‹ latitudes arboreous species will find appropriate conditions far m‹ to the north than the actual boundaries of their natural habitats are located. In the European part of Russia they will be able to settle down as far as the Arctic Ocean coast, in the Asian part the potential boundary of taiga forest will advance by 4-5°N.L. (by 45C 550 km) to the north. Arboreous species typical for the oceanic cli regions will be able to advance to the east (in the east of Eur-asi to the west). Comparison of the maps of recostructed present veget‹ and vegetation of the Mikulino Interglacial optimum reveals the reg where the following changes are possible under the conditions of hydrothermal regime changes:

- replacements of vegetation type and displacement of zonal boundaries;
- replacements of vegetation formations and displacement of province boundaries;
- replacements of plants within a formation (change in ration of the main components, enrichment of floristic composition, complicat of coenosis structure, etc.).

Simultaneously, the territories where transformation of the present vegetation caused by the predicted warming will be insignif ant, are revealed. Under 1°C warming judging from the map of Holoce optimum vegetation compiled by N.A.Khotinsky /1984/ for the territc of the USSR. expected transformations of vegetation cover will be c coming warming should be considered as potentially possible, and not a really expected ones. They show equilibrium state of vegetation cov corresponding to the adopted levels of global warming. During Inter glacial ages climate changes occurred gradually, that caused long duration of both optimum (at least several centures) and pre-optimu (several millenniums) phases. Vegetation, despite the inertia typic for it, had the time to transform along with the changing climate, during the optimums it reached quasi-equilibrium with the climate. Reconstructions depicting this state of vegetation should be consid the balanced models of vegetation.

The predicted human induced climate changes will occur with th unnatural rate, which is a few tens of years. To make the assessmen of changes in the state of vegetation more realistic, a number of factors should be taken into account, which determine significant differences between the situation formed under the climatic changes and the situation which may be characterized by the balanced models In this connection unbalanced models were used which include the necessary data base on the rate of plant spreading, reaction of the existing vegetation, on the competition within local species and between local and immigrant species under the conditions of the cha: hydrothermal regime. Unbalanced simulation should be done on the regional scale.

Period of the expected vegetation transformation is about 10 years only before the beginning of the 21st century, when the incre: of the average global temperature is 1°C comparing with the recent values, and about 40 years till the 2030s, when it is 2°C. If we us the rates of arboreous species spreading in the first part of Holoc average 200-300 m/year, for pioneer species 500-1000 m/year (which should be considered as maximum), then we have to conclude that during this period dislocation of the plant natural area boundaries wil be no more than 5-10 km, and, consequently, there is no reason to expect significant dislocations of the zonal and regional boundarie:

Relations of the components of the existing communities under new conditions between each other and between them and possible

immigrants is determined by a combination of factors. These are th
main of them:

- ecological amplitude of the dominant species of the local zon
vegetation (i.e. whether the forming hydrothermal regime lays withi
the climatic natural habitat area of the species or not);

- competitive ability of the dominant species of zonal coenoses in comparison with the competitive ability of immigrants;

- location of possible immigrants;

- degree of agricultural development of the territory and natura vegetation cover disturbance.

Combination of the factors not only affects the rate of plant formation changes, but also will lead to the realization of differe variants of reconstruction of the vegetation composition and struct under the impact of the predicted warming.

1. The main dominant species of the zonal coenoses can not exist under new conditions and dissappear from the plant cover. Its place is taken by rapidly spreading pioneer species (in the forests of th Euroasia these are first of all birch and aspen). Later on they are likely to be replaced by the coenosis-forming immigrants with highe competitive ability.

2. One of the co-dominant species in the zonal plant formation can not exist under new conditions, its place is taken by more thermophyllous components of the same formation (eg., spruce-deciduous forests of the Eastern Europe).

3. New conditions satisfy local vegetation, but its competitive a is not high enough to stop intrusion of the immigrants with higher competitive ability. This variant includes, in particular, the processes of forest supplanting tundra and forest supplanting steppe.

We understand now the processes of the coming transformation of vegetation in a very general way. To deepen our understanding it see informative to study in detail vegetation successions during pre-optimum Interglacial and Holocene intervals.

III. Recommendations

1. For the purpose of monitoring it is reasonable to use the existing network of nature reserves, first of all, the ones located close to the global and regional boundaries and in the areas where significant transformations of the existing vegetation are probable.

2. It is necessary to develop further on spatial scenarios and models both on the base of numerical simulation (on the basis of the Palaeonthological Institute of R.A.S., Yassa, Godar Institute for

Space Studies), and on the base of palaeontologic analogues (incl field studies, analysis of vegetation of moderate and high latitu creation of data bank on the basis of the Laboratory of Evolution: Geography of the Institute of Geography, R.A.S.).

3. It is desirable to develop theoretical studies of the clima· genic successions and assessment of plants' reaction to rapid warı (including experimental studies).

Permafrost

Taking into account that permafrost is first of all a climatc phenomenon, prediction of the permafrost zone transformation cause the global (anthropogenic) climate warming at the end of the 20th in the 21st century, is one of the actual problems, which mankind going to face in the process of resources development and environı management within vast areas in high and middle latitudes.

Study of permafrost zone dynamics in the coming tens of years may be based on two approaches: first - empirical survey for the actual changes of the permafrost parameters (geocryological monito to reveal trends in its real development. Secondly, use of differe types of models.

I. Monitoring

The data on a number of regions in the Northern Eur-asia for last tens of years show warming of the upper permafrost layers dow: 10-15 m, increase in thickness of seasonally active layer, active intensification of cryogenic processes, melting of permafrost grou from the roof and from the bottom (Mel'nikov, Pavlov, Report on th National Program "Global changes of the environment and climate",1 Thus, for example, the depth of seasonally active layer during th last 10-15 years increased by 15-20 cm, thermal flows increased by 30-40%. Ground temperature in Yakutiya outside industrial areas and settlements increased during the last 30 years by 2°C. A new phenomenon is noted: within permafrost zone landslides, earthflows very gentle slopes with the triangles of only 2-3° have become very active. These processes are very intensive now in the Yamal Peninsu

II. Simulation

Simulation of the cryolithic zone status under global warming should base first of all on the scenarios of climatic situations expected in the future. For these purposes two types of models are supposed to be used: palaeogeographical and mathematical models allowing us to assess regional status of climate under the growing global warming by +1°; by +2°; by +3° and +4°. As it is known, analysis of the expected climatic changes has shown that neithe climatic nor permafrost temperature parameters will reach the le of the Pliocene optimum(+3 +4°C).

It is supposed to develop two classes of the models of cryc zone:

- balanced, when cryolithic zone reaches quasi-balanced relat with climate,
- and unbalanced.

The balanced models of the state of cryolithic zone for the palaeogeographical periods depict significant reduction of its a and changes in a number of its parameters in comparison with the modern state (Velichko, Klimanov, Nechaev, 1989). Development of variants depicting more adequately the predicted periods of chang which is 40-45 years for the global anthropogenic warming by 2°C taking into account palaeogeographical data, is based also on the empirical data on air and ground temperature changes in the 21st when a clear trend to warming was noted.

As an example, the results of preliminary assessments obtaine with the help of unbalanced models may be given. The following assessments of changes in the status of permafrost for the nearest tens of years may be made (Velichko, Nechaev, 1992).

Under the global warming by 1-2°C in the south of the perma zone within [illegible] years later under the average global anthropogenic warming by 2°C the ground temperature everywhere in the north of cryolithic zone (including its eastern segment) may increase by 3-4°C, while thickness of seasonally activ layer will increase by 40-50 cm comparing with the present.

Lowering of the roof of permafrost grounds and increase in t: temperature occurring everywhere within permafrost zone in the n areas of Eurasia, will intensify in the end of the 20th and the : quarter - one third of the 21st century the processes of soliflu thermokarst and thermoerosion, swamping, degradation of forests "permafrost" grounds. Even nowdays, while developing resources i northern regions, we must take into account these negative proce of the close future.

A more detailed spatial and temporal analysis of the unbala models of the permafrost zone status under global warming by +1° +2°C shows, that it is possible to define three groups of regions In the first group the potential warming may occur already in the nearest 15-20 years (North of Europe, Central Alaska, Far East). the second group (Western and Eastern Siberia, Canada) the warmin occus more or less evenly in the nearest four-five tens of years. lastly, in the third group (North-East of Asia, south of the East Siberia) significant changes in the status of permafrost will occ only in the first quarter - one third of the 21st century.

III. Recommendations

Monitoring

At present northern territories of Eurasia have a very spars network of basic scientific permafrost stations (6) making comple researches of the cryolithic zone for the last (2-7) tens of year The data obtained by them should be used to reveal real trends in permafrost zone development, which requires a more detailed netwo of the stations. For this purpose hydrometeostations along with me stations in the natural reserves and automatic stations, may be us Special attention should be given to the following:

1. Detailed survey of ground temperature changes at depth 10- (more careful during the first tens of years in the regions with t oceanic climate).

2. Detailed survey of seasonal melting dynamics in the contin permafrost zone at the absolute depth(of 0.5-1.5m); in the zone of discontinuous permafrost at depth 1.0-2.0 m; in the zone of sporadic permafrost at depth 1.5-3.0 m.

3. Some service to survey geomorphological processes and succession of plant communities should be organized in the permafr stations.

It is desirable to obtain the same data for different grounds (including peat grounds). The programs for permafrost stations activity mentioned above, should be developed by joint efforts of the Counsil for Earth Cryology R.A.S., Institute of Permafrost Stud Siberian Branch R.A.S., PNIIIS Gosstroy of Russian Federation, Moscow State University (Geological and Geographical departments)

Simulation

1. Development of the systems of regional mathematical simulat taking into account direct and back relations "climate-permafrost".

2. Creation of empirical data bank with the conduction of the necessary field and analythical works and computer programs to asse the state of cryogenic area in the past for different thermal level

a) period of instrumental survey,

b) phases of sharp short -term changes of climate (Dryas II - Allerod - Dryas III)

c) levels, corresponding to global warming by +1°C and +

3. Development of dynamic models of the cryolithic zone status under continuous rapid change (growth) of warmth supply (trend) and under sharp deformation of the trend.

Assessment of the Environmental Components Under the Transformation of Permafrost Zone

1) Regional analysis of the relief forming processes (thermokarst, thermoerosion, solifluction, creep, etc.)
2) Status of the forest and tundra communities under the increase of seasonally active layer, increase in humidity and swamping, and solifluction development.
3) Hydrological regime of river and lake systems under the dynamics of cryolithic zone.
4) Fodder resources and living conditions of animal population in cryolithic zone.

The "Recommendations" have been prepared by A.A.Velichko, E.M.Zelikson, V.P.Nechaev

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METHANE: MAJOR NATURAL AND ANTHROPOGENIC SOURCES, CONTENT IN THE ATMOSPHERE

F.YA.ROVINSKY, V.I.EGOROV

Introduction

Methane is one of the priority "green-house" gases having an important role in the atmospheric chemistry. Methane concentration variations in the atmosphere can influence the state of the ozone layer changing the velocity of its elementary reactions with atomic chlorine and hydroxile those participate in catalytic reactions of ozone destruction.

The noted increase in the methane content in the global atmosphere is about 1 per cent annually [1.2] that might result in the serious environmental effects linked with the Earth surface temperature increase by 0.3° comparing to the beginning of the century due to the "green-house" effect [3]. The rate of the global temperature growing following the methane content increase is about 15 per cent of the similar effect of carbon dioxide in the atmosphere over the same time period.

Observed methane concentration increase in the atmosphere on the global scale makes it necessary to analyze thoroughly the data on its anthropogenic and natural sources and spatio-temporal distribution of methane in the atmosphere. This information is expedient for the prognosis of methane content in the atmosphere and its environmental impacts. The results of the analysis and prognosis should be the basis for the international community to take the measures necessary for diminishing and preventing the adverse environmental impacts.

Natural and anthropogenic sources of methane emission to the atmosphere

The major sources of methane to the atmosphere are located at the Earth surface in inner layers. The percentage of the global methane emission from the surface of oceans, seas, fresh water bodies does not exceed 2-3 per cent of its total emission.

The major methane emission sources are as follows: wetlands surface emission (tundra, bogs, irrigated territories) due to the microbiological decomposition of organic matter under anaerobic conditions; fermentation processes in food chains of pasture grazing mammals and microbiological decomposition of their wastes; biomass and fossil fuel combustion; methane losses while extracting fossil fuel and methane transportation to industrial centres.

The data available on the magnitude of methane fluxes to the atmosphere vary greatly. According to the data given in literature the overall annual methane emission could be from 269 up to 765 Tg (1 Tg = 10^{12} g) [2,4,5]. The most uncertain estimates are linked with such sources as wetlands, animal living processes, biomass combustion, and termite living processes.

The major methane sources and their power assessments are given in Table 1 [2,6].

Table 1. Methane emission to the atmosphere from natural and anthropogenic sources, in Tg/year

Source	Available assessment range	Recommended assessment of emissions
plains)	11-300	110 [2,6]
Rice plantations	60-170	110 [2,6]
Cattle living processes	70-120	76 [2,6]
Biomass combustion	50-100	55 [2,6]
Termite living processes	10-100	40 [2,6]
Organic matter decomposition in soil, including solid wastes	30-70	40 [2,6]
Coal mining	25-45	35 [2,6]
Drilling and exploitation of oil and gas deposits, natural gas transportation losses	25-50	45 [2,6]
Oceans	5-20	10 [2,6]
Fresh water bodies	1-25	5 [2,6]
Methane hydrates destabilization	0-130	5 [2,6]
Total:	345-1000	531

The data given in the table should be considered as the lower limit of the methane emission to the atmosphere as the methane content is currently increasing. The observed methane content increase (0.9±0.1)% corresponds to the rise of methane flux to the atmosphere or to the reduction of its sink by a figure of 32-48 Tg annually, assuming that the total methane content in the atmosphere equals to $4 \cdot 10^{15}$ g [5] or $4.8 \cdot 10^{15}$ g [7].

It should be noted that there is no at present data explaining the true reason of methane concentration increase in the atmosphere. That is why the explanation of the effect observed exclusively by the annual methane flux increase to the atmosphere is not adequate. Among the factors influencing the quasistationary methane concentration level in the air are its major sinks from the atmosphere, including its interaction with hydroxile [8], soil absorption [9] and methane oxidation by the soil bacteria [10]. One of the reasons of methane concentration increase in the atmosphere could be the decrease of hydroxile content in the atmosphere due to its reactions with carbon monoxide, as carbon monoxide content in the global atmosphere increases over the last twenty years.

The rise of the methane content in the atmosphere on the global scale could be evidently explained both by the increase of its flux to the atmosphere (first of all of the anthropogenic origin) and by the decrease of its sink from the atmosphere. The preliminary estimate shows the effect of the last factor to be about 30 %, but the emission increase gives about 70 % of methane surplus in the atmosphere [8].

The question of determining of the most important sources/sinks of methane resulting in its growth in the atmosphere is one of the key items of prognosis of the degree of "green-house" effect and its environmental effects. This question need to be examined thoroughly.

The methods and results of the major methane source magnitude assessment.

The methane emission to the atmosphere from the surface of wetlands is an important methane source on the global scale, but the uncertainty in the presently known values of it should be mentioned (from 11 up to 300 Tg/yr) [2,4,7,9,11,12]. The data of field measurements of methane emission from the area unit of wetlands using the special cameras are usually used while making assessments of methane flux from the source mentioned. The emission calculations are done following methane measurements and its temporal variability in a camera where methane enters from the surface through an opened camera side with an area of 1 to several m^2. The relative methane emission can be also determined according to its vertical gradients measured from the gradient towers, aircraft laboratories or other mobile platforms (tied or free moving balloons) equipped with sampling (flasks) or analytical instruments. The value of the global methane emission from the source given could be obtained by multiplying the relative methane emission by the area under wetlands. The assessment uncertainty of this value is primarily determined by the considerable dependance of the relative methane emission on the dominating ecosystem type representing the territory, on soil temperature, humidity and acidity, on ground water level, on soil organic matter [12,13,14].

Variability of the above factors influencing the methane flux from the surface, results in different values of relative methane emission. Thus, relative methane emission from the wetlands surface unit can vary from 0.001 to 0.25 g of methane per square meter per day [15,16].

The more detailed inventory of territories according to the ecosystem type and more precise assessment of areas under them over the Earth are necessary for more accurate calculations of global methane emission from wetlands.

The development of field observations of relative methane emission under different conditions in various natural climatic zones using methane gradient observations near the earth surface and using cameras as well is very important. It is expedient to realize the above procedures within the framework of ad-hoc international projects as they are relatively expensive.

The inclusion of systematic observations of methane fluxes from surface ecosystems in the programme of monitoring stations does not seem reasonable. The periodical field experiments with participation of highly qualified specialist using high precision instruments in territories representative for terrestrial ecosystems is recommended. Those studies should be accompanied by hydrometeorological measurements, analyses of soil hydrochemical composition and its microflora.

In future, assuming the global climate warming the methane emission from wetlands can increase mainly in tundra zone where permafrost melting, surface soil temperature and humidity increase will result in higher microbiological activity and higher methane emission to the atmosphere.

The necessity in development of research work in the regions of tropical and sub-tropical bogs where information is insufficient at present for assessment of their input to the global methane emission should be recognized as an important field of study on global methane emission assessment;

According to preliminary assessments the major input to the global methane emission (60%) is given by wetlands located in the latitudes from 50° to 70°. The input of tropical and subtropical bogs located in the latitudes from 20° to 30° forms not less than 25%.

The methane emission from rice paddies surface is also an important methane source on the global scale that could be compared to wetlands emission. The assessments of methane emission from rice paddies were done on the basis of field measurements data, methane relative emission calculations and inventory of the territories under rice plants [16,17,18]. The range of methane emission from the above source is of 60-170 Tg. The uncertainty of this value results considerably from the uncertainty of relative methane emission measurements. The considerable variations of the relative emission depend in its turn on the environmental factors including soil bacteria species, type of soil, water use features, soil humidity and temperature, fertilizers use [19].

The recommended value of the annual global methane emission is 110 Tg.

Having in mind the urgency of the food problem for increasing population it is very likely to find in the nearest future the enlarged rice paddies and increased methane emission to the atmosphere.

The considerable methane source on the global scale is cattle and wild animals living activity. The assessments available give the values from 70 to 220 Tg [11,20,21]. The uncertainty of the global emission results from the uncertainty of the data on animal quantity and species and on vegetation taken as nutrition by them; on methane amount formed as a result of living activity of various animal species.

Methane production by living processes of animals is the result of fermentation processes of hydrocarbons in food products and also of food wastes oxidation. This value of relative emission can be determined by calculations based on energy balance of an animal and energy resources of the consumed food. Thus, emission value is determined by the rate of fermentation processes and food wastes oxidation, food calory balance, living conditions of an animal, its weight and age and varies widely. For example, annual methane production of a milk cow in Germany is about 95 kg, in the USA - 84 kg, in India - 35 kg [21]. As for sheep annual relative emission of methane varies from 5 to 8 kg and for pigs - from 1 to 5 kg.

Assumed value of global methane emission due to living processes of cattle and wild animals equals 76 Tg and is received from the most precise FAO data on animal population and distribution in the World with high spatial resolution (1° x 1°). In that case the error of the global emission assessment is less than 15% [21].

The necessity of work to be done for improvement of the methods for calculations of relative methane emission from selected animal species should be mentioned along with verification of the calculated data by the results of field measurements in the regions of intensive cattle breeding and in places of cattle keeping.

The global spatial distribution of animal methane sources is considerably inhomogeneous. Territories characterized by the highest methane emission values corresponds to the most populated regions of the planet (Indostan Peninsula, Southern and Eastern China, USA, Russia, Ukraine, Kazakhstan, Brazil, Central Europe). On the whole, about 76% of the total methane emission due to animal living processes are attributed to the Northern hemisphere of the Earth. The Earth population growth, especially in the Asian continent, intensification of the processes of food production of animal origin will result in the increase in methane emission in these regions and on the global scale.

The calculated data of methane emission to the atmosphere from biomass combustion vary significantly (from 50 to 100 Tg/yr) [4,22]. The uncertainty of the value is determined by the insufficient information on the annual amount of biomass combustion and its types, on the character and completeness of combustion processes, water content in plants and other factors needed for calculations. According to the estimates available the amount of methane annual emission of 55 Tg could be recommended for use in global emission calculations [2]. The value no doubt can change with time due to the changes in climatic conditions (increased number of forest fires as a result of air temperature rise), anthropogenic activities, meteorological conditions favourable to fires in forests, savanna etc. This source should be noted as one of the most unspecified, and forecasting of its power variations in time is currently a difficult problem.

Among the methane sources which quantitative characteristics should be specified lies the emission of methane producing by termite living processes. The assessments available on give global value of 10-100 Tg of methane annually [9,23,24]. The importance of that methane source has been studied for the first time during the laboratory researches of composition of termite byproducts [22]. Following the probable error due to extrapolation of laboratory data to natural conditions, the different termite species, the food consumed and living conditions the uncertainty of the given methane global source is quite considerable. The value of 40 Tg could be taken as a pure estimating one [2].

The important methane source which power will increase together with the population growth is the biological processes of organic matter destruction in soil (fertilizers, solid wastes, food industry wastes etc.) under anaerobic conditions. The assessed methane emission value from this source varies in the limits of 30-70 Tg annually and depends on waste total amount, fertilizers use in agriculture, soil microbiological composition, depth and terms of waste disposal. The value of 40 Tg of the global methane emission could be used here [2].

The considerable methane source under the climate warming could appear from hydrated methane, that is methane molecular inside the solid matrix of water molecular. The hydrates of methane storages are concentrated mainly in permafrost zones and in sea sediments on the borders of continental shelf [25].

The assessments of hydrated methane storages vary greatly (from $1.7 \cdot 10^{18}$ g up to $4 \cdot 10^{21}$ g [26, 27]). Hydrates of methane are fixed in a relatively narrow temperature and pressure range and under the temperature rise (e.g., following the climate warming) their destabilization could lead to methane emission to the atmosphere. The existence of the positive feedback between Earth surface temperature rise due to "green-house" effect and methane content in the atmosphere could lead to methane discharging processes from its hydrated forms. According to the preliminary estimates the predicted temperature rise in the coming century could result in the annual methane emission from that source of 130 Tg [2], that would exceed any of the existing methane sources. However, the considerable uncertainty of assessments of methane emission from its destabilized hydrated forms must be noted, that follows the uncertainty of the data on its storages, spatial distribution of methane hydrates on the global scale, of mathematical modelling of methane destabilization processes.

As the data available show the major amount of hydrated methane to be concentrated in sea coastal sediments at the considerable depth (from 200 to 700 m) the certain inertia of the World Ocean water mass warming could lead to less methane emission in the nearest future as compared to the existing assessments. In this connection available data on this source of methane should be critically analyzed, serious amount of research work aimed at the assessment of methane hydrates resources and their spatial distribution should be done and methods of prognosis of the effect of environment condition changes on methane emission rate should be improved.

The value of annual methane emission, given in Table I represents approximate assessment of the minimum emission rate caused by the influence of continental regions.

The currently known methane hydrates resources are located in the Northern hemisphere where polar and sub-polar regions with the highest potential methane resources should be specially mentioned.

Background content and global distribution of methane in the atmosphere

The background content of methane in the atmosphere vary from 1633 to 1792 ppb (mean annual concentrations) in the regions with minimum anthropogenic pressure [28].

The highest methane concentrations are registered in the atmosphere of sub-polar and temperate latitudes of the Northern hemisphere following the maximum methane emission in the zones mentioned on the global scale.

The analyses of the data testifies to the existence of the latitudinal gradient of methane concentration in the atmosphere of the Northern hemisphere and to the insignificant variations of this gradient from equatorial zones to the South pole (fig. 1). The existence of the methane latitudinal gradient in the atmosphere and of vertical gradient (due to interaction with hydroxile, oxygen and chlorine atoms) makes it difficult to assess the mean global methane content in the atmospheric air on the basis of its measurements in near-the-surface air. However, the results of those measurements allow to estimate the character of the multi-year methane variability, to assess the trend value that equals to 12-16 ppb per year over the last decade [7, 29] (fig 2).

The operating stations for methane background content monitoring in the atmosphere are not evenly distributed over the globe: the number of those stations in the Southern hemisphere is significantly less than in the Northern one. Noting the importance of the tropical wetlands and of the regions of developed cattle breeding, it expedient to enlarge the network of the methane systematic observations in the Southern hemisphere.

Noting the considerable input of sub-polar regions to the global methane emission and bearing in mind the potentiality of significant methane emission to the atmosphere from its hydrates in permafrost zones under climate warming it is recommended to expand the network of methane monitoring in those regions of the Northern hemisphere. As there are no systematic methane measurements in sub-polar regions and wetlands of West Siberia it is recommended to establish three background stations in those territories of Russia.

The absence of the systematic methane observations in southern and eastern regions of China, in India and Pakistan - the regions of intensive agriculture (cattle-breeding, rice growing) being the important methane source on the global scale should be also noted.

Thus, the polar and sub-polar regions, wetlands in West Siberian taiga of Russia, densely populated regions of China, India and Pakistan possess the high priority from the point of view of organization of methane systematic observations over their territories.

It should be also mentioned the lack of the scientifically grounded demands to the spatio-temporal aspects of methane measurements at the background level, to the spatial distribution of the global network of stations for methane monitoring. The problem mentioned is one of the priority problems connected with atmospheric methane and it needs to be solved shortly with the help of experts from different countries within the framework of SACTEMA programme.

Gas-chromatography method with flame-ionization detector is widely used for determination of methane concentrations in air at the background level. That method is used both for methane concentration measurements in air samples taken in special flasks from places with difficult access, and for continuous observations at background monitoring stations, as well [1]. Gas chromatography instruments Carle 211-M3 or 04270-A with the automated system for data processing of Hewlett-Packard 3390 or 3393A could be recommended for the above work. The measurement error of those instruments is about 0.3-0.5% and is satisfactory for the background measurements and assessment of the long-term trends of methane in the atmosphere.

The absence of the methane unified standard gas mixtures necessary for calibration of instruments used in different countries is also one of priority problems. The creation of the international Centre for methane measurements comparison, supplying of measurements with the unified means for instruments calibration or verification of the national standards by the Centre for comparison are very important for the quality assurance of data on methane content in the atmosphere and on its emission on regional and global scales.

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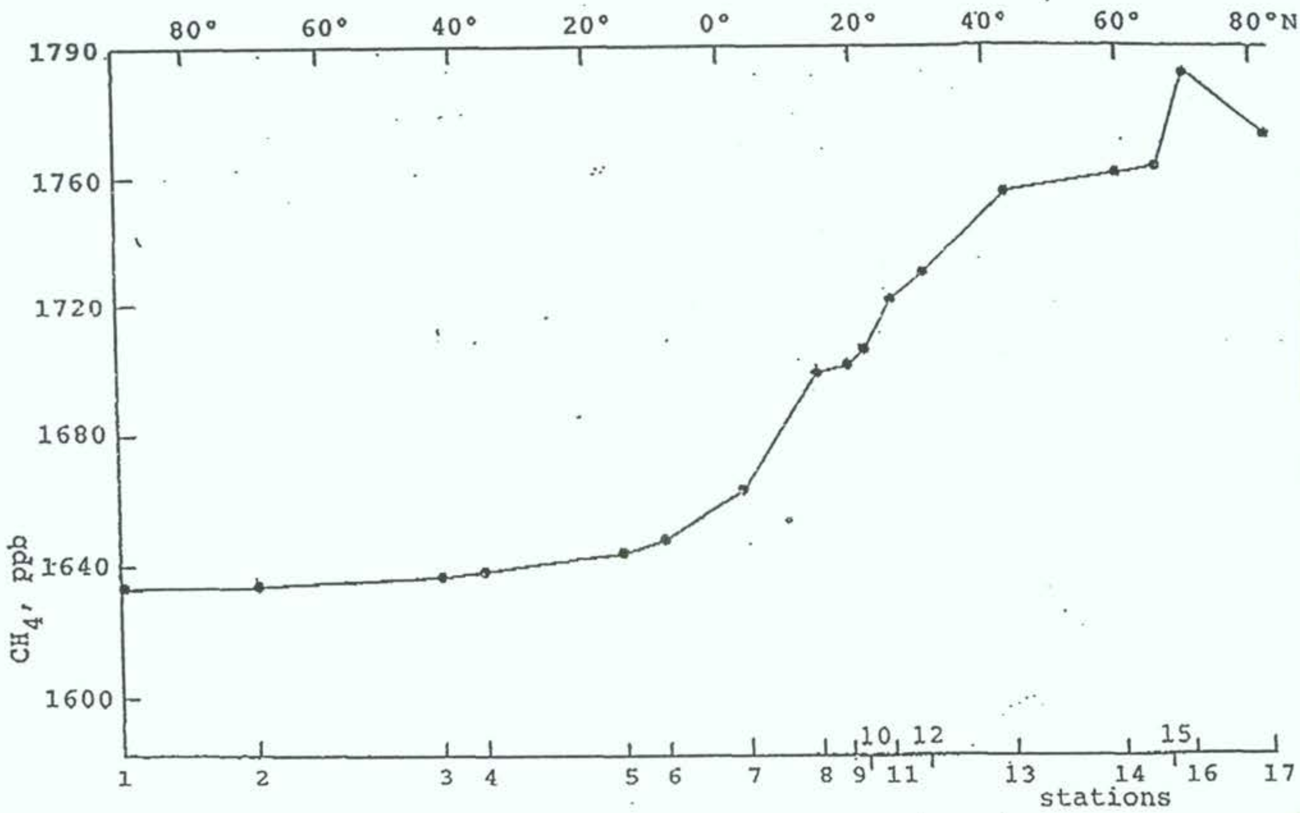

Fig.1. Latitudinal distribution of methane in the atmosphere according to the data of monitoring stations (mean annual values, 1989) [28]: 1-South Pole, Antarctica; 2-Syowa station, Antarctica; 3-Cape Grim, Tasmania; 4-Amsterdam Island; 5-American Samoa; 6-Ascention Island; 7-Christmas Island; 8-Barbados Island (Ragged Point); 9-Virginia Island; 10-Hawaii Island (Mauna Loa); 11-Florida; 12-Midway Island; 13-Cape Mears, Oregon; 14-Shemya Island, Alaska; 15-Gold Bay, Alaska; 16-Barrow, Alaska; 17-Alert, Canada

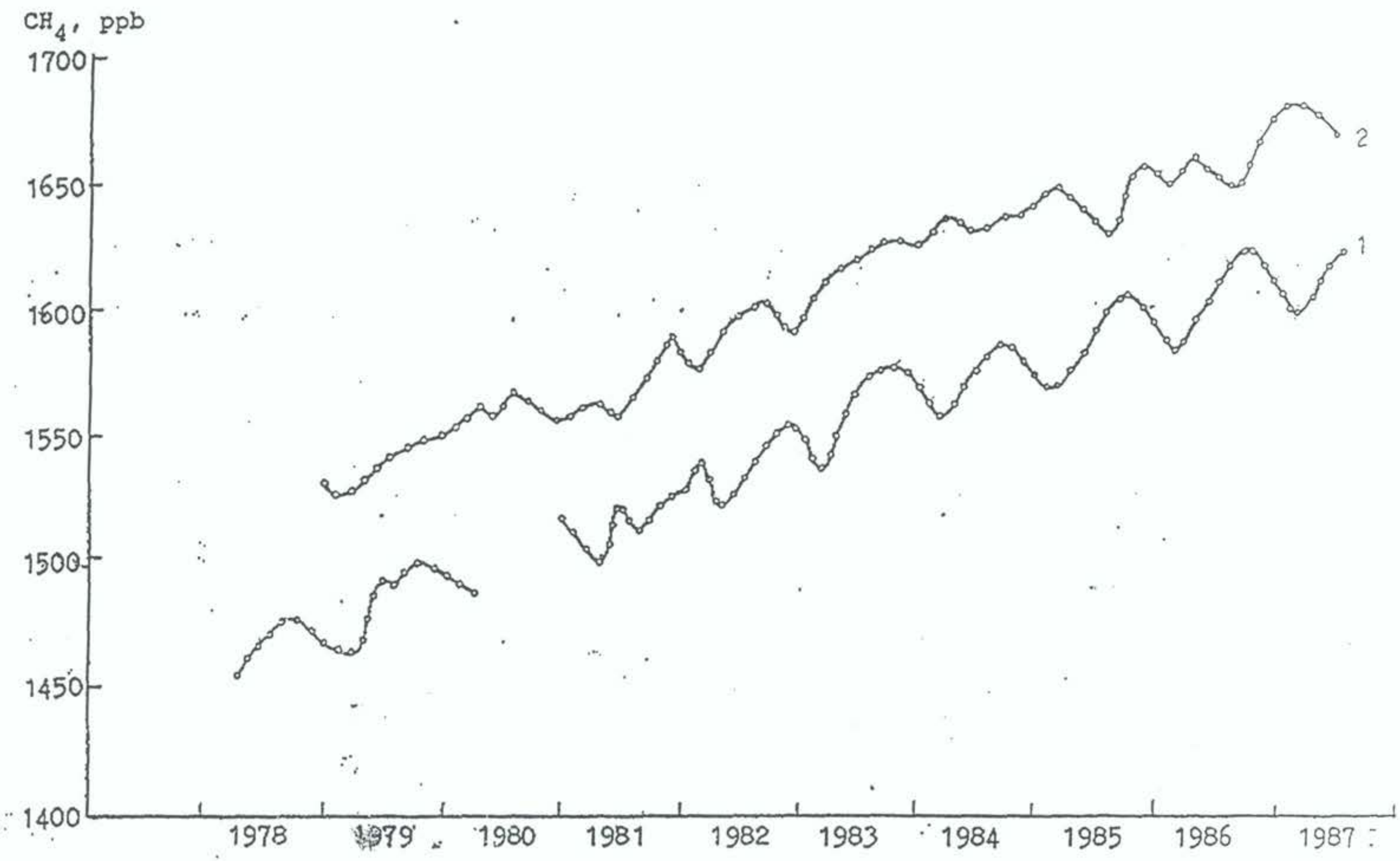

Fig.2. Background methane content variations in the atmosphere of the northern and southern hemisphere according to the monitoring stations data [29]:
1 - Cape Grim, Tasmania, Australia
2 - Cape Mears, Oregon, USA

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The problem of detecting shifts of potential vegetation zone boundaries in marginal monitoring sites

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INTRODUCTION

The IPCC Working Group 1 (Houghton et al. 1990) predicts an unequal global distribution of future temperature increase; in the case of the polar regions an increase of as much as twice the global mean is predicted, i.e. in the range of 3 °C to 8-10 ° C. It therefore seems reasonable that a major effort on impact studies and monitoring of terrestrial ecosystems should be made in the northern areas. In this paper, the northern areas are synonymous with the boreal and arctic vegetation zones (Tuhkanen 1984). Although the suggestions made below are mainly aimed at the northern areas, the general comments and views on ecotonal monitoring (EM) or ecological boundary monitoring are applicable to every biome on the Earth.

METHODOLOGY AND MONITORING DESIGN

Ecotonal monitoring (EM)

The general principles, design and methodology for EM for the transition between the boreal and arctic vegetation zones are described by Holten & Carey (1992). We have suggested that EM should be the flag method for climate change monitoring globally, regionally by (e.g. Europe), nationally and locally. The main reason is that most ecotones have sharp climatic gradients that are very often correlateable with some other abiotic factor. It is therefore suggested that ecotones are very sensitive to climate change. The general design for EM for the boreal-alpine ecotone is shown in Figure 1. The alpine and arctic treelines are the best known ecotones in northern latitudes, and we suggest that the empiric treelines of Norway spruce (Picea abies), Scots pine (Pinus sylvestris), birch (Betula pubescens) and other boreal tree species are very sensitive to increase in temperature, i.e. they can easily move upwards or northwards. The general design also takes into account the less likely situation that climate can deteriorate; studies on the lower or southern side of the treeline are therefore also included. However, the main activities, including instrumentation, should be located on the upper or northern side of the treeline.

EM is necessarily a transect monitoring method. In the case of sloping countryside, such as the alpine treeline and the snow bed-ridge ecotone, it will constitute short transects (200-800 m), whereas ecotones in flatter countryside, such as the forest-tundra ecotone in North America and Siberia, the forest-steppe, savanna-steppe and the steppe-desert ecotones, will require transects of 10-100 km or more. The migration of treelines across ecotones could respond to changes in either the hygric or the thermic components of the climate regime. The alpine and arctic treelines will mainly respond to changes in the thermic regime because **summer temperature** (heat sum) is the minimum factor for growth and establishment. The forest-steppe ecotone will respond to changes in the precipitation and hydrological regimes because **drought** is the main factor limiting trees and other species from invading the drier steppe and prairie regions.

PARAMETERS FOR MONITORING SHIFTS AT MARGINAL LOCATIONS

A more specified methodology for intensive ecotonal monitoring (IEM) of the forest-tundra ecotone, based on the general EM concept, is described below. (See Figures 2 and 3A & B). The IEM sites should take the form of transects where various research activities (see also McCauley & Meier 1991) are carried on along with more routinely monitoring. The transects for the IEM sites should be carefully chosen and be primarily located in natural (climax) vegetation. The vegetation gradient across the ecotone should ideally be the same for the routine monitoring in permanent plots, the sites for measuring abiotic parameters and the manipulation plots, in order to be able tocorrelate changes in the abiotic parameters with changes in the various biotic parameters. The quality of the site will also be important for cause-effect studies, to provide better founded predictions for later modelling.

Mainly because of the expected high costs of IEM, only 7 sites in the circumpolar and circumboreal regions (see Figures 3A & B and Table 1) are proposed for IEM monitoring of the climate povered changes at the boreal forest-arctic ecotone. However, there is a great need to cover the main macroclimatic oceanity sectors in the circumboreal area (e.g. in the sense of Tuhkanen (1984)). Sites 1, 3, 4 and 7 cover the coastal margins of the two continents. Coastal margins have a different biota than the interior of the continents, and both areas are equally important for future monitoring and research programmes related to the predicted climate change.

A global network of sites for more extensive EM may be termed EEM (Extensive Ecotonal Monitoring). EEM should not include the research element. It should have a much simpler design for measuring abiotic variables and only cover minimum set of important sensitive, biotic variables.

Monitoring parameters and indicators in IEM
(* = important variables/indicators that should be monitored at all EM sites).

Abiotic parameters
- Temperature
  Needs to be measured continuously and automatically at stations at various distances (see Figure 2) from the treeline and at various levels above and below the ground (2 m, 0.5 m, 0.1 m, 0 m, - 0.1 m, - 0.5 m)
- Precipitation (automatic, continuous)
* - Snow cover (depth and duration)
  Frequency: 5-10 times a year?
* - Active layer (depth)
  Frequency: 5-10 times a year?

Biotic parameters
* A: Phenology
Carry out phenological studies of widespread arctic and boreal plant species, including all the tree species that define the arctic timberline. Candidate species for EM may be found in Murray's (1992) draft report to the ITEX global change research programme. Many of Murray's candidates are arctic to northern boreal (subarctic) species, and can perhaps serve as candidates for an EEM phenological programme:
Carex bigelowii s.l.
Cassiope tetragona
Dryas integrifolia/Dryas octopetala
Eriophorum vaginatum
Oxyria digyna
Saxifraga oppositifolia
Silene acaulis
Betula nana
Polygonum viviparum
Saxifraga cernua

B. Tentative list of climatically sensitive species

The widespread species in the above-mentioned list may be important for the comparing changes at the EEM sites. However, widespread species, including most of the dominant boreal tree species, are generally resilient to changes in ecological conditions; hence, they are poor indicators or show little little sensitivity. One of the main research activities at the IEM sites should therefore be to point out the climatically most sensitive biological indicators, most of the latter probably being single plant species.

I Thermic patterns
1. Frost-sensitive species
   In a strict sense, these are not represented in the boreal area. However, many species that prefer snow-rich sites may suffer frost damage if the depth and duration of snow cover is reduced (see group II 1 below).

2. Species that avoid the winter-mild coasts of the continents (= southwest coast avoiding species):
   Picea abies ssp. abies
   Picea abies ssp. obovata
   Larix sibirica
   Larix gmelinii
   Orthilia secunda etc.

II. Hygric patterns

1. **Humidiphilous and very often oligotrophic species (relevant for the coastal IEM sites)**
   Betula pubescens ssp. tortuosa
   Cornus suecica
   Cryptogramma crispa
   Athyrium distentifolium
   Rhodiola rosea
   Saxifraga stellaris
   Bartsia alpina
   Alchemilla alpina
   Phyllodoce caerulea
   Gnaphalium norvegicum

These species have a general amphi-atlantic distribution pattern and are closely associated with the occurrence of mountain birch forests, preferring a North Atlantic snow-rich climate.

2. Xerophilous boreal to arctic species
   - **Main occurrence in northern to central Siberia? Many grass and sedge species?**
     Festuca ovina?
     Androsace septentrionalis?

III. **"Edaphic"** patterns (azonal patterns)

A group of extremely eutrophic or extremely oligotrophic (calcifuge) species may indicate changes in the nutritional conditions:
   Cryptogramma crispa (calcifuge)

Many boreal/arctic plant communities may also be sensitive to changes in some abiotic factor (e.g. temperature, precipitation or snow cover). The low alpine (and low arctic?) Vaccinium myrtillus heaths are probably sensitive to changes in the snow cover. The response may be measured as much by a structural change as by a change in floristic composition. Major large-scale structural changes along the northern boreal-arctic ecotone may be more easily detected by remote-sensing technology than by traditional phytosociological methods. However, on a detailed scale (locally and in each monitoring plot) the latter methods are unavoidable. Examples of major structural changes are that the low arctic lichen heaths will retreat, or that dwarf-shrub heaths will be replaced by grasses and/or herbs.

* C. **Growth parameters (primary production)**
To be carried out on some tree and shrub species (e.g. Salix spp.) using standard techniques:
- Diameter of the trunk
- Height of dwarf shrub

D: **Vitality parameters**
- flowering
- fruit production (fertility)
- seed dispersal

* E. **The local distribution of some sensitive species**

Research priorities at the proposed IEM sites

In order to detect treeline movements that result from climate change, the following processes should be quantified in time and space for each of the IEM sites in a research strategy:
- Migration and dispersal
- Establishment
- Competition

Various destructive experimental approaches (see Figure 2), are suggested:
- **Transplantation** of single species or whole vegetation mats may be carried out across the treeline, primarily upwards or northwards, to try to quantify the various stress responses.
- **Altering the density** of species in the understory by removing dominants. This can, for instance, be achieved by experimentally making five different densities for some dominant species, e.g. Vaccinium myrtillus.
- **Greenhouses**
  To determine growth rates under various temperature and hygric conditions.
- Extending the growing season by **removing snow cover.**

An important non-destructive research strategy is to study the population dynamics (demographic studies) of species that are thought to be sensitive to some abiote climate parameter, perhaps some low-growing rosette plants.

REMOTE SENSING TECHNIQUES IN IEM AND EEM PROGRAMMES

Various remote sensing techniques may be able to cover the needs of parts of IEM and EEM monitoring programmes. The existing long term LANDSAT series is very useful for showing trends in the movement of the arctic treeline during the last one to two decades. The LANDSAT series will probably also be useful in an EEM program for testing basic theories over large areas and for detecting the potential future displacement of the arctic treeline. The IEM programme can probably receive more detailed spatial resolution from SPOT satellite imagery (pers. comm. Arnt Brox, GRID-Arendal).

Mulhern & Goward (1992) mention the advantages of the Coastal Zone Color Scanner (CZCS) for mapping the circumpolar boreal forest-tundra ecotone, although it is designed to monitor oceanic biological productivity. In particular, CZCS observations in blue, green and near infra-red wavelengths are well suited for detection of the spectral contrasts between lichens and green vascular vegetation. Mulhern & Goward (1992) conclude that improved understanding of subarctic reflectance properties are crucial to geographical applications of satellite observations of northern regions. The spectral heterogeneity of subarctic vegetation mosaic constituents needs to be recognized in order to fully explore satellite multispectral data for mapping northern vegetation. They also conclude that such a baseline map is critical for monitoring and quantifying potential environmental changes as northern latitude ecosystems may be particularly sensitive to global warming (see also Juday 1990 & Viereck et al. 1990).

If the spatial resolution of satellite imagery improves still more, it will probably be able to detect population changes in some major species at the IEM sites. This will be a great advantage for an objective comparison of successional trends at the IEM sites, and a good test of "ground truth" including traditional maps of species distribution.

EXISTING MONITORING METHODOLOGIES AND THEIR USEFULNESS FOR CLIMATE CHANGE MONITORING

Most of the existing integrated terrestrial monitoring programmes are directed towards detecting air pollution effects on ecosystems, mainly forest ecosystems and tree species. However, some of the programmes, like the Swedish PMK (Bråkenhielm 1989) and the Norwegian TOV (Fremstad 1991), monitor the vegetation in numerous permanent plots, in the case of TOV in oligotrophic mountain birch forests and low alpine Vaccinium myrtillus heaths. Some of the monitoring programmes are well designed for detecting vegetation changes and successional trends. A common feature of the existing programmes seems to be that the biological parameters give general responses to changes in ecological conditions (growth, primary production), that is, the biological parameters are probably not sensitive enough to give early warnings. The best indicators for monitoring both air pollution and climate change impacts, may be a lichen that is sensitive to SO_2, a humidiphilous liverwort, a thermophilous herb or a frost-sensitive shrub. In the coming years, we should seek out plant indicators that will provide much better answers to the questions:

- What is the species' critical load? (Chemical tolerance levels).
- What is the species' critical temperature or humidity level? (Climatic tolerance levels).

No existing monitoring programme has been found satisfactory for monitoring climate change. However, plans are currently being made to add such parameters to existing programmes, e.g. the United Nations Global Environment Monitoring System (GEMS) and the Norwegian TOV programme.

The North American EMAP programme (Environmental Monitoring and Assessment Program) stresses the use of various ecological indicators (see Hunsaker & Carpenter 1990) for monitoring terrestrial, aquatic and near-coastal ecosystems. The EMAP's indicator strategy for research and monitoring is complicated, but seems to be well suited for use in the various biomes. One of the EMAP's research indicators (parameters) (p. 11-4) is the Ecotone Location of Vegetation.

The pan-Arctic AMAP programme (Arctic Monitoring and Assessment Programme) also mentions Climate Change and Variability as a parameter category. Vegetation border is the only specific biotic parameter mentioned here. The first priority of AMAP (initiated in Oslo in 1990) is to monitor the levels and assess the effects of anthropogenic pollutants in the Arctic environment. The AMAP Task Force will leave the measuring of the causes and effects of climate change and the understanding of its processes to other international groupings, to which they would like to develop links (Reiersen 1991).

The ARCSS programme is perhaps the best programme currently being planned to cover biotic parameters from the point of view of monitoring, research and methodology for climate change use. The ARCSS programme catalogue (McCauley & Meier 1991) gives detailed descriptions of process studies, manipulation experiments, long-term monitoring and measurements, and modelling that are needed, as well as research priorities and an anticipated schedule for the various activities.

SELECTION CRITERIA FOR SITE LOCATION

Figures 3A and 3 show only the approximate locations of the 7 sites for intensive ecotonal monitoring (IEM) the proposed for circumboreal/polar region. The sites are transects and may cover a long north-south distance (tens of kilometres), monitoring and research activities taking place only at certain points along the individual transects. The required IEM sites are probably not covered by any existing monitoring or research programmes.

General criteria for selecting of IEM monitoring sites and transects (in order of decreasing priority):
- The site (transect) should be a typical and a not too broad ecotone between the northern boreal and low arctic vegetation zones.
- The site (transect) should be representative for the oceanity sector concerned.

- The site should have species, populations and vegetation that are thought to be sensitive to climate change.
- Relatively strict **area protection** (nature reserve? national park?) should exist.
- **Logistics.** Laboratories, accommodation for international research teams, good transportation, communications and power supplies should be availaable.
- Linkage with existing remote sensing programmes should be possible.

The selection criteria for the EEM (Extensive Ecotonal Monitoring) sites are:
- The site (transect) should be a **typical** and a not too broad ecotone between the northern boreal and low arctic vegetation zones.
- **Some area protection** should exist, but less strict than for the IEM sites.
- The site (transect) should at least have some species, populations and vegetation that are thought to be sensitive to climate change.
- **Logistics.** Reasonable transportation, reasonable accommodation facilities.

For climate change monitoring within the biomes, which Izrael & Semenov term intra-ecosystem monitoring, it seems most reasonable to extend the existing forest assessment methodologies, adding biotic parameters that are thought to be sensitive to changes in the climate. This will necessitate separate research activity to find better and more specific parameters than those already existing in forest monitoring programmes. Ecosystem process studies related to climatic factors must no doubt also be carried out along with the parameter studies and the existing long term monitoring programmes.

The UN - ECE programme (see Cerny et al. 1992) on integrated monitoring of air pollution effects on ecosystems can peeerhaps be extended to include the above-mentioned parameters and can then constitute the biological monitoring of intra-ecosystem climate-driven changes proposed by Izrael & Semenov (1992).

SUMMARY

A draft for an ecotonal monitoring (EM) methodology is put forward. An intensive ecotonal monitoring (IEM) strategy including research and measurement of abiotic parameters that are relevant for climate change is suggested for 7 circumboreal/circumpolar sites. A less ambitious strategy, named extensive ecotonal monitoring (EEM), is also suggested for a number of marginal circumboreal/circumpolar sites. Draft lists are given of plant species that are thought to represent relatively sensitive biological parameters for detecting climate change impacts in terrestrial ecosystems. The use of remote sensing techniques to monitor displacements of

vegetation boundaries and vegetation structure and composition is discussed. It is suggested that existing monitoring programmes be extended to provide biological monitoring of intrazonal climate powered changes. There is an urgent need for a separate parameter research (find more sensitive parameters).

RECOMMENDATIONS (non-priority order)

- **Select sites for IEM and EEM on the basis of map studies (including satellite imagery) and discussions between SACTEMA and the planned GTOS (Global Terrestrial Monitoring System) programme within GCTE (arrange excursion(s) in 1993?)**

- **Improve the drafts of the IEM, EEM and other methodologies** for monitoring climate change impacts (establish a group of experts)

- **Regionalization of research and monitoring as suggested by Eddy et al. (1991) (the START initiative) and Cerny et al. (1992)**

- Establish better contact between research groups currently initiating climate change monitoring and the more established integrated monitoring programmes, in order to extend the latter.

- Establish better contact between extended monitoring programmes and the remote-sensing mapping programmes.

- Draw up extended, variable lists of sensitive parameters for global climate change monitoring purposes (establish a group of experts?) (cf. GCTE workshop in Paris, July 1992)

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Table 1. Potential and preliminary location of intensively run IEM sites in a circumboreal system of ecotonal monitoring (for the transition between the boreal and arctic zone) with reference to climate change

	Oceanicity sectors (O_3 - OC - C_3) sensu Tuhkanen 1984
North America	
Alaska	
1 Noatak (Baird Mountains)	Sector OC
NW Territories	
2 North of Great Bear Lake	Sector C_1
Quebec	
3 Ungava peninsula	Sector OC
Eurasia	
Norway	
4 Finnmark	Sector O_2 to O_3
Russia	
5 Vorkuta (North Ural Mountains)	Sector C_1
6 North Lena	Sector C_2 to C_3
7 Anadyr area	Sector OC to O_1

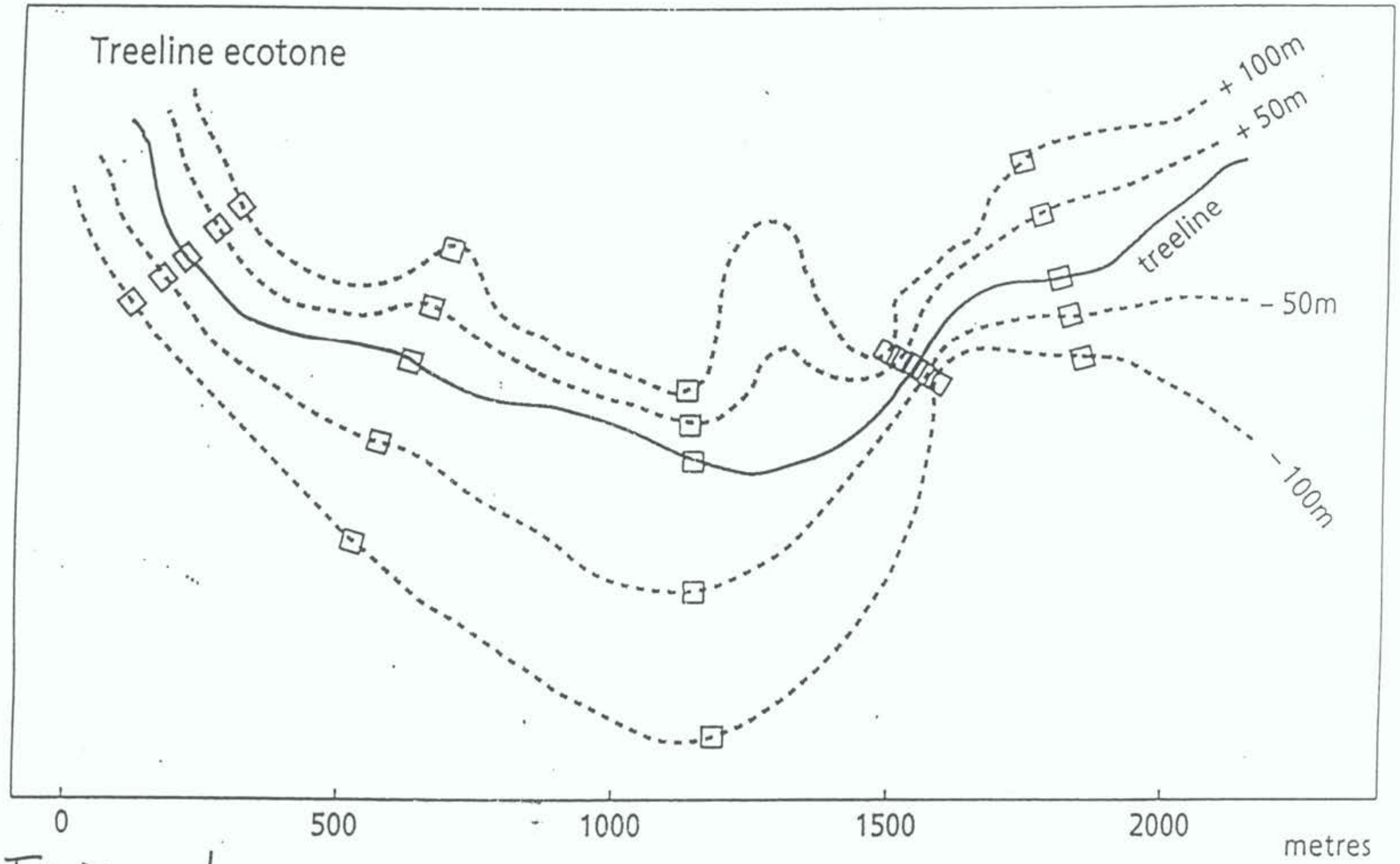

Figure 1

A possible general design for monitoring population processes along a three-tier transect. The example given here shows how the system could be applied to investigate sensitive ecotones. The ecotone chosen for the example, the boreal-alpine ecotone, is one of several that could be investigated in this way. From Holten & Carey 1992.

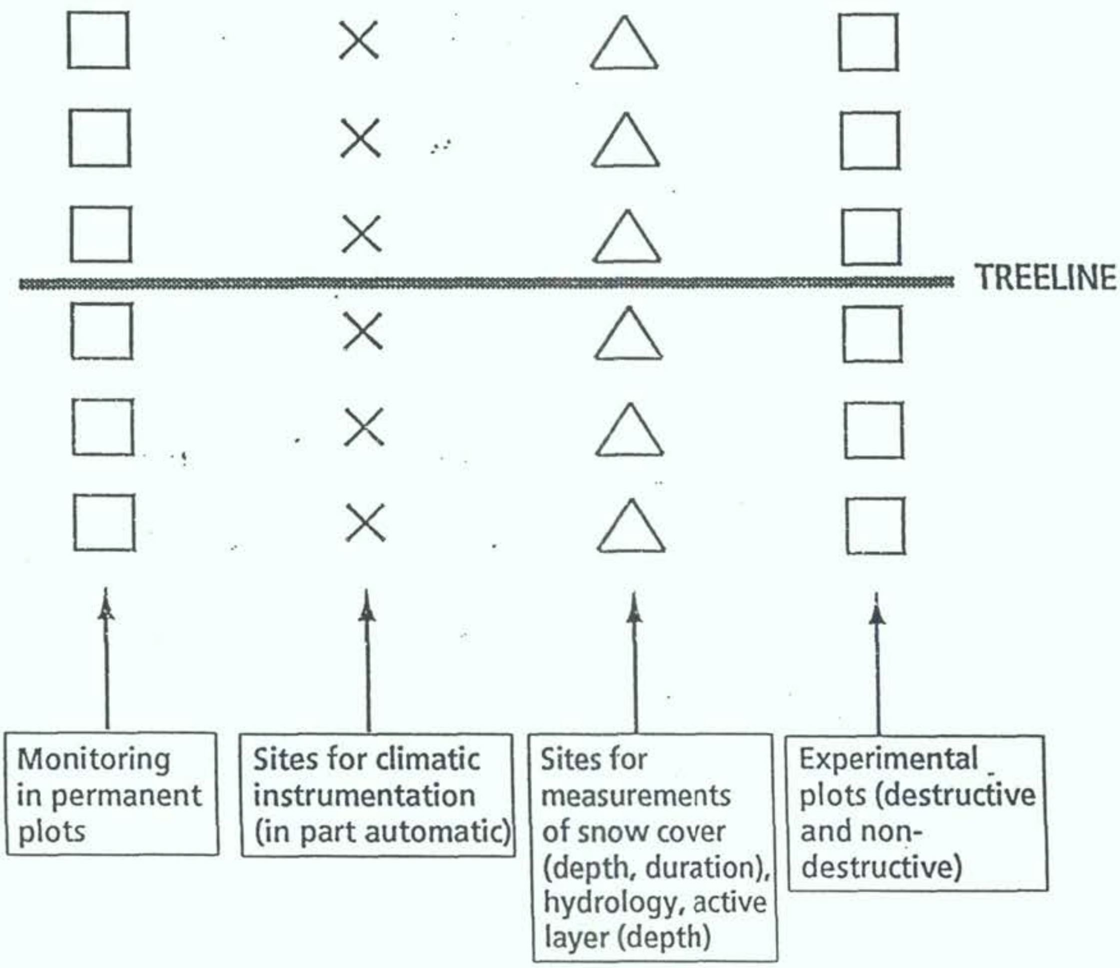

Figure 2. Design of intensive ecotonal monitoring (IEM) including location of ecological research activities and instrumentation for measuring abiotic parameters

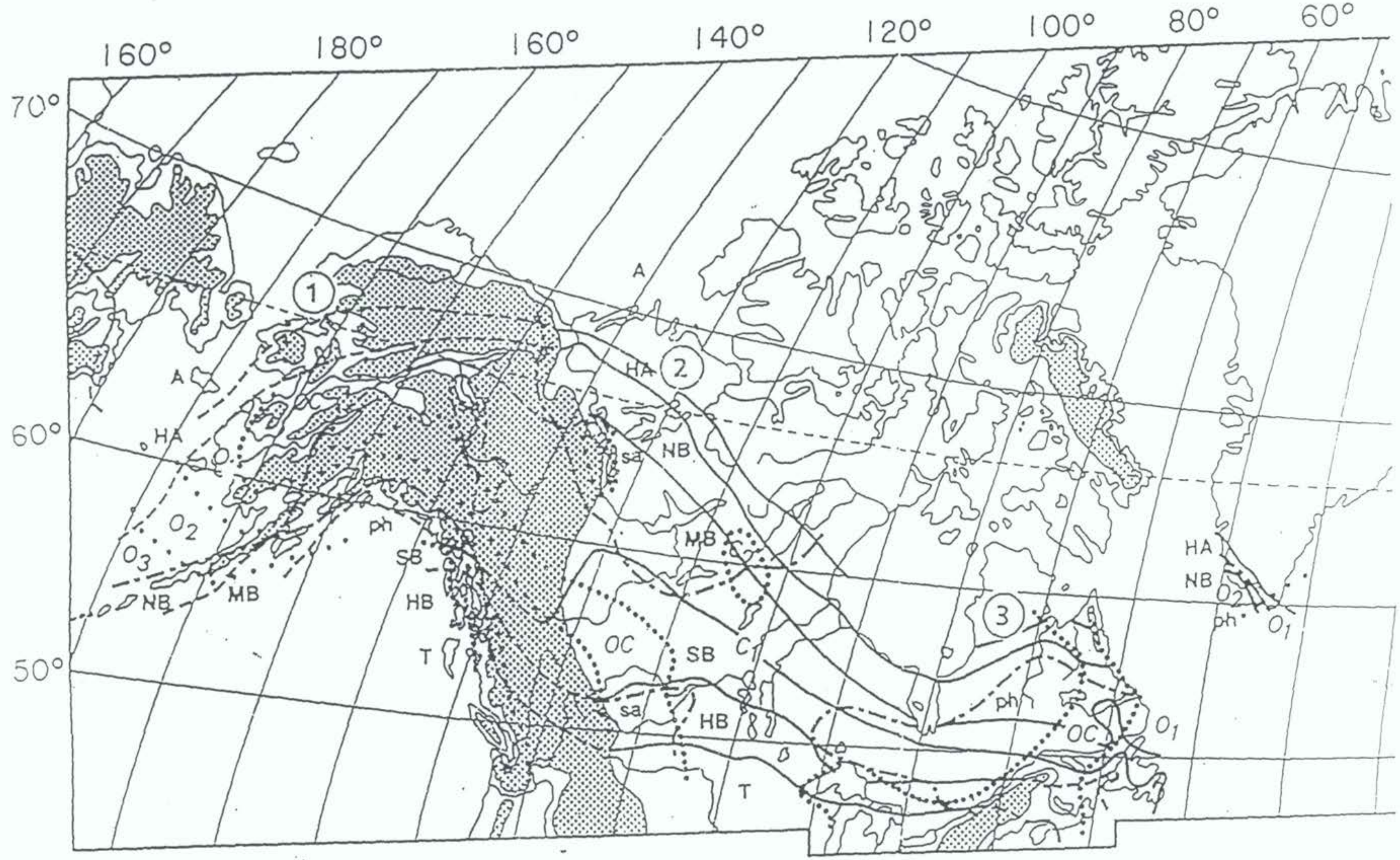

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Figure 3A. Circumboreal climatic-phytogeographical regions. T = temperate zone; boreal subzones: HB = hemiboreal zone, SB = southern boreal zone, MB = middle boreal zone, NB = northern boreal zone; HA = hemiarctic zone, A = arctic zone; O_1–C_1 = oceanity sectors; sa = semi-arid province, ph = perhumid province. Humid (h) provinces not specifically indicated (= other areas than semi-arid or perhumid provinces). (1) zone boundaries, (2) sector boundaries, (3) province boundaries. Zonal and sectoral Subdivision: Tuhkanen 1984.

Site location North America: (1) Noatak (Baird Mts.), Al. (3) Ungava peninsula, Q
(2). N of Gt. Bear Lake, NW Terr.

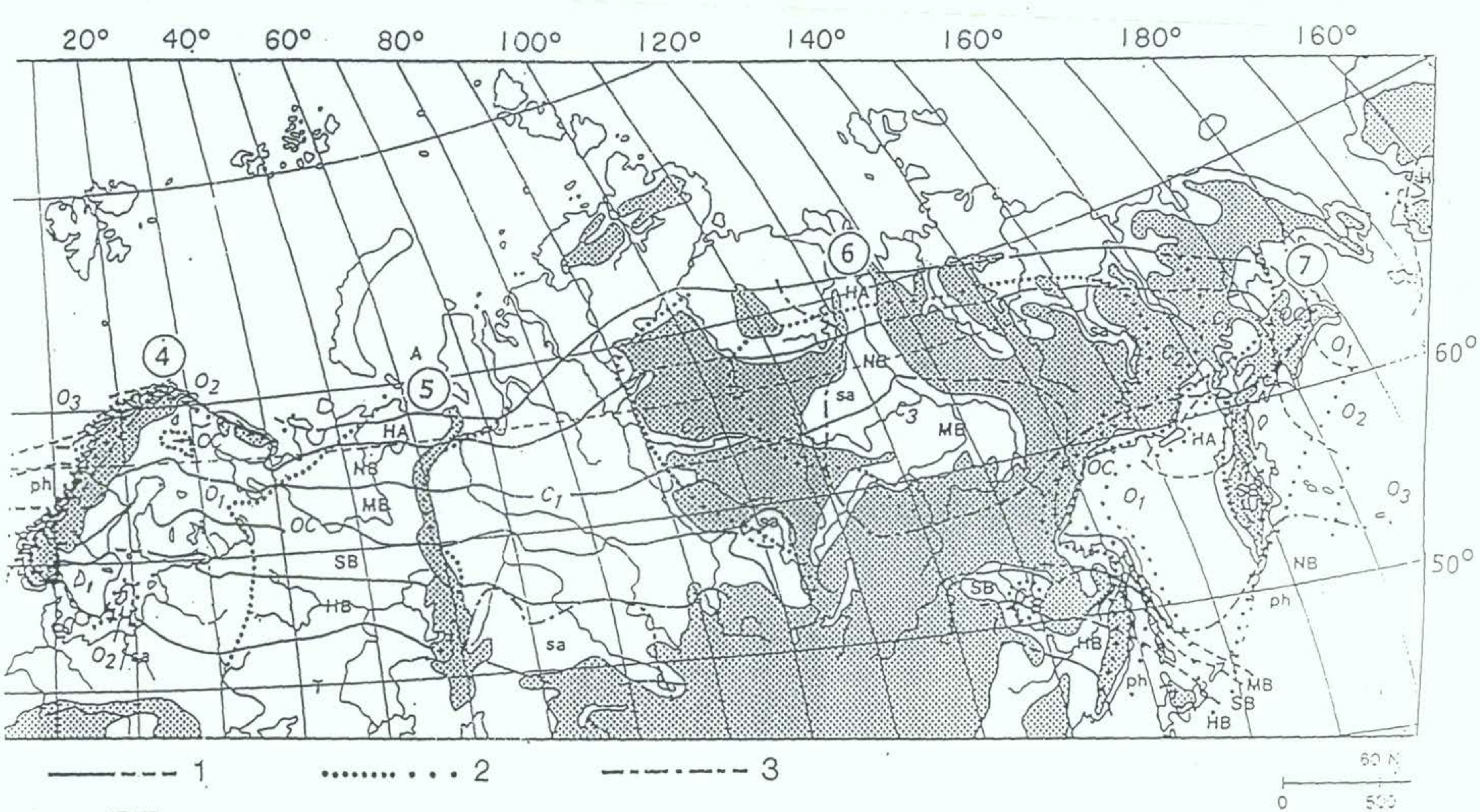

Figure 3B. Circumboreal climatic-phytogeographical regions. T = temperate zone; boreal subzones: HB = hemiboreal zone, SB = southern boreal zone, MB = middle boreal zone, NB = northern boreal zone; HA = hemiarctic zone, A = arctic zone; O_3–C_3 = oceanity sectors; sa = semi-arid province, ph = perhumid province. Humid (h) provinces not specifically indicated (= other areas than semi-arid or perhumid provinces). (1) zone boundaries, (2) sector boundaries, (3) province boundaries. Zonal and sectorial subdivision: Tuhkanen 1984.

Site location Eurasia:

4 - Finnmark, Norway

5 - Vorkuta (N Ural Mts), Russia

6 - North Lena, Russia

7 - Anadyr area, Russia

Yu. A. IZRAEL, S.M. SEMENOV

ON THE BIOCLIMATOLOGICAL ASPECTS OF TERRESTRIAL ECOSYSTEM MONITORING

(Discussion paper submitted to the 1st session of SACTEMA, 9-11 September, Prague)

Abstract

Since eventual climate change driven shift of vegetation zone boundaries has been recognized as one of the major environmental threats of the global scale a global observation programme should be run to monitor the climate impacts and respective ecological responses.

Remote-sensing satellite technique should be used for monitoring of the shifts of vegetation zones.

The ground observation stations should be set near both sides of recent vegetation zone boundaries (at least one station for a vegetation zone is absolutely necessary) to monitor gradual ecosystem changes.

The Global Integrated Monitoring (GIM) sites should be used for ground monitoring, where climate & pollution parameters are measured simultaneously with ecological variables. Some sites within existing networks (e.g.,

-the Global Atmosphere Watch/WMO & UNEP stations;

-UN ECE EMEP stations and Integrated Monitoring Programme sites;

-Background Integrated Monitoring stations in Eastern Europe;

-UNESCO Biosphere Reserves)

met GIM requirements very closely can be used for above-mentioned purposes.

Existing networks and methodological basis are sufficient for starting the minimum programme of bioclimatological observations at the GIM sites since 1993, however an advanced programme implementation requires additional research, further development of monitoring methodology, measurement equipment elaboration and observational network extension.

All these activities are within the scope of WMO, FAO, UNEP, UNESCO and to be coordinated by them in close cooperation with IPCC/WMO, IGBP/ICSU and other international & national scientific advisory bodies.

On the Integrated Monitoring Concept Extension

Since the International Conference on Human Environment (Stockholm, 1972) one of the major areas of national and international ecological efforts is environmental pollution problem. The large (even global)-scale character of environmental pollution (especially air pollution) is still evident and required respective monitoring and control activities.

Many important steps were undertaken in this field during recent two decades, e.g.

-concept basis of global integrated (multimedia) monitoring was created [1,12,14,13,21,22,34,28,29,32,37,47,53];

-global integrated monitoring methodology for physical, chemical and partly biological observations was provided [7,16,20,33,35,39,41,42];

-several large-scale integrated monitoring networks have been run (Global Atmosphere Watch/WMO & UNEP stations, UN ECE EMEP stations and Integrated Monitoring Programme sites,Background Integrated Monitoring stations in Eastern Europe and some others) and some valuable reviews of the state of the environment and existing monitoring systems have been undertaken [2,3,4,5,15,17,31,38,43,48, 51,52];

-in some case the political feedbacks from monitoring results to emission control measures were set (for instance, within UN ECE system).

The International Conference on the assessment of the role of carbon dioxide and of other greenhouse gases in climate variations and associated impacts (Villach,Austria,9-15 October 1985) has opened a new page in our environmental history. The problems of a global warming due to greenhouse gases emissions are being played the priority role and attracted attention of public, scientists and politicians.

The major problems for terrestrial ecosystems that could be caused by eventual global climate change have been outlined in the Report to the Intergovernmental Panel on Climate Change from its Working Group II [27]. However, significant uncertainty still remains in the assessment of the ecological consequences of predicted climate change. The uncertainty is caused by a lack of theoretical concepts and reliable field/experimental data on the other hand.

It means that respective global observation programme should be run to monitor the climate impacts and their ecological consequences.Of course, their is no necessity to establish an absolutely new network for these purposes.The classical integrated monitoring concept has to be extended [30] by climatological and bioclimatological elements, existing integrated monitoring programme could be completed by respective items and acting integrated monitoring networks can serve as a basis for a climate change impact and its ecological consequence observations.

The high importance of simultaneous ecological and atmospheric (climate & pollution) monitoring can be illustrated by the following points:

- atmospheric events,such as air pollution and climate change are not independent,e.g. air pollution by greenhouse gases cause climate change (global warming) and a climate change, in particular precipitation bulk change can modify strongly air pollution level (and pollution deposition as well);

-above mentioned atmospheric events do not operate independently upon ecosystems; significant interactions occur (including synergetic and antagonistic effects), thus direct monitoring of the key elements and processes within impacted ecosystems is extremely useful for comprehensive assessment of respective ecological effects;

-ecosystems also exert impacts upon the atmosphere that are highly relevant to the issue of air pollution and climate change; therefore data on the state of vegetation and other renewable resources are necessary in order to account for terrestrial feedback mechanisms in the understanding of atmospheric conditions;

-the scientific community currently recognizes and uses many biological indicators for the specific purpose of air pollution and climate change monitoring; often these indicators are common for both types of impacts.

Monitoring Subjects

The most serious problems for terrestrial ecosystems (non-coastal) are connected with eventual shifts of the vegetation zone boundaries towards the poles for long distances (100 km and more over next 50 years).The main reason for these shifts are the global annual mean temperature increase and precipitation change as well [27].

However, the virtual vegetation zone shifts will occur significantly later than changes in climatic conditions.The delay is caused by a limit of the tree seed dispersal rate (about 1 km/year [49]).

That means that the boundaries of territories where climate is suitable for a given type of vegetation could shift hundreds of km in 50 years,but virtual boundaries of the given type of vegetation could shift only several scores of km for the same time (i.e., slower by a factor of ten).

Thus, the processes of recent phytocenosis transformation may occur earlier and within a significantly more vast territory than where a visible vegetation zone shift can be observed.

The brief estimates presented above show the necessity of a flexible approach for the setting of BIOCLIMATOLOGICAL MONITORING, i.e.

> BIOLOGICAL MONITORING WHICH IS TO IDENTIFY THE ECOLOGICAL CONSEQUENCES OF CLIMATE CHANGE.

Remote-sensing monitoring can be extremely useful for the identification of visible shifts in vegetation zones, but traditional field observation methodology remains the best one for monitoring of the gradual phytocenosis transformation (including exogenous succession).

One has no doubt that

* geographical boundaries of the recent vegetation zones are a subject for remote-sensing monitoring.

The situation with field observations is not completely clear yet (additional research is needed). But, one can decide in principle that the priority subjects for such observations should be state of species-indicators (for early identification of future changes), state of species-edificators (which directly define the "face" of an ecosystem) and the key dynamic processes at the ecosystem level.

Taking these points into consideration the following types of parameters could be suggested for field bioclimatological observations:

* for indicators (i.e. taxonomic groups which are the most sensitive to climatic conditions)

    -species composition,
    -occurrence/density;

* for edificators (i.e. a group of the main species of higher plants for given biocenosis)

    - phenology,
    - level of diseases and pests,
    - indices of growth;

* for ecosystems as a whole

    - primary production,
    - rate of decomposition of dead organic matter,
    - evapotranspiration, and
    - exogenous succession which directly drives a shift of the vegetation zone.

Requirements for Spatial Setting of Observational Network

Logically, the ecological changes to be identified are expected first near the recent boundaries of the vegetation zones.Thus, one of the initial methodological requirements for setting a bioclimatological monitoring site should be following:

* the sites for bioclimatological observations are to be set near both sides of the recent boundaries of the vegetation zones (but of course not directly at them to avoid any marginal effects).

This strategy will enable detection of eventual boundary shifts northward or southward.Two sites are recommended because of the remained uncertainty of predictions for eventual shifts in direction. Of course, many practical circumstances (for instance,a need to use already existing networks) could cause this requirement to be modified, but at a minimum one site per vegetation zone is necessary.

As far as the planned network for monitoring GLOBAL climate change and its large-scale ecological consequences,the following requirements are to be met as well:

* each site is to be situated in a remote area (50 km or more

far from the big towns or industrial centers) to avoid possible local effects;

* a land-use model at the area should remain invariable for the planned period of observations, and the opportunity for non-stop observations should be guaranteed;

* the distance to the nearest climate/meteorological station should be reasonably short (to ensure that meteorological/climatological data are representative for the given site).

It is well known that biological parameters are much more variable in space as compared with abiotic parameters, with temperature.Therefore , one should ensure that at least the following specific ecological requirement is met:

* each biological site should be of a size not less than 1 ha within a more vast area (at least 1 square km) which is fairly homogeneous with respect to its vegetative cover and representative for a given vegetation zone.

The Programme of Bioclimatological Observations and Methodological Issues

Many of the types of observations described above do not correspond with current operating procedures. Therefore, it is expedient to compile some "Minimum programme" that is methodologically implementable and therefore ,can be run immediately or within some reasonable time (see table 1).

Minimum programme of Bioclimatological Observations **Table 1**

N	Subject of observation	Indices, units	Frequency of measurements	Methodological comments
1	Epiphytic lichenoflora (for forest sites only)	Species composition	1 per 10 years	The methodology has recently been developed and approved [23-26]; lichen sensitivity to climate impacts is described in [41]
		Occurrence (by species), dimensionless		
		Linear coverage (by species) at the standardized height on trunks of main tree species , %		

2	Epigeal vegetation (main layer)	Species composition For trees: density (by species), individuals/ha For grasses and epigeal mosses and lichens: square coverage (by species), %	1 per 10 years	Traditional methodology (taxation, geobotany)
3	Plant size (for trees only)	Age, years; Height, m Diameter, cm	1 per 10 years	Traditional methodology (taxation)
4	Phenology of the higher plants	Begin/end of: vegetative period; leaf/needle growth; flowering, year-month-day/ year-month-day	Annually	Traditional methodology (phenological observations)
5	Plant pathology (for coniferous forests only)	Qualitative estimates of needle losses, points/ classes	Annually	The methodology for conifers has recently been developed and approved [5,16,17]
6	Plant growth (for trees only)	Radial growth rate for each species (to be measured at the standardized height), mm/year	Annually	Methodology is known [8,9,18, 19,44] and approved

7.	Biological turnover within an ecosystem	Net primary production, t / ha x year Rate of decomposition of dead organic matter, 1 / year	Annually	Methodology is known [6,10,11, 36] and approved (but in forests is extremely labour-intensive)

This brief overview of methodology shows that in general there is a satisfactory methodological basis to begin bioclimatological observations.

As far as further development of methodology is concerned some important deliberation should be undertaken prior to starting an advanced programme:

* there is no generally accepted method to estimate levels of a leaf damage (e.g. caused by air pollution,climate stress etc.);

* some traditional methods to estimate a level of plant deceases/pests exists [45,46,50], however, nothing universal or generally accepted in terms of points or classes is available that could be helpful for routine annual observations;

* traditional field methods for primary production measurements are extremely labour-intensive and it is doubtful that they could be applicable as a routine monitoring procedure (especially for forest ecosystems).

Thus it is quite clear that additional research,methods elaboration and their approval in field conditions are needed to implement the complete list of observations implementable as a part of routine monitoring activities.

Short-term Plan of Actions

Some practical arrangements should be undertaken at the national and international level prior to minimum programme implementation,in particular:

- the sites for bioclimatological observations that meet the basic requirements discussed above should be chosen; initial geographical,ecological and landscape descriptions should be provided;

- the Focal Programme Centres-FPC (including the scientific institution which is to take care of given site(s) and data bank/archive)should be chosen and should accept respective responsibilities ;contact person(s) should be identified;

- the particular measurement procedures should be clarified in final, and adjusted by specialists. Field and Laboratory Manual should be compiled and disseminated among observers through the FPC;

- the format in which the observational outcome is to be arranged should be decided, and a Data Input Manual should be provided and disseminated among observers through the FPC.

Data Storing and Processing

"Raw" observation data are to be submitted to a Focal Programme Centre (FPC) and stored in the focal data banks and archives only. Of course, some cooperation is possible (if necessary); for instance ,use of a common data bank/archive for a group of sites. These biological data should also be processed there (as well as
abiotic data) and can be used afterwards for many local and regional purposes:

* statistical and model analysis of data series, including

  implementation of averaging and estimation of standard deviations;

* data quality evaluation;

* implementation of environmental forecasts, ecosystem state and

  trends assessments and scenario simulations.

The averaged ecological information is to be submitted (upon request) to the Global Programme Centre (GPC). Its main functions should be

* to carry out the above-mentioned work (and/or to summarize the results of the focal centres) on a large (global)-scale basis;

* to ensure the development of monitoring methodology and

* to promote transfer of environmental information and its transformation from a primary form ("raw" data) to more advanced forms,including the packages of options for use by decision-makers.

The principle scheme of information flows is presented in fig.1.

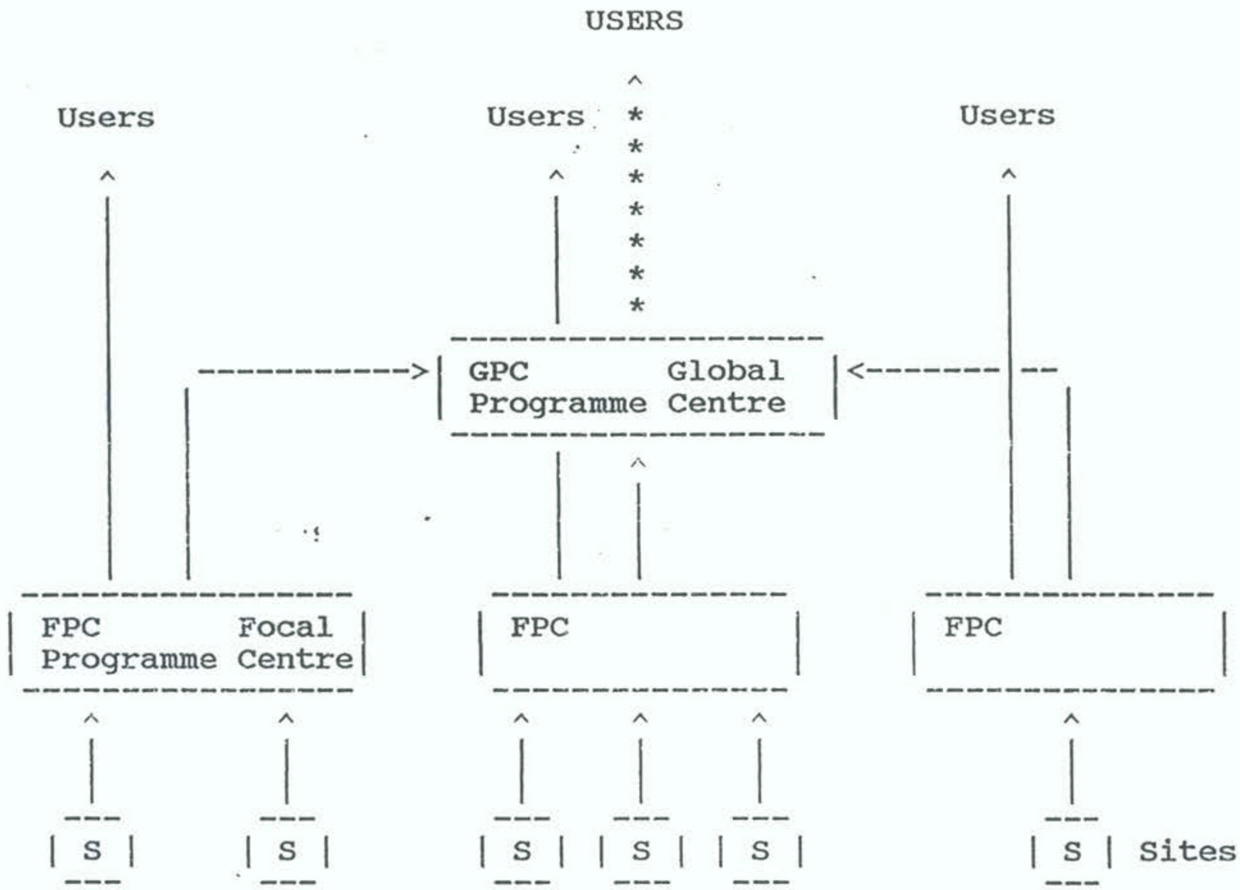

Fig. 1. Global Integrated Monitoring network structure and environmental information flows

Summary of Findings

The most serious problems for terrestrial non-coastal ecosystems could be caused by eventual shifts of vegetation zones,therefore respective global observation network is to be run to monitor these shifts.

The virtual vegetation zone shifts will significantly lag behind climate condition changes, thus the processes of gradual phytocenosis transformation may occur earlier and within a significantly vast territory than where a visible shifts can be observed.

Remote-sensing monitoring can be extremely useful for identification of visible shifts, but traditional field observation approach remains the best one for monitoring of gradual phytocenosis transformation.

The subject for bioclimatological monitoring (i.e. biological monitoring which is to identify biota response to climate change) could be outlined as following:

for remote-sensing monitoring
* boundaries of vegetation zones;

for ground observations at the monitoring stations
* species-indicators;* species-edificators;* key ecosystem processes.

Programmatic considerations and methodology review have shown that existing basis is quite sufficient for starting a minimum programme of bioclimatological observations.However, some methodological gaps still exist and additional research is needed.

The Global Integrated Monitoring (GIM) sites where simultaneous measurements of global climate & pollution and respective ecological responses are expected to be carried out according GIM concept comprise a suitable global network basis for above-mentioned monitoring activity. Some sites of existing networks have been already met GIM requirements rather closely, however in many cases a programme extension,additional equipment supply and station staff training are needed.

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WATER BUDGET OF TERRESTRIAL ECOSYSTEMS AS A POTENTIAL INDICATOR OF CLIMATE CHANGE

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Hydrological budgets

Water budgets from individual catrchments are important as indicators of global climate change for at least two rasons:

- patterns and amounts of precipitation as well as evapotranspiration are all factors that are likely to chage as a result of global climate change. A global network of catchments with high quality long trem hydrologicl monitoring will serve as important tools to quantify such changes. Monitoring of water budgets are also nessesary to verify changes that are predicted by mathematical modelling of ecosystem effects as a result of changes in global climate.

- at higher latitudes large pools of carbon, nitrogen, sulphur and heavy metals like mercury from natural and anthropogenic sources have been stored in the organc soil layers over long time.

Mineralisation rates may increase due to changes in temperatur and /or the water budget, which could result in increased output fluxes of these elements from the soils to streams and lakes. Such changes in the chemical fluxes can result in acidification of soils and water, eutophication, increased methyl mercury content in fish and other effects in the ecosystem.

Measurements of water budgets

Precipitation, throughfall, stemflow (forested sites with broad leafed trees), ground water level and runoff measured on a more or less contineous basis are minnimum requirements at forested sites to calculate good water budgets. Also measurements of soil water tention in the unsaturated zone are important but may only be used at more advanced sites. At non forested sites minimum requirements are measurments of precipitation, ground water level and runoff. These measurements are generally simpel, routine low cost and less labour-demanding than most biological and chemical measurements.

At forested sites in the northern Hemisphere total evapotranspiration often equals or exceeds 50% of the yearly precipitation. The water budget of a Norway spruce forest at Gårdsjön in southwest Sweden showed that 30%-40% was evaporation and 10%-20% is transpiration of an annual precipitation of about 1 100 mm.

These data are derived from indirect measurements and model calculations rather than expensive direct measurements. Eddy correlation technique is not used at any of the monitored catchments in Sweden.

Monitoring of the water budget could be combined with hydrological modelling. The models allow for predictions of changes in the water budget with changes in climate at selected sites. Most models use daily meterological data as driving variables (temperature, relative humidity, windspeed, precipitation and global radiation). Other important data are soil properties such as soil water tension (pF curves), hydrolic coductivity, thermal conductivity and heat capacity. The plant properties are those controling water uptake and tranpiration. Such data are seasonal variations in leaf area index, surfsce resistance of the vegetation and root development. Several of these measurements are expensive and labour-demanding and modeling can therefore only be used on more intensly studied sites.

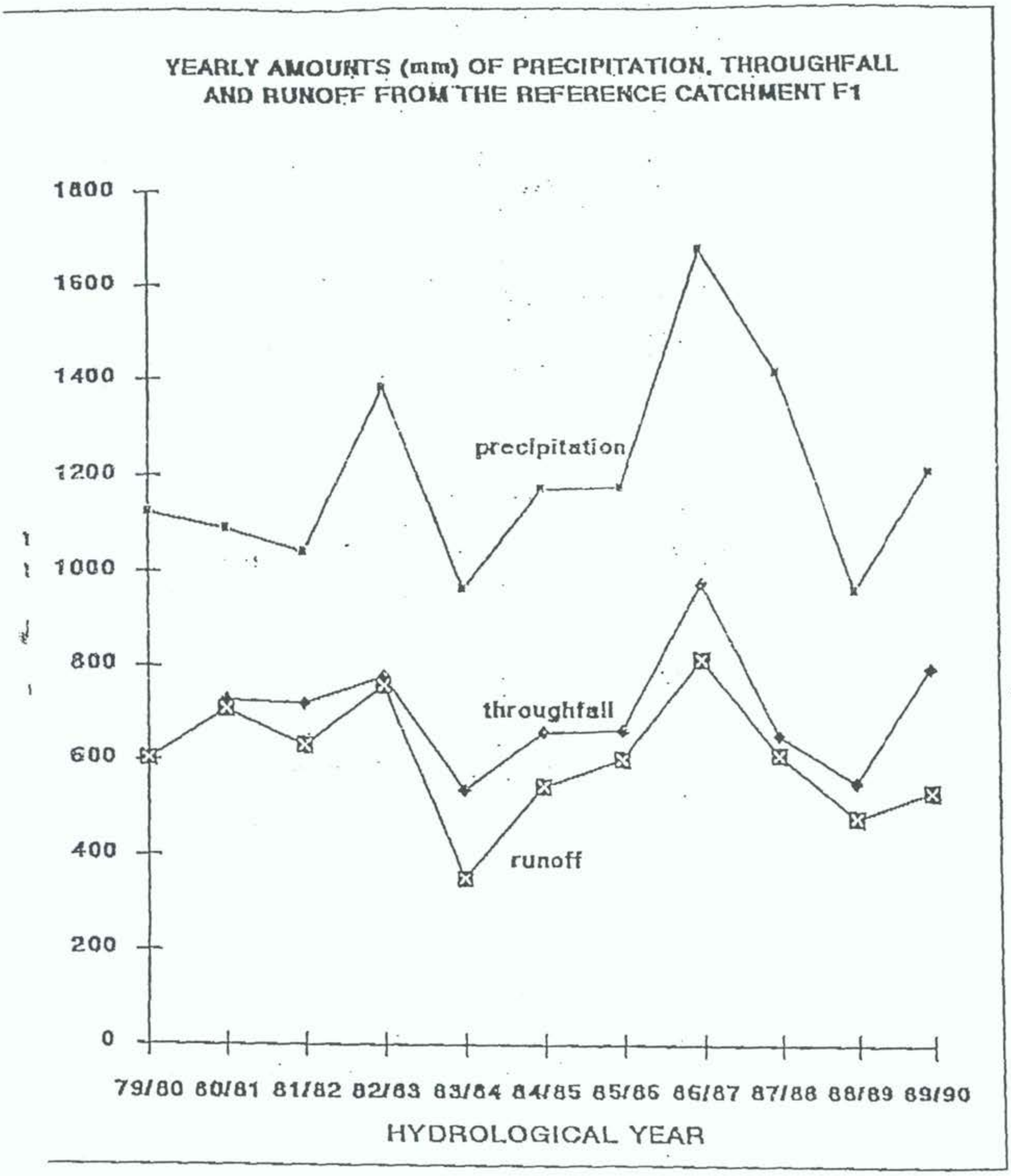
Suitable parameters for climate change

Changes in seasonal pattern and quantity of runoff water from catchments has a high sensitivity to climate change and a known natural variability in different regions over large parts of the globe.

The most sutible sites are small catchments with a uniform soil and vegetation cover, watertight bedrock equipped with a dam, water level recorder and weir at the outlet of the catchment.

Together with precipitation monitoring this will give basic data for detection of changes in the water budget due to climate change. At forested sites throughfall and if broad leafed trees are important also stemflow should be monitored to allow for estimates of evaporation from the tree crowns. If sutible sites are available these measurements are the least expensive, least labour intense and can be used over large parts of the globe.
These input-output budgets of water can also be used for flux measurements of ions of which some are sensitive to climate change.

At some representative sites soil water tension, transpiration rate should be monitored and modelling of the water budget should be performed.


YEARLY AMOUNTS (mm) OF PRECIPITATION, THROUGHFALL
AND RUNOFF FROM THE REFERENCE CATCHMENT F1
1800
1600
1400
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800
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precipitation
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HYDROLOGICAL YEAR

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Chapter 3

CLIMATE CONSTRAINTS ON CROPPING SYSTEMS

M.F. HUTCHINSON, H.A. NIX and J.P. McMAHON

INTRODUCTION

The dominant control exerted by climate on the global distribution of both natural and cultivated vegetation has long been recognized. Accordingly, early classifications of the world's climates, notably those of Köppen (1900, 1923) and Thornthwaite (1931), though based on long-term monthly mean values of rainfall and temperature, have class limits that correspond with the boundaries of natural vegetation formations. These classifications rely on plants to integrate the effects of the enormous diversity in climate over the surface of the earth in order to define "natural" climatic divisions. Functional links between climate and vegetation are not explicitly defined, although they are implicit in the classification process. Most applications of these global classifications have been descriptive. They have limited utility in important dynamic roles such as assessing the potential of new crops in particular regions or identifying aspects of existing crops which can be enhanced by selective breeding or modified management practices.

Later classifications such as those of Thornthwaite (1948) and Papadakis (1975) have addressed these inadequacies by adopting a more functional approach to the effects of temperature and soil moisture on the growth of plants. As pointed out by Thornthwaite and Mather (1954), these analyses are in the tradition of much earlier work by de Réaumur (1735), who devised the method of temperature summation to quantify the heat required to bring plants to various stages of maturity. Continuing in this tradition, computer models have been devised in more recent times which seek to model the growth and development of crops in terms of climate and other factors to varying levels of detail (Robertson, 1983). However, the more comprehensive such models become, the more limiting becomes the availability of specified input data. Obviously a balance must be struck between model complexity and data availability.

In order to gain a more functional understanding of the constraints imposed by climate on crop growth, as exemplified by such crop growth models, we present a new classification of the world's climates based on output from a relatively simple but robust general plant growth model GROWEST. This has been applied to monthly climatic data for 4159 stations worldwide. The GROWEST model, which runs on a weekly time step, was developed initially by Fitzpatrick and Nix (1970) for use in a comparative analysis of temperate and tropical pasture species at a continental scale, and was expanded and more fully described by Nix (1981). It incorporates the responses of plants to the three major climatic determinants of crop growth and development: light, temperature and moisture. Moisture availability is modelled by running a simple weekly water balance depending on mean precipitation and potential evapotranspiration. The GROWEST model is of necessity generalized, in view of both the level of available climatic data and the difficulties of incorporating more detailed species-specific responses.

We first describe the constraints imposed on crop growth by light, temperature and moisture, including those simulated by the GROWEST model. Practical problems of estimating missing climate data, particularly values of solar radiation and potential evaporation, are also addressed. For the present study, solar radiation has been estimated from sunshine duration using a modified

Ångström equation which takes into account the effects of both surface albedo and prevailing air mass. Pan evaporation has been estimated from solar radiation, temperature and saturation deficit using an empirical regression formula motivated by the semi-empirical combination formula of Penman (1948).

Frequently climatic data are unavailable at locations where crops are grown, and necessary data must be interpolated from neighbouring meteorological stations. The nature of the spatial variation of climate at both microscale and mesoscale is therefore briefly described. Over half of the 4159 stations in the present study recorded neither solar radiation nor sunshine duration, so an objective spatial interpolation method has been applied to calculate estimates of solar radiation for these stations.

The climate classification has been obtained using a numerical taxonomy package (Belbin et al., 1984) to classify selected GROWEST indices for each of the 4159 stations. The classification into 34 classes provides a basis for evaluation of crop response to macroclimate and is illustrated by choosing a representative station from each class. For each selected station the light, temperature, moisture and growth indices as output from the GROWEST model are plotted and the relevant limiting features of the climte are discussed.

CLIMATIC CONSTRAINTS ON CROP GROWTH

The generalized response functions, from which the GROWEST model is constructed, transform the dynamic, non-linear responses of plants to solar radiation, temperature and available soil moisture into three dimensionless indices on a linear scale from zero to unity. Each of these derived indices: light index (LI), temperature index (TI) and moisture index (MI), represents plant dry matter production relative to dry matter production at non-limiting values of that factor. Thus, each index has values ranging from zero (completely limiting conditions) to unity (non-limiting conditions for growth). These core functional relationships have been fully described by Nix (1981).

Solar radiation

Crop production can be regarded as the conversion of solar energy into useful end-products. In the absence of other restrictions, crop growth is determined by the photosynthetically active component of incident solar radiation. This is modified in practice by complex interactions between the structure of the plant canopy and physiological properties, so that measured efficiencies of the conversion of incident solar radiation into biological yields do not exceeed 1% and are often much less (Holliday, 1966; Penman, 1968). Thus, while all other inputs to the crop are ultimately dependent on received solar radiation, this factor is not in itself a strong discriminant of crop growth. There is sufficient solar radiation for crop growth over much of the earth's surface, and temperature and available moisture are usually more critical limiting factors of the climate. The functional relationship between dry matter production (expressed as a fraction of the maximum possible, or potential, production) and total daily solar radiation used in the GROWEST model is based on theoretical considerations by Davidson and Philip (1958) and de Wit (1959, 1965), together with experimental data relating to a range of tropical and temperate species (Hesketh, 1963; Cooper, 1966; Tanaka et al., 1966). The resulting light index is formulated as

$$LI = 1.0 - \exp(-3.5\, R) \tag{1}$$

where R is total daily solar radiation expressed as a fraction of an assigned upper limit to daily solar radiation of 31.4 MJ m^{-2} day^{-1}.

Apart from its effect on temperature and potential evaporation, which are treated separately, a significant effect of the daily solar cycle, and its determination of daylength (photoperiod), is its influence on development rates of crops. Short-day crops require daylengths less than 12–14 h to induce flowering. They include rice (*Oryza indica*), soybean, sugar-cane, coffee, tropical yam, potato and maize. On the other hand, long-day crops require daylengths longer than 12–14 h to promote flowering, and include wheat, barley, oats, onion and sunflower. Crops which are day-neutral include pineapple, rice (*O. japonica*), tomato, early peas, sweet potatoes, apple, cotton and squash (Thorne, 1979; Robertson, 1983).

Temperature

Provided light conditions are non-limiting, and sufficient moisture is available to maintain plant turgor and prevent stomatal closure during the day, temperatures play a primary role in determining growth and maturation rates. Temperature summation methods provide a first approximation to estimates of critical phenological stages in crop development (Robertson, 1983). The generalized GROWEST model simulates the effect of temperature on rates of growth, but does not simulate phenological development because this is species- and cultivar-specific. However, it is not difficult to incorporate this component when required for more detailed crop-specific analysis.

Plant species exhibit characteristic response curves to temperature in terms of rates of dry matter accumulation, with a lower temperature threshold, an optimum and a higher temperature threshold. Analysis of growth and dry matter production for a wide range of species has indicated a series of distinct groups of plants, each exhibiting broadly similar thermal responses (Nix, 1981). Thus it is possible to recognize a microtherm assemblage (mainly conifers and plants of the cool-temperate climates) with thermal optima in the 10 to 12°C range, lower temperature threshold at 0°C or lower, and upper temperature threshold at around 25°C; a mesotherm assemblage (including all the major temperate crop species such as wheat, barley, oats) with thermal optima in the 19 to 22°C range, lower temperature threshold at around 5°C, and upper temperature threshold at around 35°C; and a megatherm assemblage which differentiates into two broad groups depending on their possession of a C_3 or C_4 photosynthetic pathway. Megatherms with the C_3 pathway (tropical broad-leaved plants) have thermal optima in the 28 to 30°C range, lower temperature thresholds at around 10°C, and upper temperature threshold at around 40°C. Megatherms with the C_4 pathway (tropical grasses) have thermal optima in the 35 to 40°C range and lower temperature thresholds at around 10°C. Since daily mean temperatures for any week at any location do not exceed 40°C, the supraoptimal range is not applicable. Moreover, because C_4 species have much higher growth rates, the single megatherm C_3 response curve provides an approximation for both groups.

The derived curves relating fractional dry matter production to mean daily temperature are specified mathematically by a combination of power functions based on the relative deviations of temperature above or below the specified optimum temperature. The maximum absolute deviations are taken as the differences between the optimum temperature and the upper and lower thresholds, at which fractional dry matter production is zero. Thus the thermal index TI is unity at the optimum daily temperature.

The other critical effect of temperature, which is not explicitly included in the GROWEST model, is that due to temperature extremes. These can cause serious losses, in particular those associated with frost and heatwaves. Accordingly, we have included as factors in our classification the mean minimum temperature for the coldest month and the mean maximum temperature for the hottest month. Seasonal and diurnal variations in temperature both tend to become more extreme with increasing continentality.

Moisture

While moisture is a critical determinant of crop growth, its effect cannot be estimated simply from precipitation. The real moisture limit to plant growth is set by the amount of water available to the plant in the root zone. Since the soil can store water, this is determined by recent input due to precipitation and irrigation as well as depletion due to evapotranspiration. This process is modelled in the GROWEST model by maintaining a simple weekly water balance. Though actual day-to-day variation of precipitation and evapotranspiration can be large, errors in estimating weekly precipitation and potential evaporation from long-term monthly mean values are ameliorated by the integrative effect of maintaining a store of available water.

For the purposes of comparative study the moisture index MI is related in a linear 1:1 relationship to E_a/E_t as calculated from the weekly water balance (Nix, 1981). Here E_t is potential evapotranspiration and E_a is actual evapotranspiration. A simple exponential function is used to relate E_a/E_t to the relative available water storage in the root zone. It is also assumed for the purposes of comparative study that:

– the vegetated surface can achieve full canopy where water is non-limiting, so that E_t can

be equated to E_o, the potential evaporation as measured by a class A pan evaporimeter.
— the drying curve used to estimate E_a/E_t as a function of relative water storage represents a medium-textured, clay loam soil with available water storage in the root zone of 150 mm.

The GROWEST model

The overall GROWEST model is constructed by combining the separate environmental indices into a single multifactor growth index defined by

$$GI = LI \times TI \times MI \tag{2}$$

No simple relation can hope to describe fully the complex genotype–environment interactions involved in plant response to light, temperature and moisture. However, sensitivity analysis indicates that, for a weekly time step, this multiplicative function is marginally superior to the law of the minimum where the value of the growth index is taken to be the value of the most limiting factor (Nix, 1981). In its simplest form the model is calibrated to simulate actual dry matter production by using the growth index as a factor in a simple growth-rate equation given by

$$dW/dt = k \times GI \times W \tag{3}$$

where W is the weight of dry matter, t is time and k is a crop-dependent constant. Over periods up to a few months this equation gives rise to growth curves which can be reasonably approximated by a linear function of accumulated growth index GI. Hence we use quarterly (that is, 13-week) sums of GI as the primary basis for our classification of climate.

ESTIMATING MISSING DATA

The provision of adequate climatic data for a world classification is a major task. The problem of estimating missing data for particular sites is ever-present. Most meteorological stations record daily minimum and maximum temperature and daily precipitation, but relatively few record total solar radiation or potential evaporation. Agroclimatology abounds with attempts to estimate these two variables from other more routinely measured quantities. We briefly describe below the methods we have adopted to estimate monthly mean solar radiation from sunshine duration and monthly mean potential evaporation from solar radiation, temperature and saturation deficit. Further details will appear elsewhere.

For sites without a suitable data base for estimation of missing climate variables, it becomes necessary to interpolate values using data from nearby stations. Objective techniques for spatial interpolation which have recently been developed can take advantage of the spatial coherence displayed by most monthly mean climate values, particularly in relation to elevation, to provide estimates with errors which are comparable with actual measurement error.

Estimating monthly mean solar radiation

The review by Martinez-Lozano et al. (1984) describes the long history of attempts to estimate solar radiation from sunshine duration. The basic relationship is a modification due to Prescott (1940) of a linear regression developed by Ångström (1924) between relative solar radiation and relative sunshine duration. The modified equation takes the form

$$Q/Q_E = a + b\, n/N \tag{4}$$

where Q is total radiation at the earth's surface, Q_E is the radiation received on a horizontal surface at the top of the atmosphere, n is the actual duration of sunshine and N the maximum possible duration of sunshine. Q_E and N are astronomically determined quantities which vary systematically with latitude and time of year. The constants a and b are determined by least-squares linear regression, and are found in practice to vary slightly with geographic location.

Hay (1979) has shown that some of this variation can be accounted for by considering surface albedo. This is approximately 0.2 for much of the earth's land surface but can be as high as 0.8 over snow. Hay's modified equation is given by

$$Q'/Q_E = a + b\, n/N \tag{5}$$

where Q' is actual solar radiation before multiple reflections between the earth's surface and cloud, with a and b again determined by regression analysis.

We have employed a further modification of the Ångström equation which takes account of the prevailing air mass through which solar radiation has to penetrate to reach the earth's surface in a more physically interpretable fashion than earlier empirical attempts by Glover and McCulloch (1958). Our equation is given by

$$Q'/Q_E = 0.224 + 0.536\ w\ n/N \quad (6)$$

where $w = \exp(-0.1\ m)$ and m is the effective mean optical air mass over all daylight hours for the month (see Hay, 1979). This equation was fitted to monthly mean solar radiation and sunshine hour data for 289 stations ranging in latitude from 50°S to 70°N with $R^2 = 80\%$. The standard error for this regression expressed in percentage terms was 8.5%. This equation was used to estimate monthly mean total solar radiation from monthly mean sunshine duration for 736 stations.

Estimating monthly mean pan evaporation

We have taken class A pan evaporation as a measure of potential evaporation. The well-known combination formula for calculating potential evaporation (Penman, 1948), is based partly on physical consideration of the relative contribution of net radiation and advective effects on potential evaporation, and partly on empirical formulae for estimating both net radiation and the precise nature of the advective effects. The relative contribution of net radiation and advection is a function of temperature, while the advective contribution is determined by the saturation deficit modified in an empirical manner by mean wind-speed. Saturation deficit is a standard function of temperature and relative humidity (Abbott and Tabony, 1985).

Since standardized wind-speed measurements are rarely available, and the Penman formula is already partially empirical, we have developed an empirical regression relating measured class A pan evaporation to total radiation, temperature and saturation deficit. Its form is motivated in part by a simpler formula developed by Hargreaves (1981), as well as the Penman formula itself. It is given by

$$E_p = -0.40 + 0.122\ R - 0.023\ T + 0.0036\ R\ T + 0.246\ S \quad (7)$$

where E_p is pan evaporation in mm day^{-1}, R is total radiation in MJ m^{-2} day^{-1}, T is daily mean temperature in °C and S is saturation deficit in mbar at temperature T. Linear regression using monthly evaporation data for 395 stations worldwide yielded the constants given with $R^2 = 92\%$ and a standard error of 0.89 mm day^{-1}. This equation was used to estimate monthly mean potential evaporation for 3609 stations.

Spatial variation and interpolation of monthly climate means

Monthly mean climate values show significant variation at both the microscale and mesoscale. At the level of the individual plant there can be significant variations in temperature due to shading, both within the crop canopy and between the canopy and the soil. Soil temperatures are more stable than air temperatures, tending to be cooler than the air temperature during the day and warmer at night.

At somewhat larger scales, topographic effects such as slope and aspect can significantly affect received radiation and temperature. At night, cold-air drainage induced by topography can lead to local temperature inversions, the coldest areas occurring at the bottom of slopes and in depressions. In addition, proximity to large water bodies can markedly reduce the diurnal range in temperatures.

At a still larger mesoscale the effects of elevation on temperature and precipitation are well known. Temperatures decrease by about 6°C per rise of 1000 m in elevation. The effect of elevation on precipitation is less systematic but nonetheless significant. In the study by Hutchinson and Bischof (1983), annual precipitation on the east coast of New South Wales, Australia, was found to increase by approximately 1 mm for each rise of 1 m in elevation. These dependencies can be used to advantage when interpolating monthly mean climate values between meteorological stations. The method of Laplacian or thin plate smoothing splines (Wahba and Wendelberger, 1980) can incorporate independent variables such as elevation in addition to the usual two spatial variables. This technique has been used to interpolate monthly mean maximum and minimum temperatures across Australia, to within a standard error of 0.5°C, and monthly mean precipitation to within a standard error of about 10% (Hutchinson, 1984).

The spatial distribution of solar radiation in the absence of cloud is determined principally by astronomical calculations depending on latitude, time of year and the solar constant. Significant cloud, associated primarily, but not always, with precipitation, modifies this distribution. Hutchinson et al. (1984) have used Laplacian smoothing spline techniques to interpolate monthly mean total solar radiation across Australia, to within an accuracy of a few per cent, by incorporating a cloudiness index based on monthly mean precipitation. For 2136 stations used in the present study neither sunshine data nor solar radiation data were available. Simplifying this technique, by using elevation instead of a cloudiness index, continent-wide surfaces were fitted to monthly mean solar radiation data from a total of 2023 stations in order to obtain estimates of solar radiation where no suitable data were available. Standard errors for these estimates were approximately the same as for the modified Ångström relationship described above.

A CLASSIFICATION OF CLIMATE BASED ON POTENTIAL CROP PRODUCTION

Our classification of the world's climates is based on monthly data for 4159 stations distributed over most of the world's land surface as shown in Fig. 3.1. The number of stations for each continent is given in Table 3.1. Coverage is adequate to define macroclimate except for parts of Indonesia and the more remote continental parts of Asia. A numerical taxonomy package called NTP, developed by Belbin et al. (1984), was used to classify the 4159 stations according to 30 attributes. Except for the mean and seasonality attributes and the two attributes based on temperature extremes, the attributes were based on successive 13-week accumulated values of indices calculated by the GROWEST crop growth model for each week of the year for mesotherm plants (temperature optimum = 19°C) and C_3 megatherms (temperature optimum = 28°C). Thirteen standard weeks equals 91 days, which corresponds to the growing period for the earliest-maturing grain crops grown in very favourable climates, and also provides a measure of the most important period for growth of later-maturing and perennial crops. With subscripts denoting the optimum temperature where relevant, these attributes were grouped into six temperature, growth and moisture groups as follows:

TABLE 3.1

Numbers of meteorological stations by continent used in the classification

Continent	Number of stations
North America	449
South America	553
Europe	345
Asia	1045
Africa	588
Australasia	1135
Oceania	44

1. Thermal regime — mesotherm.
   1. Annual mean TI_{19}.
   2. Seasonality (i.e. coefficient of variation) of weekly TI_{19}.
   3. Lowest 13-week mean TI_{19}.
   4. Highest 13-week mean TI_{19}.
   5. Mean TI_{19} for the lowest 13-week mean GI_{19}.
   6. Mean TI_{19} for the highest 13-week mean GI_{19}.

2. Growth pattern — mesotherm.
   7. Annual mean GI_{19}.
   8. Seasonality of weekly GI_{19}.
   9. Lowest 13-week mean GI_{19}.
   10. Highest 13-week mean GI_{19}.

3. Thermal regime — megatherm.
   11. Annual mean TI_{28}.
   12. Seasonality of weekly TI_{28}.
   13. Lowest 13-week mean TI_{28}.
   14. Highest 13-week mean TI_{28}.
   15. Mean TI_{28} for the lowest 13-week mean GI_{28}.
   16. Mean TI_{28} for the highest 13-week mean GI_{28}.

4. Growth pattern — megatherm.
   17. Annual mean GI_{28}.
   18. Seasonality of weekly GI_{28}.
   19. Lowest 13-week mean GI_{28}.
   20. Highest 13-week mean GI_{28}.

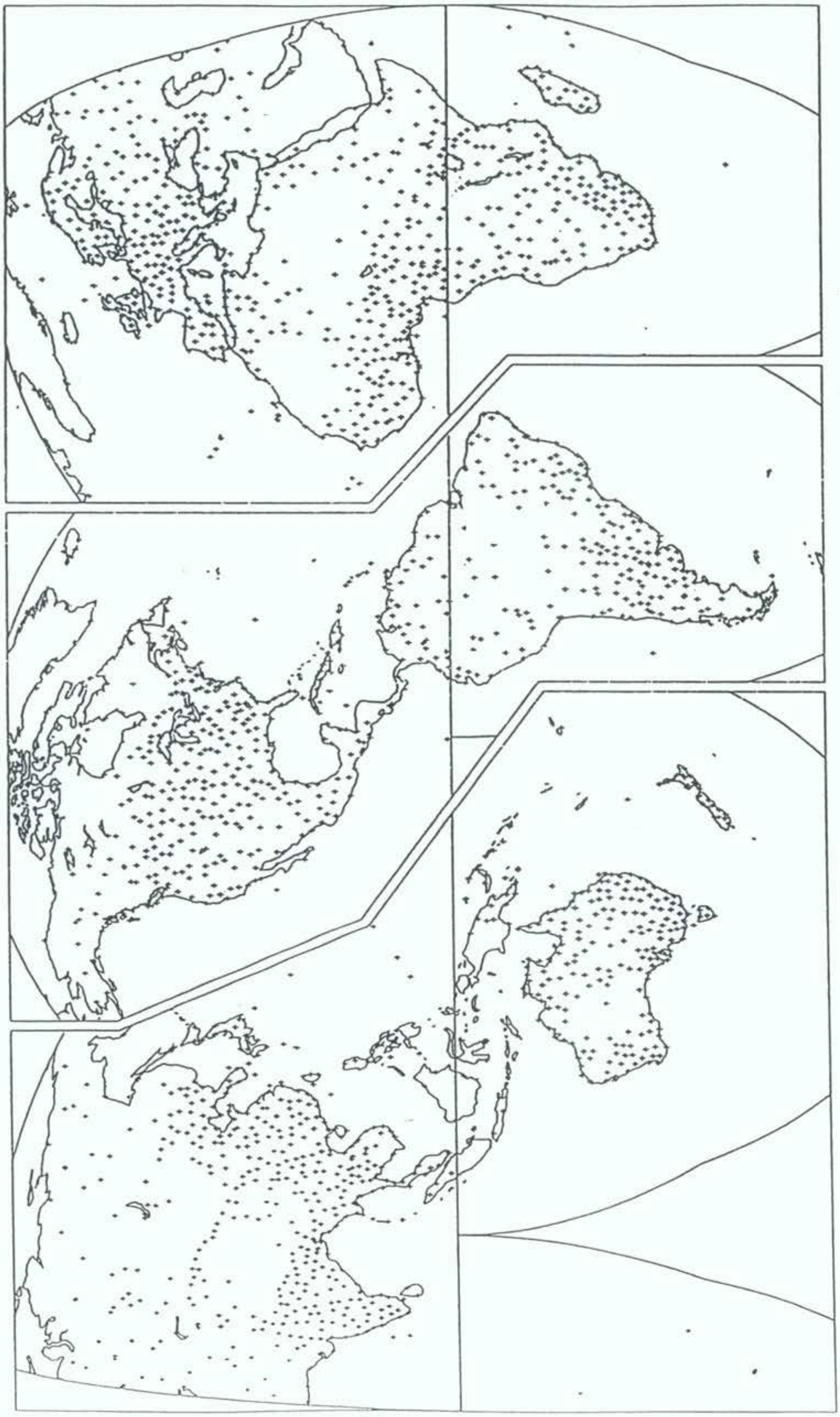


Fig. 3.1 The spatial distribution of the 4159 stations used in the world climate classification. Each + symbol may denote more than one station.

5. Moisture regime — mesotherm and megatherm.
   21. Annual mean MI.
   22. Seasonality of weekly MI.
   23. Lowest 13-week mean MI.
   24. Highest 13-week mean MI.
   25. Mean MI for the lowest 13-week mean GI_{19}.
   26. Mean MI for the highest 13-week mean GI_{19}.
   27. Mean MI for the lowest 13-week mean GI_{28}.
   28. Mean MI for the highest 13-week mean GI_{28}.

6. Temperature extremes.
   29. Mean daily minimum temperature for the coldest month.
   30. Mean daily maximum temperature for the hottest month.

These attributes describe the temperature, moisture and growth regimes and identify how temperature and moisture combine to produce various growth regimes. The inclusion of growth indices for both mesotherm and megatherm groups provides a basis for the analysis of climate on the basis of growth potential for all major field crops.

Stations were classified into 76 groups using a non-hierarchical, agglomerative technique (Belbin et al., 1984) which employed the Gower metric (Gower, 1971) applied to the 30 attributes grouped as above. The effect of the grouping of the attributes is to weight the overall differences for each group equally. This allows for reasonable spatial variation for individual attributes within each group across a climatic region, while still maintaining the overall character of each attribute group. The classification is essentially polythetic and therefore distinct from the monothetic classifications of Köppen, Thornthwaite and others which treat temperature and moisture regimes separately. Moreover, as with the classification of Papadakis (1975), the net result of the various climatic regimes as expressed in the growth index is a significant factor in the classification.

Though the classification is polythetic and non-hierarchical, it is possible to measure associations between groups according to the six groups of attributes described above, and to perform an agglomerative fusion or cluster analysis (Belbin, 1984). A weighted average strategy (WPGMA) was chosen. This weights fusion candidates equally regardless of group size, and is appropriate both with regard to the uneven sampling density of stations within each climatic region and, more importantly, so that the cluster analysis obtained is defined purely in terms of variation of the attributes. The generally recommended unweighted strategy (UPGMA), which weights fusion candidates in proportion to the number of members in each group, led to "chaining" of smaller groups onto larger ones.

The cluster analysis produced groupings of climatic regions which were consistent with their spatial associations. Significant differences between attributes at each step in the fusion indicated the relevant defining attributes for each climate group and collection of groups. Interestingly, though the classification is not monothetic, the broadest groupings were based on temperature except for the warm/hot and very dry (desert) climates. This parallels the principal Köppen divisions. The next divisions were principally based on moisture, giving rise to 10 broad groups:

A — very cold
B — cold
C — cool, dry
D — cool, wet
E — warm, seasonally wet/dry
F — warm, wet
G — warm to hot, very dry
H — hot, dry
I — hot, seasonally wet/dry
J — hot, wet

These ten groups were further subdivided using the cluster analysis into 34 groups and mapped in Fig. 3.2. The significant limiting attributes of climate for each of the 34 groups and the relations of each group to the climate classifications of Köppen (Strahler, 1975) and Papadakis (1975) are now described. The description also lists the natural vegetation and the principal field crops found in each class. For each class, a sample station has been selected and GROWEST index curves have been plotted in Fig. 3.3. The position and elevation above sea level are given for each example. A summary of the more significant GROWEST attributes consisting of annual mean TI_{19}, highest 13-week mean GI_{19}, annual mean TI_{28}, highest

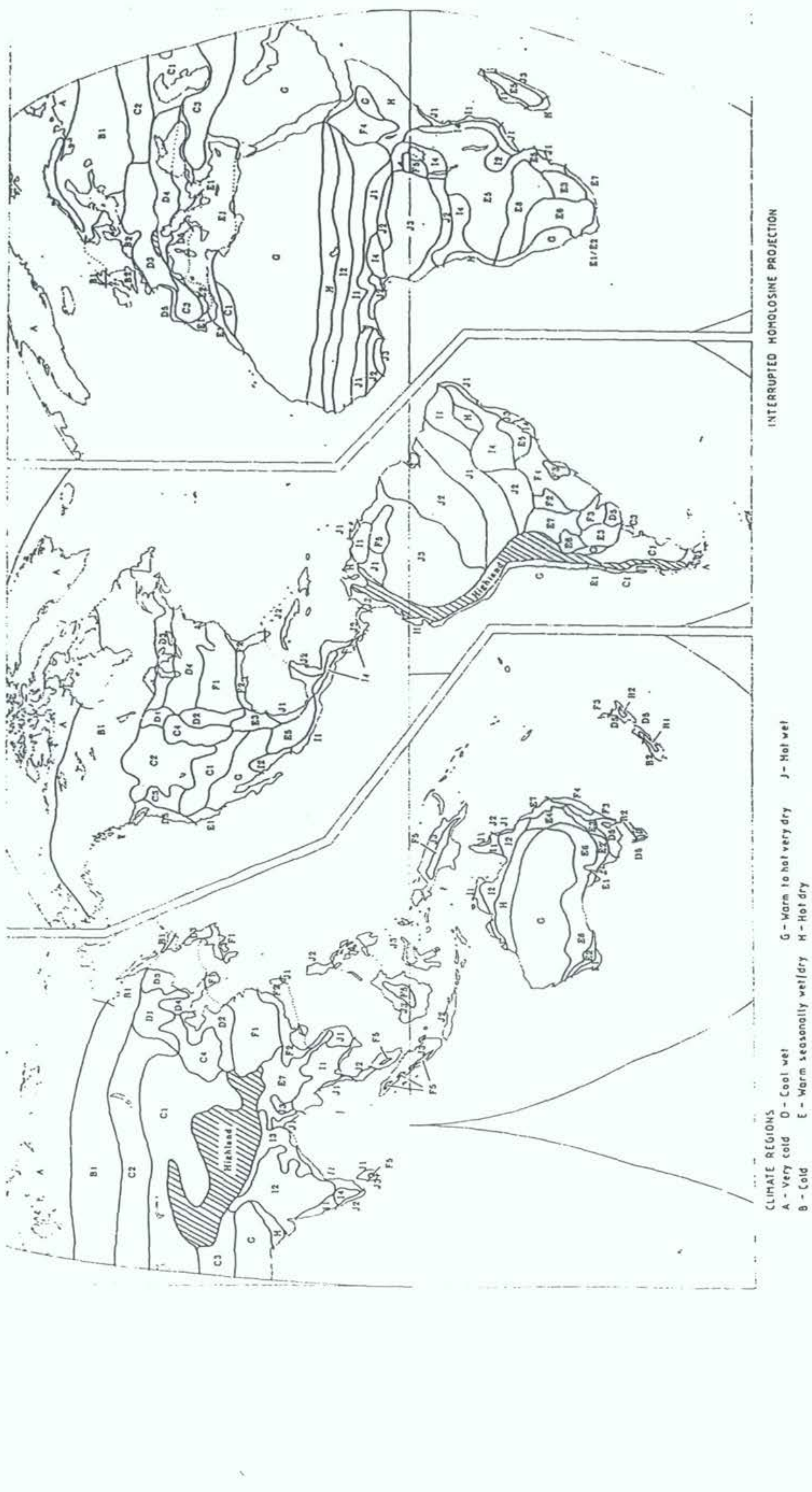


Fig. 3.2. An agro-climatic classification of world climate into 34 classes.

TABLE 3.2

GROWEST parameters for the 34 major agro-climatic groups

Group	Annual mean TI_{19}	Highest quarter GI_{19}	Annual mean TI_{28}	Highest quarter GI_{28}	Annual mean MI
Very cold					
A	0.09	0.16	0.00	0.00	0.82
Cold					
B1	0.27	0.57	0.04	0.10	0.90
B2	0.42	0.72	0.05	0.13	0.94
Cool, dry					
C1	0.49	0.13	0.25	0.06	0.23
C2	0.39	0.28	0.14	0.11	0.45
C3	0.56	0.31	0.27	0.10	0.45
C4	0.49	0.41	0.27	0.32	0.32
Cool, wet					
D1	0.38	0.64	0.17	0.40	0.59
D2	0.49	0.57	0.38	0.61	0.53
D3	0.43	0.78	0.13	0.33	0.91
D4	0.50	0.79	0.26	0.56	0.88
D5	0.63	0.66	0.17	0.18	0.76
Warm, seasonally wet/dry					
E1	0.81	0.65	0.35	0.13	0.55
E2	0.79	0.37	0.37	0.09	0.37
E3	0.75	0.46	0.36	0.30	0.45
E4	0.79	0.30	0.56	0.34	0.32
E5	0.97	0.85	0.51	0.51	0.57
E6	0.80	0.19	0.47	0.12	0.17
E7	0.89	0.69	0.54	0.62	0.62
E8	0.90	0.51	0.60	0.47	0.29
Warm, wet					
F1	0.57	0.78	0.43	0.81	0.91
F2	0.74	0.77	0.66	0.86	0.89
F3	0.84	0.81	0.35	0.51	0.78
F4	0.94	0.85	0.50	0.66	0.87
F5	0.98	0.89	0.63	0.66	0.96
Warm to hot, very dry					
G	0.63	0.10	0.64	0.12	0.10
Hot, dry					
H	0.56	0.19	0.89	0.44	0.20
Hot, seasonally wet/dry					
I1	0.51	0.48	0.96	0.87	0.52
I2	0.53	0.40	0.81	0.82	0.38
I3	0.62	0.60	0.78	0.87	0.64
I4	0.90	0.80	0.82	0.78	0.65
Hot, wet					
J1	0.65	0.66	0.94	0.84	0.66
J2	0.59	0.62	0.96	0.88	0.82
J3	0.68	0.67	0.94	0.88	0.97

13-week mean GI_{28} and annual mean MI is given in Table 3.2.

A. Very cold climates

These are the climates of polar and alpine regions. They are too cold for significant crop growth. Annual mean TI_{19} does not exceed 0.3 and is usually much less. Divisions can be made on the basis of moisture (annual mean MI ranges from 0.3 to 1.0), but these are hardly significant for crop growth and have not been distinguished here. This class corresponds quite closely to

Köppen class E (ice climates) and Papadakis class 10 (polar climates). Example: Nome, Alaska, lat. 64°30′N, long. 165°26′W, elev. 4 m.

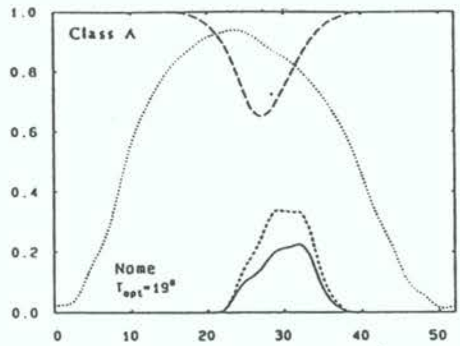
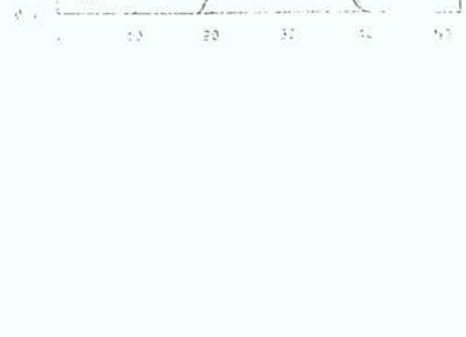


Fig. 3.3. GROWEST index curves which estimate weekly growth of vegetation for a representative station from each agro-climatic class. The horizontal scale is weeks of the year, beginning in January. (———), growth index; (- - - -), temperature index; (— — —), moisture index and (....), light index.

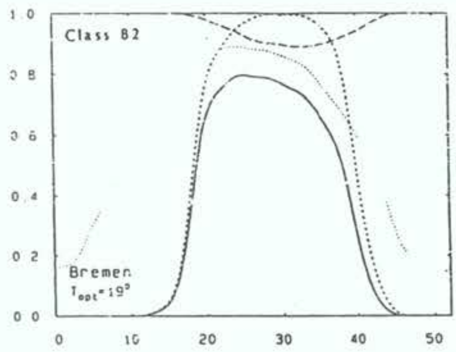
B. Cold climates

These climates have very cold winters, but short summers which are warm enough to permit significant growth. Annual mean TI_{19} varies from 0.15 to 0.6 and, of more significance for growth in these regions, the highest 13-week mean TI_{19} (i.e. in midsummer) ranges from 0.5 to 1.0. Moisture is not a major limiting factor, partly because evaporation rates are not high except in midsummer, with an annual mean MI which ranges from 0.55 to 1.0. A temperature-based subdivision can be made:

B1. This class has very cold winters and short, mild summers with an annual mean TI_{19} which ranges from 0.15 to 0.4. Summers are sufficiently warm and moist for the growth of coniferous forest in the northern regions of Europe, Asia and North America. This class corresponds to Köppen class D (snow climates) and approximately to Papadakis class 10.1 (taiga). Except for the warmer coastal margin of Finland, where barley and oats are grown, summers are too short for the growth of field crops. Example: Tomsk, Soviet Union, lat. 56°30′N, long. 84°58′E, elev. 122 m.



B2. This class has less severe winters than B1 and longer, moist summers. The annual mean TI_{19} ranges from 0.3 to 0.6. The class is associated with the more maritime parts of northern Europe between 40° and 50°N. This corresponds to the cooler half of Köppen class Cfb and approximately to Papadakis classes 7.2 (cool marine) and the maritime portion of 7.6 (cool temperate). The natural vegetation for this class is broadleaf deciduous forest. Field crops include oats, potatoes, wheat, barley and sugar beet. Example: Bremen, West Germany, lat. 53°5′N, long. 8°47′E, elev. 16 m.



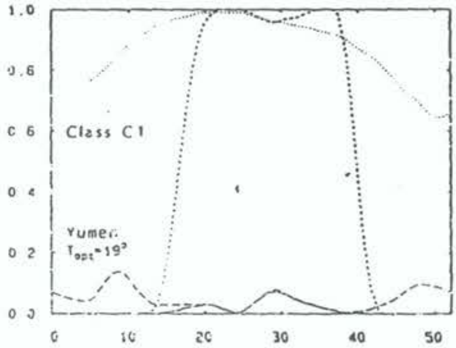
Cool climates

Cool climates have warm to hot summers and cold, growth-limiting winters. They are chiefly characterized by having an annual mean TI_{19} which ranges from 0.3 to 0.8, and a lowest 13-week mean TI_{19} which approaches zero.

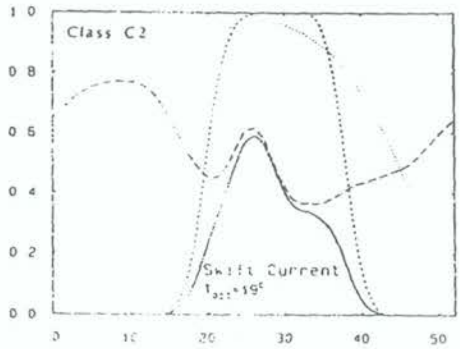
C. Cool, dry climates

Cool, dry climates are found in continental locations. They have summers which range from dry to sub-humid, with an annual mean MI which ranges from 0.0 to 0.7. Winters vary considerably in moisture, but this is of little consequence since winters are too cold for significant growth. Consequently, the principal defining characteristic of the cool, dry class within the collection of cool climates is low growth, with an annual mean GI_{19} which ranges from 0.0 to 0.25.

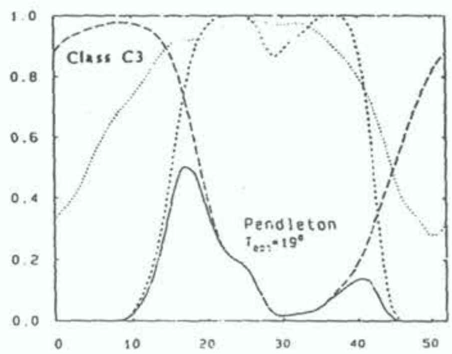
C1. Cool, very dry climates are characterized by having summers which are too dry to support significant growth and dry winters. They are found in continental and highland regions of central Asia, North and South America and north-west Africa. The highest 13-week mean GI_{19} does not usually exceed 0.3. They correspond approximately to Köppen classes BWk and Bsk, and Papadakis classes 3.7 (continental desert), 3.8 (Pampean desert) and 3.9 (Patagonian desert). Example: Yumen, China, lat. 40°16'N, long. 97°5'E, elev. 1534 m.



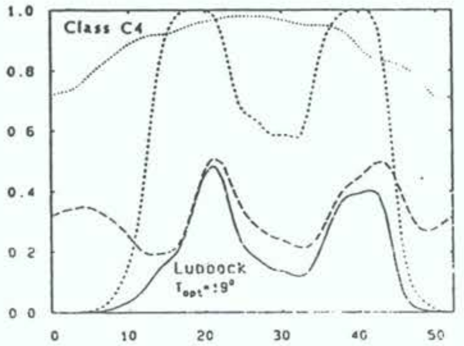
C2. This is moister than C1 and occupies continental areas of central Asia and North America. Winters tend to be moister than summer, with the annual mean MI ranging from 0.2 to 0.7. Temperature is subject to large seasonal variations due to continentality, with winter minimum temperatures ranging from −30 to 0°C and summer maximum temperatures ranging from 26 to 33°C. Natural vegetation for this class consists mainly of steppe and prairie grasslands. Field crops include spring wheat, oats, barley, linseed and cooler-adapted varieties of maize. This class corresponds approximately to Köppen class Bsk and Papadakis classes 9.2 (semi-warm steppe) and 9.3 (cold steppes). Example: Swift Current, Canada, lat. 50°17'N, long. 107°41'W, elev. 816 m.



C3. This has a cool, modified Mediterranean climate that is warmer than C2, with less severe winters and hotter summers. This is primarily due to its less continental and lower-latitude locations in the north-western United States, south-eastern South America, central Spain and southern central Asia. It has characteristically cold, wet winters and warm, dry summers, which give rise to a bimodal growth index curve with a strong peak in spring and a lesser peak in autumn. The annual mean MI is similar to that for C2, varying from 0.3 to 0.6. Natural vegetation consists mainly of steppe and prairie grassland, with coniferous forest occurring in more northerly locations in North America. Typical crops include spring wheat, oats, barley and grapes. This class corresponds to Köppen classes BSk and continental parts of Csb and to Papadakis classes 6.7 (continental Mediterranean) and 6.9 (continental semi-arid Mediterranean). Example: Pendleton, United States, lat. 45°41'N, long. 118°51'W, elev. 455 m.



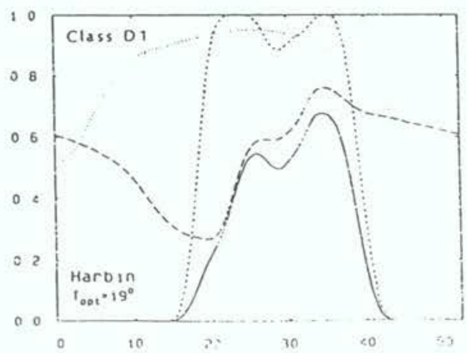
C4. This continental class differs from C2 and C3 in having drier winters and moister summers, being drier overall with an annual mean MI which ranges from 0.2 to 0.5. Temperatures exhibit the same large seasonal fluctuations as for C2, due to continental locations in the central United States and northern China. The growth index can show a bimodal character like that in C3, but this is partly due to summers being too hot for mesotherms as well as to moisture stress. Natural vegetation consists mainly of steppe and prairie grassland. Typical field crops include oats, millet and wheat, with maize and cotton grown under irrigation. This class corresponds to portions of Köppen classes Bsk, BSk and Dwb and to portions of Papadakis classes 9.2 (semi-warm steppe) and 9.8 (monsoon continental). Example: Lubbock, United States, lat. 33°39'N, long. 101°50'W, elev. 998 m.



D. Cool, wet climates

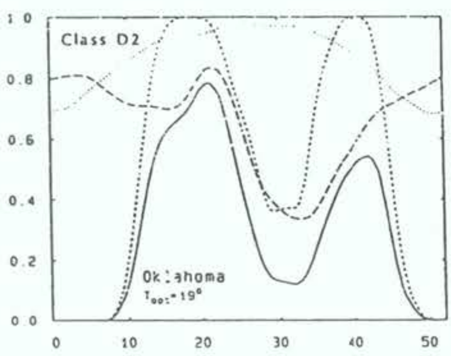
These include two drier continental classes, with an annual mean MI which ranges from 0.3 to 0.7, and three wetter classes with an annual mean MI which ranges from 0.5 to 1.0.

D1. This is the cooler of the two drier classes, and is characterized by an annual mean TI_{19} which ranges from 0.3 to 0.45. It occurs in central North America and in northern China. It has a relatively short period of good growth in midsummer, which is sharply limited by low temperatures in spring and autumn. The highest 13-week mean GI_{19} ranges from 0.5 to 0.75. Natural vegetation consists of deciduous forest, which merges into prairie grasslands in North America. Field crops can take advantage of winter moisture stored in the soil,

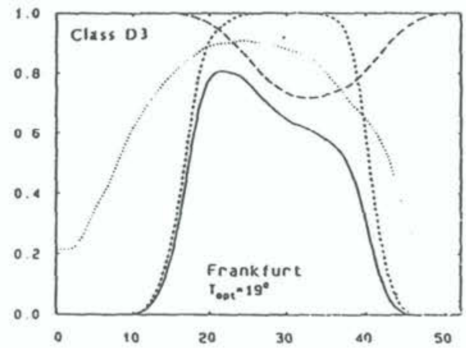


and include spring wheat, maize and soybeans. This class corresponds to Köppen classes Dfa and Dwa and Papadakis classes 8.3 (cold continental) and 9.3 (cold steppe). Example: Harbin, China, lat. 45°45'N, long. 126°38'E, elev. 145 m.

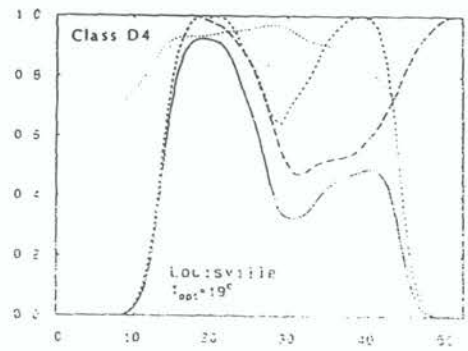
D2. This is warmer than D1, and is characterized by an annual mean TI_{19} which ranges from 0.45 to 0.6. It adjoins D1 to the south. Summers are relatively moist and hot, with a highest 13-week mean TI_{28} of around 0.9. The growth index for mesotherms is significantly limited by high temperatures in midsummer, with the highest 13-week mean GI_{19} ranging from 0.4 to 0.75. On the other hand, the growth index for megatherms is significantly limited by low temperatures in spring and autumn. Natural vegetation consists of deciduous forest. Field crops include wheat, millet, sorghum, maize, cotton, soybeans and tobacco. This class corresponds to portions of Köppen classes Cfa and Cwa and to Papadakis classes 9.1 (warm steppe) and 9.8 (monsoon continental). Example: Oklahoma City, United States, lat. 35°24'N, long. 97°36'W, elev. 390 m.



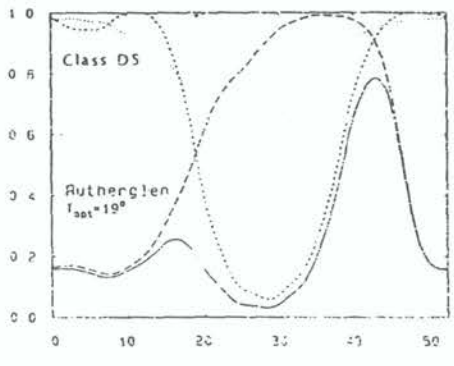
D3. This is the coolest of the three wetter classes, having relatively cold winters (lowest 13-week mean TI_{19} approximately zero) and mild summers (highest 13-week mean TI_{28} ranges from 0.3 to 0.65). The moisture regime is only slightly limiting in summer, which is long enough to permit at least 20 weeks of good growth. The highest 13-week mean GI_{19} ranges from 0.55 to 0.9. This class extends over central Europe, the Great Lakes district of the United States, northern Japan and the neighbouring coastal edge of Siberia. Natural vegetation consists of coniferous and deciduous forest. Crops cover a wide range, particularly in northern Europe, and include wheat, oats, barley, rye, sugar beet, potatoes and pome and stone fruits. This class corresponds to portions of Köppen classes Cfa, Cfb, Dfa, Dfb and Dwb and to Papadakis classes 7.6 (cool temperate) and 8.3 (cold continental). Example: Frankfurt, West Germany, lat. 50°7'N, long. 8°40'E, elev. 103 m.



D4. This is warmer than D3, having similarly cold winters but warmer summers (highest 13-week mean TI_{28} ranges from 0.65 to 0.9). The water regime is similar to that of D3, and this produces a similar growth pattern, with a highest 13-week mean GI_{19} ranging from 0.6 to 0.9. This class extends over southern continental Europe, the north-eastern United States and Korea. Natural vegetation consists mainly of deciduous forest. Crops include wheat, oats, barley, maize, rice, soybeans, sugar beet and pome and stone fruits. This class corresponds to portions of Köppen classes Cfa, Cfb and Dwa and to Papadakis classes 6.7 (continental Mediterranean), 8.2 (semi-warm continental) and 9.2 (semi-warm steppe). Example: Louisville, United States, lat. 38°11'N, long. 85°44'W, elev. 144 m.



D5. The warmest of the three wetter classes extends over mid-latitude, more maritime locations in Europe, North and South America, Australia and New Zealand. It is distinguished from D3 and D4 by having milder winters and longer summers, with a lowest 13-week mean TI_{19} which may be as high as 0.45. The moisture regime is similar to that for D3 and D4, being non-limiting in winter and only moderately limiting in summer. The highest 13-week mean GI_{19} ranges from 0.4 to 0.95. Natural vegetation consists mainly of sclerophyll forest. Crops include wheat, maize, grapes, pome and stone fruits, potatoes, sugar beet and tobacco. This class corresponds to portions of Köppen classes Cfa, Cfb and Csb and to Papadakis classes 4.1 (humid subtropical), 4.7 (marine subtropical), 6.1 (subtropical Mediterranean) and 6.5 (temperate Mediterranean). Example: Rutherglen, Australia, lat. 36°5'S, long. 146°29'E, elev. 167 m.



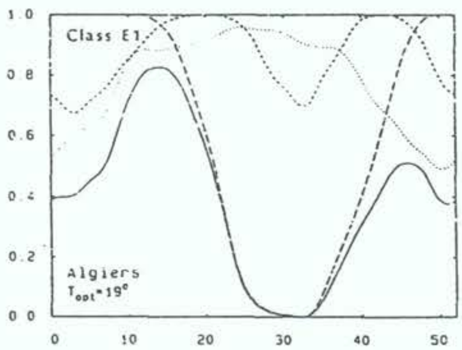
Warm climates

Warm climates have long, hot summers and mild winters which are not completely limiting to mesotherm crop growth. The annual mean TI_{19} ranges from 0.5 to 1.0 and the annual mean TI_{28} ranges from 0.0 to 0.8.

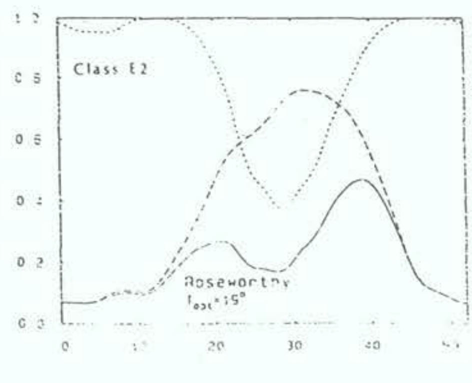
E. Warm, seasonally wet/dry climates

These are characterized by having a significant dry season, with the lowest 13-week mean MI averaging 0.15 across all classes and never being greater than about 0.5. Two classes corresponding to the classical Mediterranean climates are included in this collection. These are chiefly characterized by having a high mean TI_{19} (about 0.9) and a low mean MI (about 0.1) for the lowest 13-week mean GI_{19}. The period of lowest growth occurs in summer and is due to moisture stress, while winters are mild and moist with periods of substantial growth in autumn and spring. The remaining five members of the warm, wet/dry class occupy more continental locations and are subject to a variety of temperature and moisture constraints.

E1. This "Mediterranean" climate class has wet, very mild winters, giving rise to a bimodal growth pattern with substantial peaks in autumn and spring and moderate growth in winter. It is distinguished from the second "Mediterranean" class E2 by having a highest 13-week mean GI_{19} which ranges from 0.5 to 0.8. It extends over coastal areas of Mediterranean Europe, Australia and South Africa. Natural vegetation consists of sclerophyll forest, woodland and heath. Crops include spring wheat, barley, oats, tobacco, grapes, olives, pome and stone fruits. This class corresponds to portions of Köppen class Cs and to Papadakis classes 6.1 (subtropical Mediterranean) and 6.2 (marine Mediterranean). Example: Algiers, Algeria, lat. 36°48'N, long. 3°3'E, elev. 50 m.

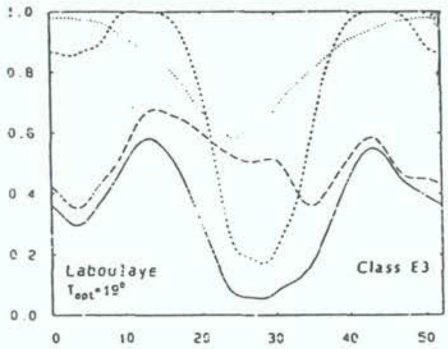


E2. This class has drier, cooler winters than E1, with a highest 13-week mean GI_{19} ranging from 0.2 to 0.5. It occurs mainly in Spain and in inland locations in southern Australia. The natural vegetation is sclerophyll forest, woodland, shrubland and heath. Crops include spring wheat, vines,

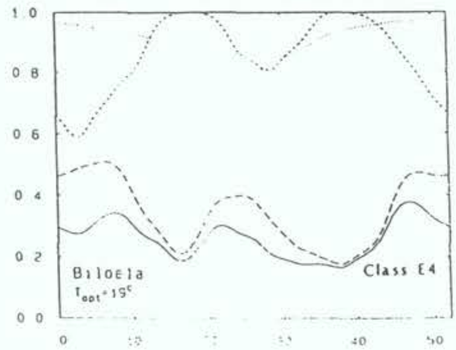


olives and citrus fruit. This class corresponds to portions of Köppen class Cs and to Papadakis class 6.8 (subtropical semi-arid Mediterranean). Example: Roseworthy, Australia, lat. 34°32'S, long. 138°41'E, elev. 65 m.

E3. This class has hot, moisture-limiting summers and cool, less wet winters, but with the highest 13-week mean GI_{19} normally occurring in summer. It is found on the western slopes of the southern highlands of Australia and Africa and in the Pampas of South America. Natural vegetation consists mainly of open woodland and grassland. Field crops include spring wheat, maize and tobacco. This class corresponds to portions of Köppen classes Cfa and BSh and to Papadakis class 5 (Pampean). Example: Laboulaye, Argentina, lat. 34°7'S, long. 63°23'W, elev. 138 m.

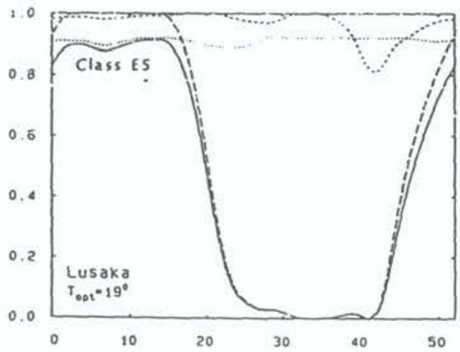


E4. This class is hotter and slightly drier than E3, and occurs only in continental eastern Australia. Winters are mild, so that moisture is the main limit to growth. Moisture is also less seasonal than in E3, so that the highest 13-week mean GI_{19} does not exceed 0.5. Natural vegetation consists of sclerophyll open forest merging into grassland. Spring wheat can be grown successfully provided use is made of moisture stored in the soil by bare

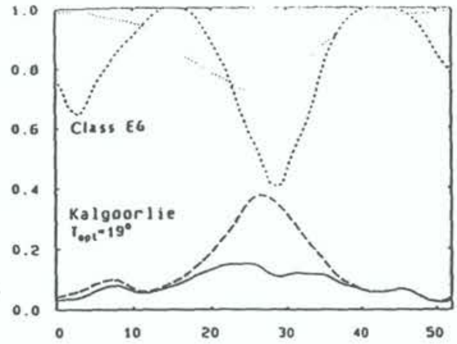


fallowing over summer. Grain sorghum and sunflowers are grown in summer. Cotton, maize and sown pasture, consisting of megatherm grasses and legumes, can be grown under irrigation. This class corresponds to portions of Köppen classes Cfa and BSh and to Papadakis class 4.2 (continental subtropical). Example: Biloela, Australia, lat. 24°24'S, long. 150°30'E, elev. 173 m.

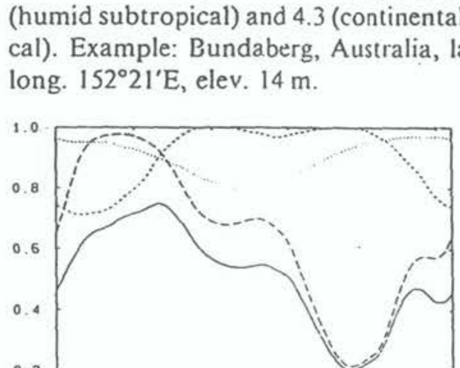
E5. This class is also a companion to E3 and is found in highland locations in southern central Africa, Madagascar, Mexico and eastern Brazil. The moisture regime is more seasonal than E4, with a moist summer and dry winter. Temperatures are less seasonal because of the highland, low latitude location. The annual mean MI ranges from 0.35 to 0.8 and the highest 13-week mean GI_{19} ranges from 0.65 to 0.9. Natural vegetation consists of savannah woodland. Field crops include maize, tobacco and tea. This class corresponds to portions of Köppen class Cwa and Papadakis classes 1.7 (humid tierra templada) and 2 (tierra fria). Example: Lusaka, Zambia, lat. 15°19'S, long. 28°27'E, elev. 1154 m.



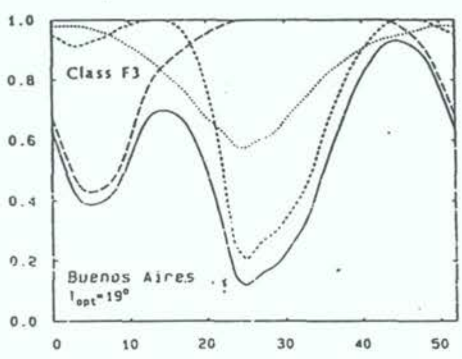
E6. This is semi-arid, forming a transition between the classes E1–E5 and the warm to hot, very dry climates. It has an annual mean MI which ranges from 0.1 to 0.3 and an annual mean GI_{19} which does not exceed 0.2. This is too dry to support field crops. It corresponds to a transition between Köppen classes BSh and BWh and forms a similar transition between Papadakis classes 3.2 (hot subtropical desert), 4.2 (continental subtropical) and 6.8 (subtropical semi-arid Mediterranean). Example: Kalgoorlie, Australia, lat. 30°47'S, long. 121°28'E, elev. 360 m.



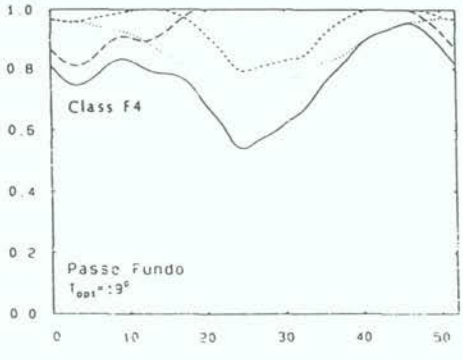
E7. This is the wettest of the warm, seasonally wet/dry climates, with an annual mean MI ranging from 0.4 to 0.8. It occurs in maritime subtropical locations in southern Africa and eastern Australia, and as a transition zone between hot, wet/dry zones and cooler, drier highlands in South America and south-eastern Asia. The more maritime and upland locations reduce the seasonal variation in temperature, so that moisture is the main limiting factor to crop growth. The highest 13-week mean GI_{19} ranges from 0.4 to 0.9. Natural vegetation consists of forest and woodland. Field-crops include sugar, cotton and tobacco. This class corresponds with portions of Köppen classes Cfa, Cfb and Cw and to portions of Papadakis classes 4.1 (humid subtropical) and 4.3 (continental semitropical). Example: Bundaberg, Australia, lat. 24°52'S, long. 152°21'E, elev. 14 m.



E8. This class is a higher latitude companion to E5 found only in highland parts of southern Africa. It is marked by a more seasonal temperature regime, with cooler winters and warmer, drier summers. The annual mean MI ranges from 0.2 to 0.4 and the highest 13-week mean GI_{19} ranges from 0.35 to 0.7. Natural vegetation consists of savannah woodland and scrub. Field crops include week mean GI_{19} ranges from 0.55 to 0.95, while the highest 13-week mean GI_{28} ranges from 0.25 to 0.75. It extends over coastal and adjacent upland areas of south-eastern Australia and South America. Natural vegetation consists mainly of rain forest and sclerophyll forest. Field crops include maize, wheat, potatoes and sown pasture. This class corresponds mainly to Köppen class Cfa and Papadakis class 5.3 (subtropical Pampean). Example: Buenos Aires, Argentina, lat. 34°35'S, long. 58°29'W, elev. 27 m.

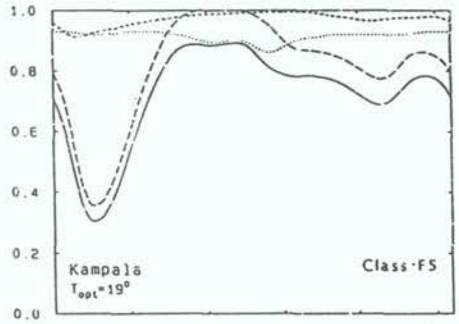


F4. This is warmer and wetter than F3, occurring on the east coast of South America and Australia immediately to the north of F3. It is also found in the highlands of Kenya and Ethiopia. Winters are mild, with a lowest 13-week mean TI_{19} ranging from 0.65 to 0.95. With annual mean MI ranging from 0.7 to 1.0, conditions for growth are very favourable, the annual mean GI_{19} ranging from 0.55 to 0.85. Natural vegetation consists of evergreen closed forest. Crops include rice, wheat, soybeans, cotton, tobacco, coffee, maize and sown pasture. This class corresponds to portions of Köppen classes Cfa and Aw and to Papadakis classes 1.7 (humid tierra templada), 4.7 (marine subtropical) and 7.1 (warm marine). Example:



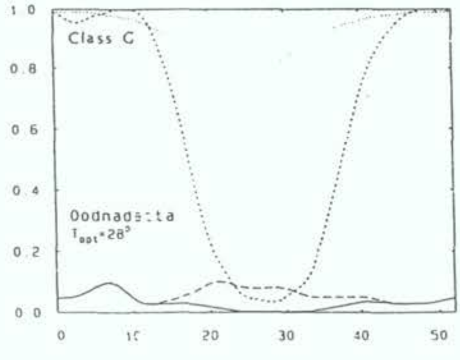
Passo Fundo, Brazil, lat. 28°15'S, long. 52°24'W, elev. 675 m.

F5. This equatorial highland class has lower, less seasonal temperatures. The annual mean TI_{19} ranges from 0.95 to 1.0 and the seasonality of TI_{19} is less than 0.1. The moisture regime is very favourable, with annual mean MI ranging from 0.8 to 1.0. The annual mean GI_{19} ranges from 0.75 to 0.9. A short, dry season is necessary for harvest. This class is situated in the equatorial highlands of Malaysia, Indonesia, New Guinea and South America. Natural vegetation consists of temperate and tropical rain forest. Crops include coffee, tea, cocoa and cooler adapted varieties of maize. This class is included in the highland Köppen class and corresponds to Papadakis class 1.7 (humid tierra templada). Example: Kampala, Uganda, lat. 0°20'N, long. 32°36'E, elev. 3720 m.

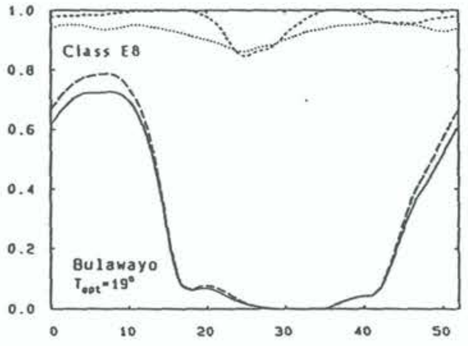


G. Warm to hot, very dry climates

These climates are principally distinguished by an annual mean MI which does not exceed 0.25. The annual mean GI_{19} and annual mean GI_{28} are both less than 0.2. A subdivision can be made on the basis of temperature, but this has little significance for crop growth. This class is found in the



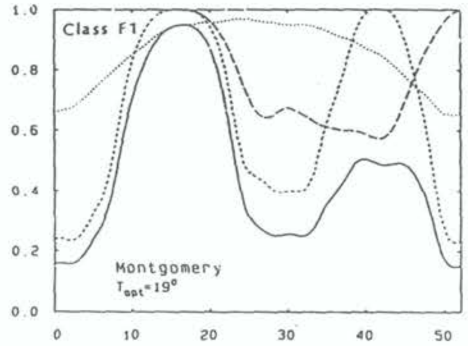
maize, sorghum, beans and tobacco. This class corresponds to portions of Köppen class BSh and Papadakis class 2 (tierra fria). Example: Bulawayo, Zimbabwe, lat. 20°9′S, long. 28°37′E, elev. 1345 m.

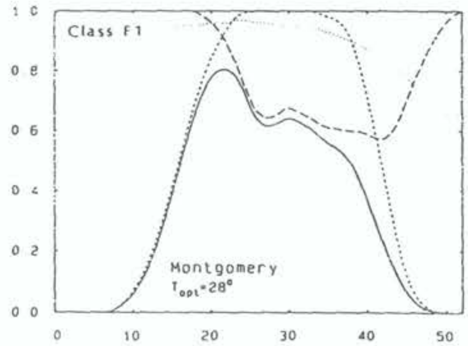


F. Warm, wet climates

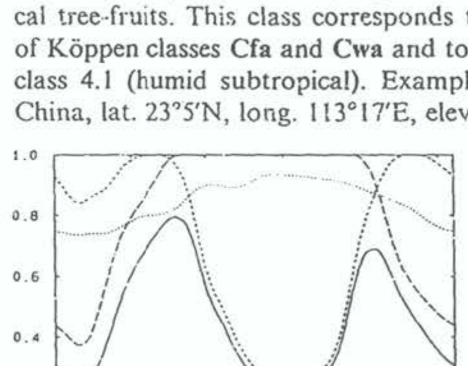
Warm, wet climates have an annual mean MI which ranges from 0.55 to 1.0. The five classes within this collection are situated in less continental subtropical locations as well as some tropical highland areas. They differ mainly in their temperature regimes.

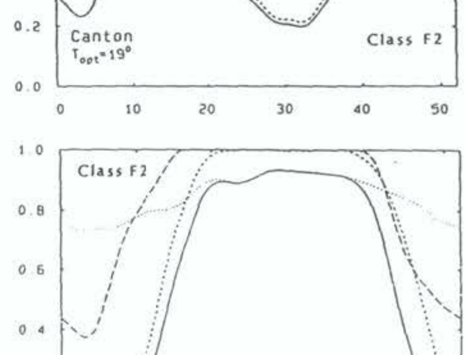
F1. This has cool winters with a lowest 13-week mean TI_{19} ranging from 0.0 to 0.3 and hot, wet summers with a highest 13-week mean TI_{28} ranging from 0.8 to 1.0. The highest 13-week mean GI_{28} ranges from 0.6 to 0.9. It extends over eastern regions of the United States and China, where the natural vegetation is deciduous forest. Field-crops include maize, barley, sugar-cane, rain-fed cotton, ground-nuts, soybeans, tobacco and rice. This class corresponds to Köppen class Cfa and Papadakis class 8.1 (warm continental). Example: Montgomery, United States, lat. 32°18′N, long. 86°24′W, elev. 59 m.





F2. This has milder winters than F1 with a lowest 13-week mean TI_{19} ranging from 0.15 to 0.6. The summer growing season is therefore longer. The class extends over south-eastern China and the United States, as well as a relatively small region in subtropical South America. Natural vegetation consists of rain forest, evergreen forest and savanna. Crops include rice, sugar-cane and tropical tree-fruits. This class corresponds to portions of Köppen classes Cfa and Cwa and to Papadakis class 4.1 (humid subtropical). Example: Canton, China, lat. 23°5′N, long. 113°17′E, elev. 18 m.





F3. This has cooler, drier summers than F1 and F2, so that the annual mean GI_{19} significantly exceeds the annual mean GI_{28}. The highest 13-

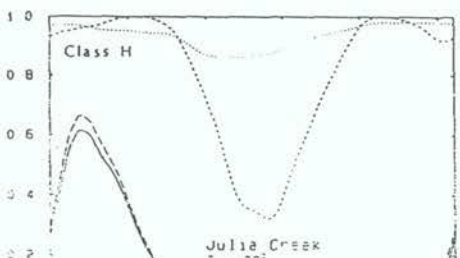
Sahara, central Australia and the west coasts of Africa and North and South America. It corresponds to Köppen classes BWh and warmer parts of BWk and to the warm to hot desert classes 3.1 to 3.4 of Papadakis. Example: Oodnadatta, Australia, lat. 27°34'S, long. 135°27'E, elev. 117 m.

Hot climates

Hot climates are principally characterized by their annual mean TI_{28}, which ranges from about 0.6 to 1.0. These climates include both equatorial climates with uniformly high temperatures throughout the year, and tropical climates with long summers and short mild winters.

H. Hot, dry climates

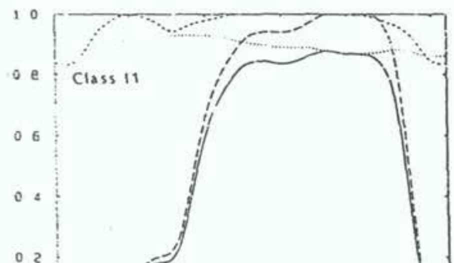
These climates form a transition between the hot, seasonally wet/dry climates and the warm to hot, very dry climates. They have an annual mean MI which ranges from 0.1 to 0.4, which is either too dry or very marginal for rain-fed crops. They extend over latitudinal bands marking the tropical edge of the Saharan, Australian, Namibian and Kalahari deserts, as well as the tropical east coast of Africa, the south-west coast of Madagascar and the continental north-east region of Brazil. Natural vegetation consists of savannah, grasslands and low open woodlands. This class corresponds to portions of Köppen classes BSh and BWh and to Papadakis classes 1.5 (semiarid tropical), 1.8 (dry tierra templada) and 4.3 (continental semi-tropical). Example: Julia Creek, Australia, lat. 20°39'S, long. 141°45', elev. 124 m.



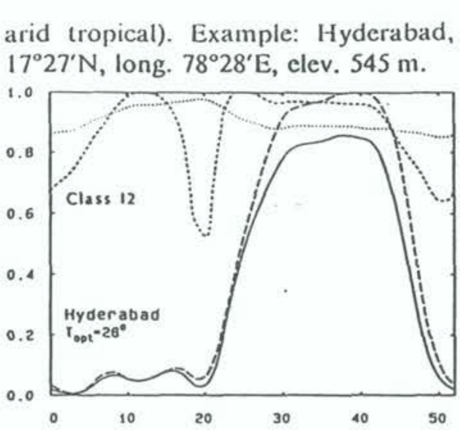
I. Hot, seasonally wet/dry climates

These climates are characterized by a markedly seasonal moisture regime with a significant wet season (average highest 13-week mean MI of 0.95) and a significant dry season (average lowest 13-week mean MI of 0.1). The annual mean MI ranges from 0.25 to 0.8. Divisions within this class are mainly due to differences in the length of wet and dry seasons.

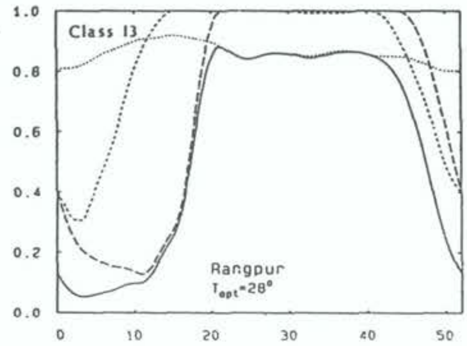
I1. This class extends over northern Australia, the east coast of Africa, Madagascar, India, Burma, Thailand, Venezuela and eastern Brazil, as well as a latitudinal band marking the northern edge of the tropical rain forest of central Africa. It has high temperatures for most of the year (lowest 13-week mean TI_{28} ranging from 0.6 to 1.0) and 5 to 6 months of very favourable conditions for megatherm growth. Natural vegetation consists mainly of monsoon forest and savannah woodland. Field crops include rice, cassava, maize, millet, groundnuts, cotton and tobacco. This class corresponds to Köppen class Aw and to Papadakis classes 1.3 (marine savannah), 1.4 (continental savannah) and 1.5 (semi-arid tropical). Example: Khon Kaen, Thailand, lat. 16°20'N, long. 102°51'E, elev. 165 m.



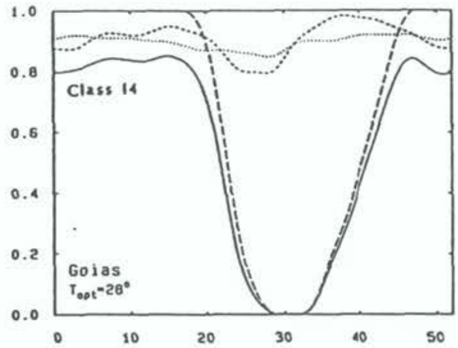
I2. This occurs further inland than I1 in northern Australia, Africa, India and Burma. A slightly cooler version of this class is also found in a partial rain-shadow area of south-eastern Africa. Temperature and moisture are both more seasonal than for I1, with a highest 13-week mean TI_{28} ranging from 0.1 to 0.9 and an annual mean MI ranging from 0.25 to 0.55. The growing season is shorter than for I1, lasting from 4 to 5 months. Natural vegetation consists mainly of savannah woodland. Field crops include sorghum, ground-nuts, millet, maize and cotton. This class corresponds to parts of Köppen classes Aw and Bsh and to Papadakis classes 1.4 (continental savannah) and 1.5 (semi-arid tropical). Example: Hyderabad, India, lat. 17°27′N, long. 78°28′E, elev. 545 m.



I3. This is cooler and wetter than I1 and I2 and is confined mainly to the Ganga (Ganges) river valley and the lowlands of Nepal. The temperature regime is more seasonal, with a lowest 13-week mean TI_{28} ranging from 0.0 to 0.7. The annual mean MI ranges from 0.4 to 0.8. However, the periods of cool and dry weather coincide, so that the growing season is long, lasting at least 6 months. Natural vegetation consists of evergreen and semi-deciduous closed forest. Crops include sugar-cane, rice, tobacco, tea and jute. This class corresponds to a portion of Köppen class Cwa and Papadakis class 1.9 (cool-winter tropical). Example: Rangpur, Bangladesh, lat. 25°45′N, long. 89°16′E, elev. 200 m.



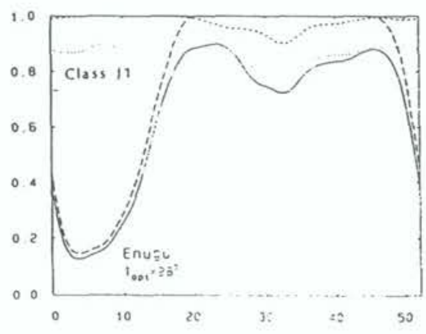
I4. This is cooler and wetter than I1 and I2 but less seasonal than I3 and confined to highland locations in southern India, central America, South America and central Africa. It has a uniform temperature regime which is equally favourable to both mesotherm and megatherm growth. The moisture regime has a relatively short dry season, with the annual mean MI ranging from 0.4 to 0.85. The growing season can exceed 6 months. Natural vegetation consists of evergreen and semi-deciduous closed forest. The principal crop is coffee. Maize, beans and cassava are also grown. This class corresponds to parts of Köppen's highland class and to Papadakis class 1.7 (humid tierra templada). Example: Goias, Brazil, lat. 15°58′S, long. 50°4′W, elev. 520 m.



J. Hot, wet climates

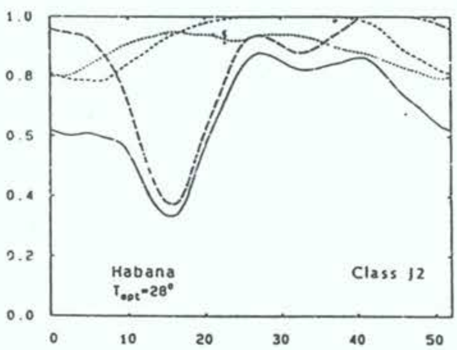
The hot, wet climates are characterized by non-seasonal temperature regimes (average seasonality of TI_{28} is 0.1) and moisture regimes which are either uniformly wet or have at most a short dry season (average annual mean MI is 0.72).

J1. This occurs at the northern and southern limits of the equatorial rain forests of Africa and South America, as well as in Bangladesh, Vietnam, Kampuchea and some coastal locations in Central and South America and north-eastern Australia. It has a short dry season, with the annual mean MI ranging from 0.5 to 0.8, and uniformly high temperatures, the seasonality of TI_{28} ranging from 0.0 to 0.3. The growing season can last from 8 to 9 months. Natural vegetation consists of evergreen closed forest. Crops include rice, rubber, sugar-cane and cotton. This class corresponds to portions of Köppen classes Aw and Am and Papadakis class

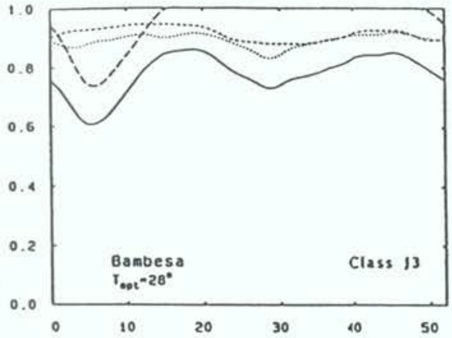


1.4 (continental savannah). Example: Enugu, Nigeria, lat. 6°28'N, long. 7°33'E, elev. 140 m.

J2. This is a transition class between J1 and J3. It occupies parts of central Africa and Brazil as well as higher latitude coastal locations in northern Malaysia, central America, Cuba and northeastern Australia. It has a shorter dry season than J1, with an annual mean MI ranging from 0.60 to 0.9. Except during this dry season, which is essential for harvest, crops can be grown for most of the year and double cropping is common. Natural vegetation consists of tropical rain forest. Field crops include sugar cane, bananas, cassava, rice, coconuts and rubber. This class corresponds mainly to Köppen class Aw and to portions of Papadakis classes 1.1 (humid equatorial) and 1.4 (continental savannah). Example: Habana, Cuba, lat. 23°8'N, long. 82°2'W, elev. 24 m.



J3. This is the true equatorial rain forest class occupying southern Malaysia, Indonesia, New Guinea, and the Amazon and Congo Basins. Smaller areas in this class can also be found on the east coasts of Madagascar and Brazil. The class is characterized by uniform temperatures and almost uniformly high moisture, with an annual mean MI which ranges from 0.85 to 1.0. Crops can be grown throughout the year. Problems such as pests, diseases and crop spoilage arise because of high humidity and waterlogging. Natural vegetation consists of equatorial rain forest. Field crops include rubber, manioc, rice, sugar-cane, cocoa and coconuts. This class corresponds to Köppen class Af and to portions of Papadakis class 1.1 (humid equatorial). Example: Bambesa, Zaire, lat. 3°27'N, long. 25°43'E, elev. 621 m.



CONCLUSION

The climatic classification developed here differs from all others in that it uses a simple plant growth response model to derive relevant agroclimatic attributes, and numerical taxonomic methods to produce groups that are defined objectively. It is closer to the agroclimatic classification of Papadakis than the general-purpose climatic classification of Köppen. Class boundaries are in substantial agreement with the boundaries of the major natural vegetation formations.

In common with previous global climatic classifications it is based on long-term mean monthly climatic data and thus does not provide any measure of within-year or year-to-year climatic variability. This is a serious deficiency, since locations with very similar plant growth response patterns based on long-term mean data can have very different probabilities of cropping success because of within-year differences in the timing of temperature extremes and/or water deficits. New methods under development will make it possible to derive realistic sequences of daily weather from simpler, published statistics. Given such data and corresponding crop models, it will be possible to generate crop-specific and even cultivar-specific analyses and classifications at a global scale.

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- DRAFT DISCUSSION PAPER -

SELECTION CRITERIA FOR A GLOBAL TERRESTRIAL OBSERVING SYSTEM (GTOS) BASED ON ENVIRONMENTAL SPACE

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An integrated, global system for detecting and monitoring change in terrestrial ecosystems is a recognized need that is receiving increasing attention from a number of international programmes. Most recently (July 1992) a meeting on this topic was held in France, sponsored by the GCTE core project of the IGBP, the OSS (Observatoire du Sahara et du Sahel) and the MAB-UNESCO Biosphere Reserve programme; and involving UNEP's GIMS (Global Integrated Monitoring) and HEMS programmes, FAO, IGBP-DIS, and several other interested groups. The major outcome of this meeting was a set of proposals relating to the development of a global terrestrial observing system (GTOS), to be the terrestrial component of the global climate observing system (GCOS), which arose from the Second World Climate Conference. GTOS would complement the atmospheric monitoring programme and the oceanic component (the Global Ocean Observing System - GOOS).

The discussions leading to the proposed framework for GTOS highlighted the importance of the criteria for site selection. GTOS will involve the integration of remote sensing with a set of site-based measurements, and the selection of these sites is critical. There are two main reasons for GTOS - detecting global terrestrial change, and validating models of global change. The two call for different (though overlapping) sets of measurements, but in all cases the choice of sites is critical.

Given the value of long-term records, much attention is being focussed on existing monitoring sites with some history of measurements, and (because of funding implications) attention has also focussed on existing sites that will, in any case, continue to be supported. While this is obviously sensible it also raises a potentially serious problem. How representative of the world's terrestrial ecosystems are such sites? What are the characteristic features of terrestrial ecosystems that need to be properly represented? If we use some sub-set of proffered, existing monitored sites, using the argument that we must take what we can get and that any information is better than none, we run the risk of biased and misleading results. What follows is a proposed framework for marrying the two concerns.

Environmental Space and Site Selection

The scientific requirements for a representative set of sites will be satisfied if that set covers the range of the major determinants of the distribution and the performance of the world's terrestrial ecosystems; in particular, those that are likely to change most significantly and directly in response to global atmospheric and land-use changes.

These determinants operate at two scales. At the broad (biome) scale they are climatic; and at the finer, regional and landscape scales they are (primarily) edaphic and (secondarily) disturbance.

Based on this assertion, which is backed up by a considerable literature (c.f. Woodward 1987, Frost *et al*. 1986), examples of the variables used to select candidates for the global set of sites are:

i) Broad-scale climatic variables
   - mean annual precipitation
   - rainfall seasonality (expressed as the monthly coefficient of variation)
   - mean minimum temperature

ii) Edaphic
   - soil depth
   - fertility index
   - topographic index

iii) Disturbance (as typified by the region)

iv) Biogeography and genetic history. Biological performance and response in climatically and physico-chemically identical sites on different continents will differ as a consequence of genetically determined potentials (i.e. species do matter).

The most efficient selection of sites calls for a hierarchical (nested) approach, in which fairly large sites are selected first on the basis of climate. Within each of these, replicated high and low fertility x soil depth (= productivity index) sites are selected, and within each of these, replicated minimal and moderate/severe disturbance sites are selected, where moderate/severe disturbance is based on the modal or most common type of disturbance in that region (fire, logging, grazing, cultivation, etc.) and implies both the degree of disturbance and time over which the disturbance has operated.

The intention of this paper is to raise the issues that need to be considered, and to suggest an approach. For this reason, it deals only with the selection of the broad-scale, climatically-defined sites. Once they have been agreed on, the selection of particular sites within them will require regional workshops.

Climate Space and Site Selection

The climate data used in this analysis were provided by R. Leemans, and are those used in the formulation of the BIOME model (Prentice *et al.* 1992). The data are interpolated to a scale of half a degree latitude and longitude, giving around 100,000 grid cells. To illustrate the range of variability that needs to be covered, Figs. 1 and 2 present a 25% sample of these sites in total rainfall - minimum temperature space and total rainfall - seasonality space.

Two main global sets of terrestrial ecosystem sites, involving two major UN agencies, are the MAB/UNESCO Biosphere Reserve sites, and the pilot set of UNEP-GIMS sites from Europe and North America. Figs. 3 to 6 present their respective distributions in environmental space.

The MAB Biosphere Reserve sites are, collectively, reasonably representative of the range of environmental space, with a few noteworthy exceptions. The coldest parts of the world (those predicted to change most) are poorly represented. The world set reflects a large number of 1/2 degree sites (in the very northern latitudes) with minimum mean monthly temperatures in the range -30 to -60°C, which are not represented in the MAB sites. The very driest and hottest sites are also somewhat under represented (though not so badly); and, finally, the wettest tropical sites are missing. In general, the MAB set contains a large number of potentially representative sites, and their further analysis, in terms of the next layers of the site-selection sieve (size, landscape and soil types, management history, available data and previous monitoring, facilities, support personnel, availability and accessibility, future status and official support, etc.) will determine which of them are appropriate candidates for the GTOS network.

The GIMS pilot sites, as expected, so far represent just a small part of the world's environmental space, and they obviously overlap with the area of environmental space in which the MAB sites are also most strongly represented. Figures 5 and 6 should be used in conjunction with Figures 1 and 2 to screen for further candidates. Certainly, no more are needed in the environmental space bounded by -15°C to +5°C minimum mean monthly temperature and 0 to 1000 mm mean annual rainfall.

This analysis represents a very preliminary effort, designed to illustrate the sort of approach we need to follow. The final version may well include other environmental variables (e.g. solar radiation) and different ways of expressing rainfall seasonality and temperature regime. When agreed on, the environmental space would be used in the procedure outlined below. It is likely that there will be several other sources of proffered sites, particularly in connection with the developing START programme of IGBP. There is no reason why many of the sites should not be combined (e.g. a proposed GIMS site being the same as one from a START Regional Research Network), but this will require a deliberate effort at achieving collaboration.

PROPOSED SELECTION PROCEDURE

1. Collect candidate (proposed) sites, and screen immediately on the basis of criteria for size, facilities, access, etc.

2. Select those which are sole representatives of required environmental combinations, with consideration given to biogeographical (continental) representation. (Note: The nature and number of required environmental combinations needs to be analysed and agreed on at the first GTOS workshop.)

3. Choose the most appropriate from amongst those which are replicates in required combinations, bearing in mind that GTOS will require replicated sites (a minimum of two) in each environmental combination. The most appropriate sites will be those that best meet the remaining criteria concerned with fertility and disturbance (management) history.

4. Seek additional candidates to fill empty combinations

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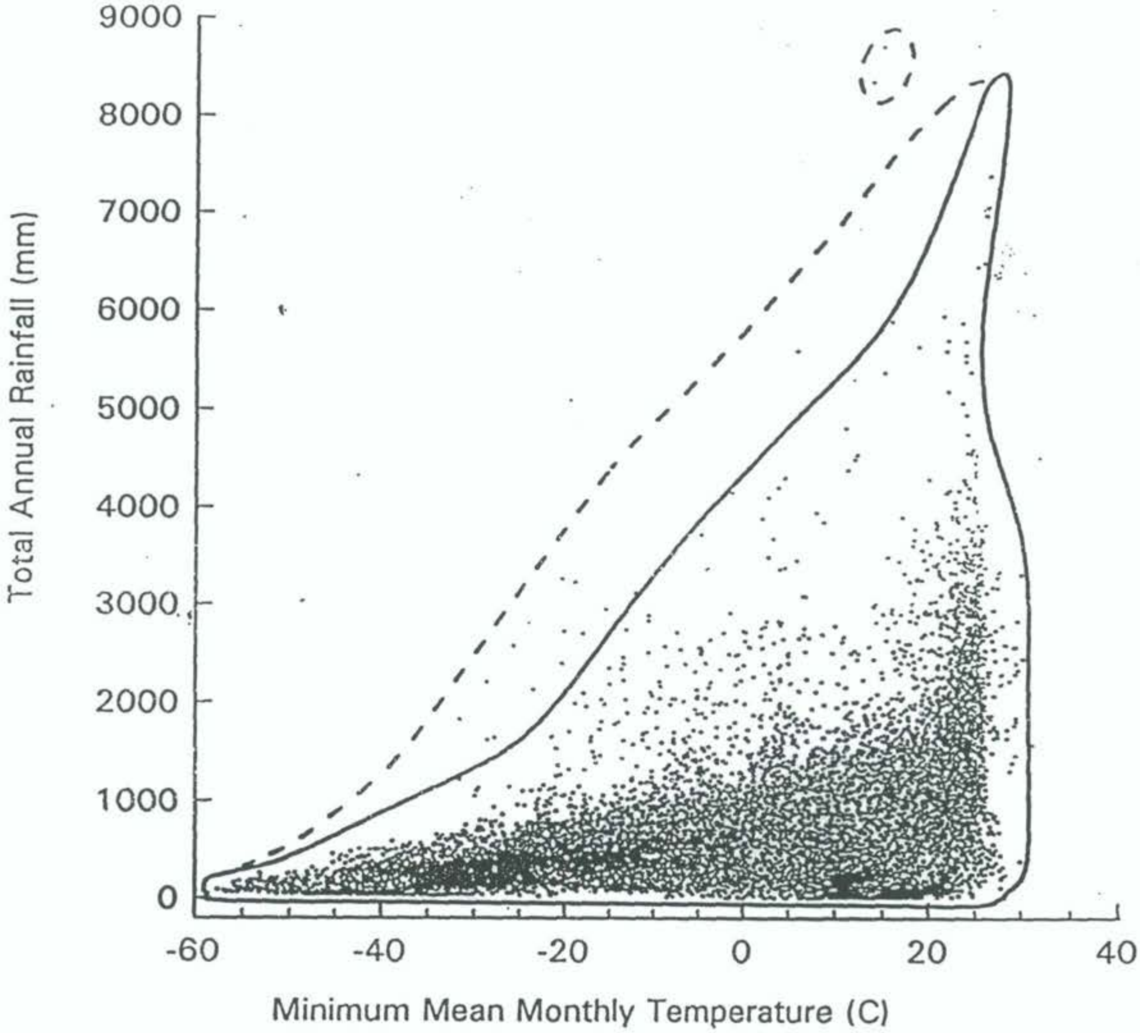

Fig 1. Environmental space of the world as defined by total annual rainfall vs minimum mean monthly temperature. The data are a 25% systematic sample of the total world's climatic averages estimated for every fourth .5 degree latitude and every fourth .5 degree longitude. The dotted line represents occasional outliers. The climatic data are those of the BIOME model (R. Leemans and W. Cramer, pers. comm.)

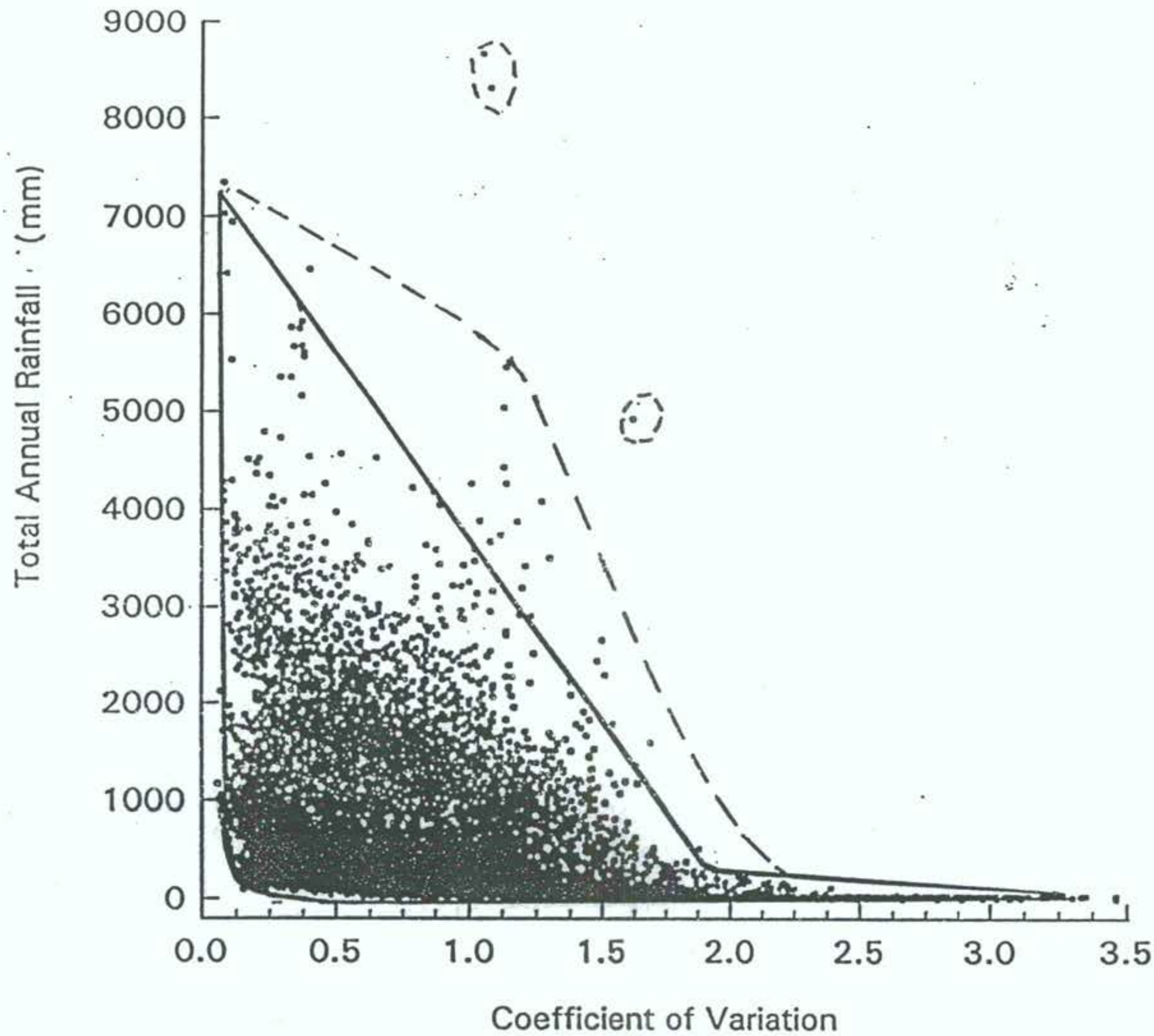

Fig 2. Environmental space of the world as defined by total annual rainfall vs a seasonality index (coefficient ofvariation). See Fig 1. text for origin.

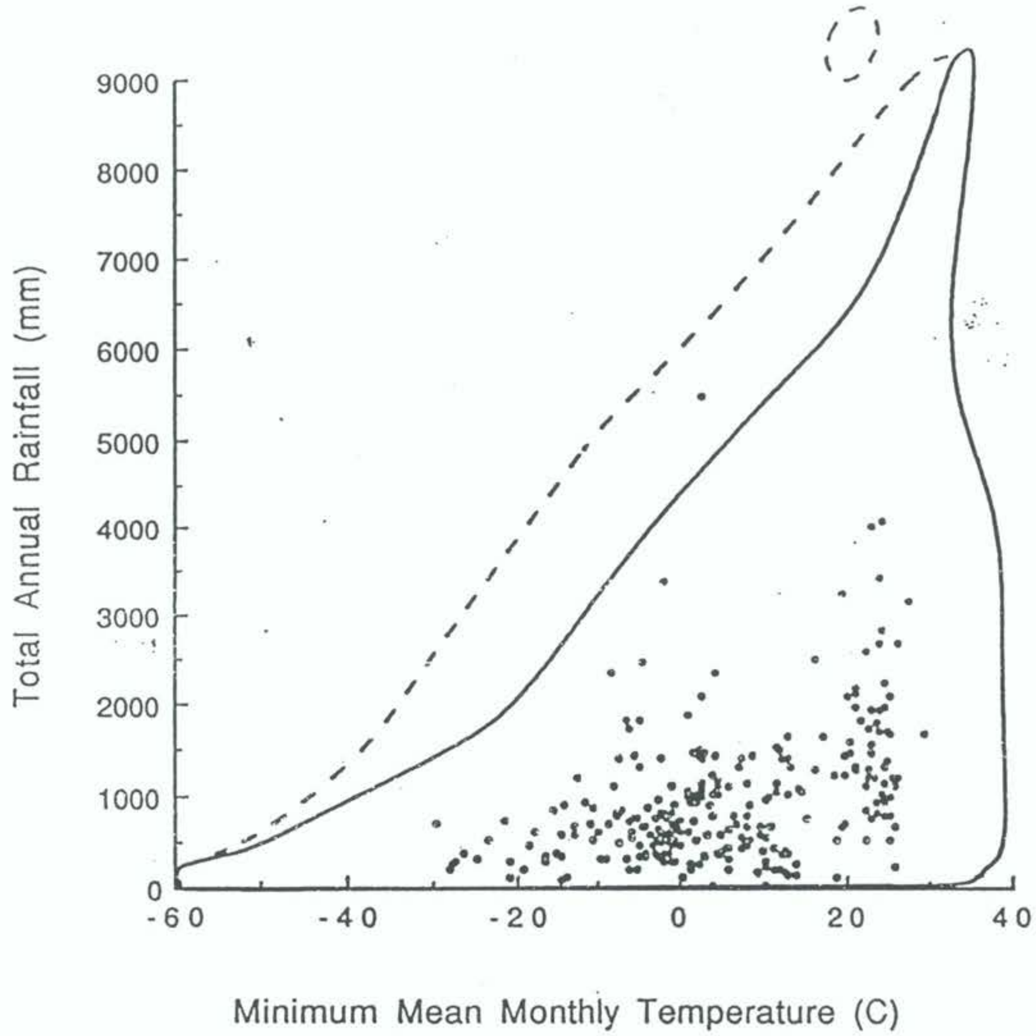

Fig 3. Distribution of the Biosphere Reserves of the Man and the Biosphere Program in total rainfall - minimum mean monthly temperature space.

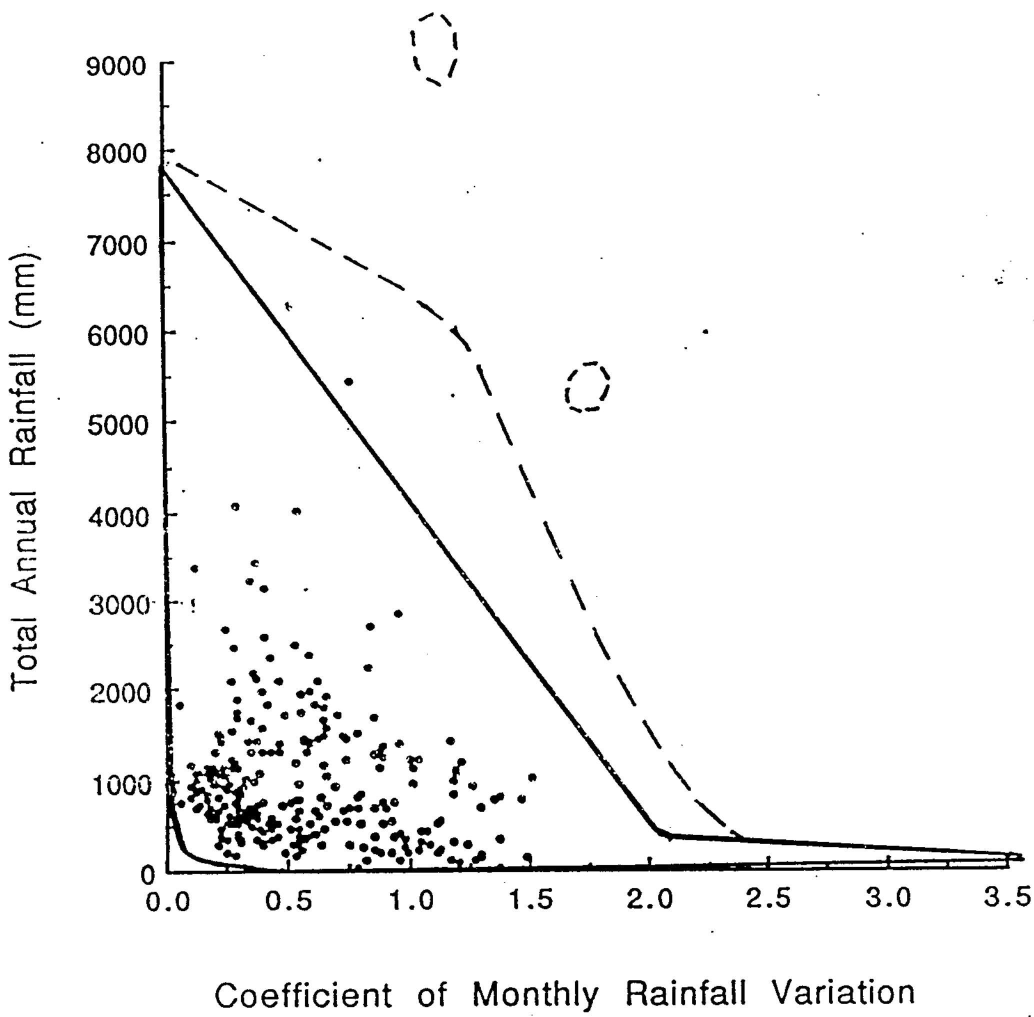

Fig 4. Distribution of the Biosphere Reserves of the Man and the Biosphere Program in total rainfall - seasonality space.

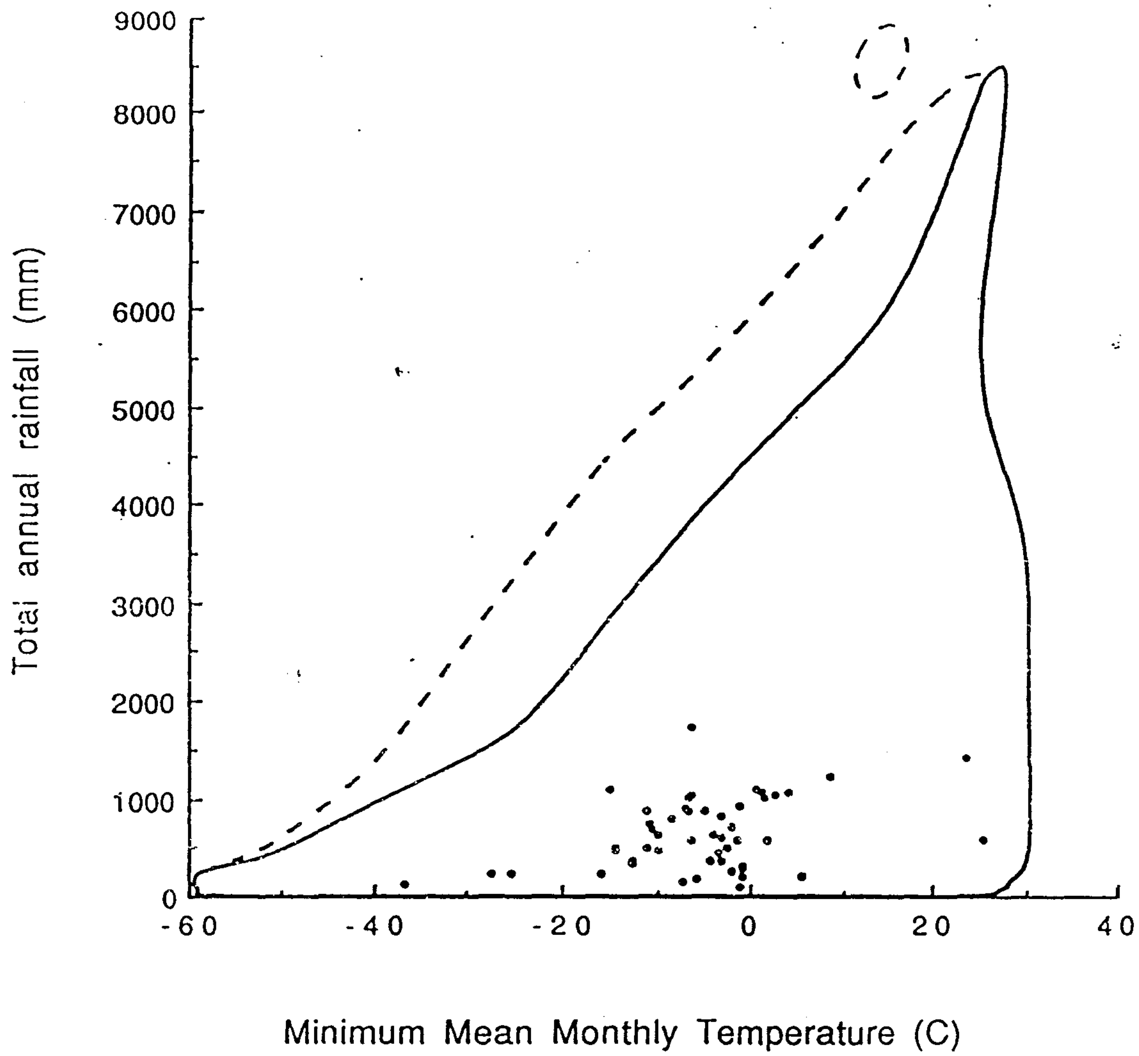

Fig 5. Distribution of the initial northern hemisphere pilot Global Integrated Monitoring Sites in total rainfall - minimum mean monthly temperature space.

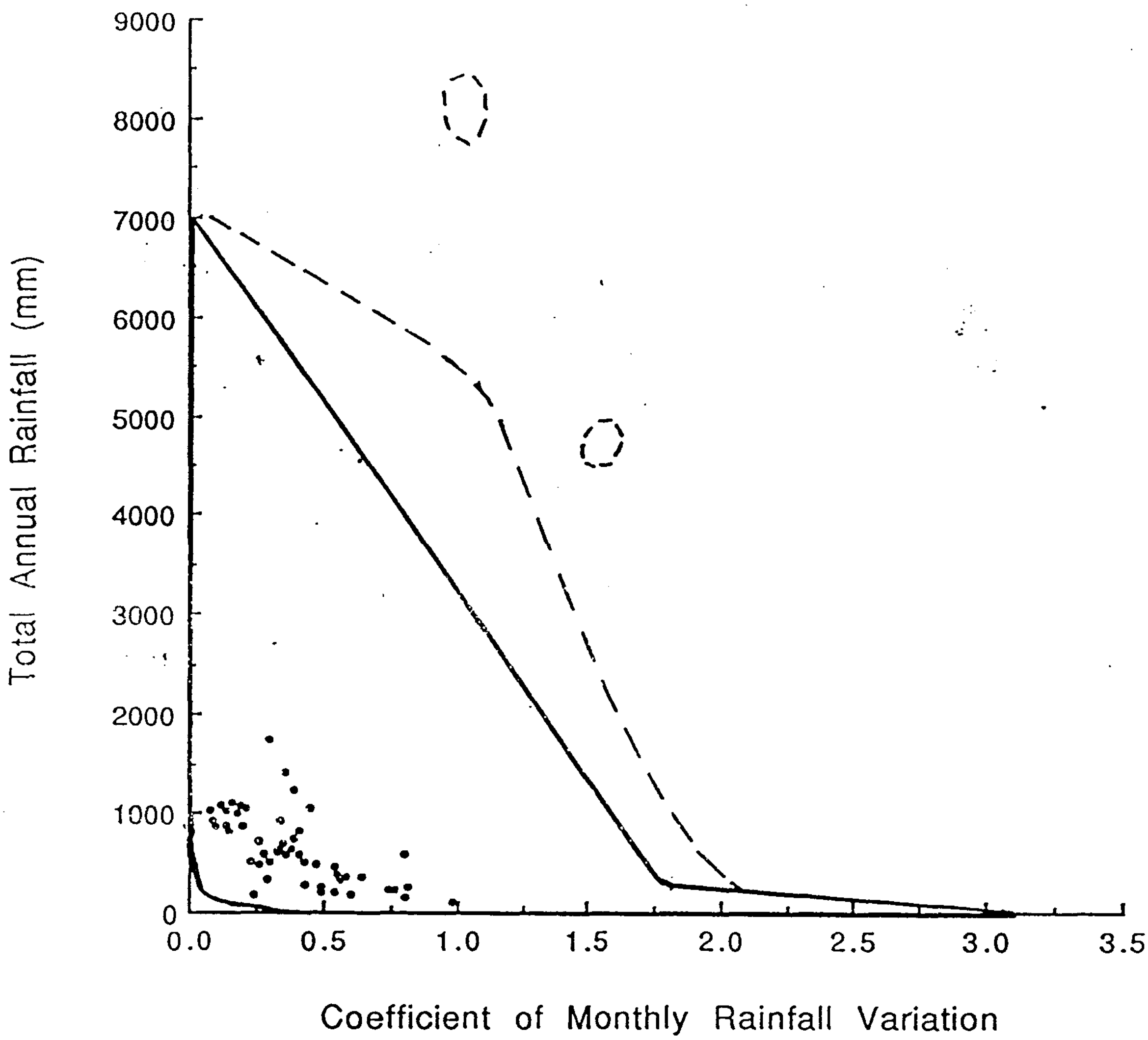

Fig 6. Distribution of the initial northern hemishere pilot Global Integrated Monitoring Sites in total rainfall - seasonality space.

ANNEX VII

Proposed Basic Observational Programme

Variables

SURFACE AIR
Temperature
Humidity
Wind speed
Irradiance
Precipitation
pH of clouds and fog
SO_2
O_3
CO_2
PAR
UV-B

VEGETATION
Dominants: flowering, fruiting

Juvenile trees:
Density
Species composition

Radial tree growth of dominant
and subdominant

Epiphitic lichens:
Occurrence
Density

Throughfall
Stemflow
Evapotranspiration

"Ecosystem-atmosphere"
CO_2 flow

Net primary production of
an ecosystem

Decomposition rate of dead
organic matter

SOIL
Temperature
"Soil-atmospheric" methane flow
Thickness of active layer

Bioindex:

WATER
Temperature
Runoff

Pesticides

Net primary production
Decomposition of dead organic
matter