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CONFERENCE PAPERS 6

**GLOBAL CHANGE  
REGIONAL RESEARCH CENTRES:  
Scientific Problems and Concept Developments**

September 25-29, 1989  
Warszawa

SEMINAR PAPERS AND IGBP WG2 REPORT

Edited by  
Alicja Breymeyer



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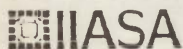
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- IIASA - International Institute for Applied Systems Analysis
- IGBP - International Geosphere-Biosphere Programme
- UNESCO - United Nations Educational Scientific and Cultural Organisation
- PAN - Polish Academy of Sciences

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## PREFACE

Alicja BREYMEYER\*

Session entitled "IGBP Network of Global Change Regional Research Centres: Scientific Problems and Concept Developments" took place on Sept. 25-29, 1989, in Warsaw. It has been divided into two parts: the first one was a seminar during which 15 lectures were presented, and the second one was a closed session of the IGBP Working Group 2 (programme of session attached in Appendix 1).

Among the seminar lectures we may distinguish those that outline the scientific background concerning the concept of observing climatic changes on Earth through remembering similar ones in the past (Gutry-Korycka, Ralska-Jasiewicz), or through indicating on a wide scale such ecological (Berg) and geomorphological (Walling) processes which ought to be studied within the IGBP network. Certain suggestions concerning the range of global transformations are provided by observations in contrasting conditions on the Earth, e.g. on Antarctica (Martianov and Rakusa-Suszczewski); suggested is the eventual influence of not very well known magnetic and cosmophysical processes (Anisimov and Michnowski). A critical analysis of the network of climatic observatories in existence on the Earth today conducted on the example of Australia, shows real possibilities of applying those measurements for the needs of IGBP (Margules).

A separate group is constituted by lectures collected during one session concerning Silesia the most polluted area in Europe (see attached programme of the seminar); changes of Earth surface (Jankowski), of vegetation (Weinert) or even of seismicity (Kijko, Niewiadomski) have already taken place on the area of this "black spot" of Europe. Will the climatic change make those symptoms worse, will synergic reactions take place? Perhaps Silesia should be considered as an area of a large-scale experiment and a specially profiled IGBP Regional Research Centre programme ought to be commenced just here?

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The lecture of Kotlyakov and co presents a biogeographical analysis of the Eurasia continent for the use of IGBP; this is the first in a series of reports discussing the concepts and technical conditions of establishing a network of IGBP Regional Research Centres; only this lecture concerning RRC's is printed in this volume as an author's elaboration. The remaining statements from this part of the seminar have been included into the WG2 Report, which constitutes the second, very important part of this volume. The report, prepared after consultations in appropriate agencies of the IGBP, summarizes the opinion of the Secretariat and the WG2; separately we present comments of UNESCO-MAB, prepared by the representative of this organization for the session, Dr. J. Robertson.

As a whole, the achievements of the seminar seem to be both interesting and useful: certain aspects of the geosphere-biosphere relations were analysed, certain climatic, hydrological, geomorphological and ecological phenomena have been presented in a scale appropriate for the case of global change.

I believe that on behalf of all participants I can express our thanks and gratitude to the sponsoring organization: IGBP, IIASA, UNESCO and PAS. The editor owes special thanks to dr Margules, who provided 400 copies of his colorful map of climatic zones in Australia.



## MONITORING CONTEMPORARY GEOMORPHOLOGICAL PROCESSES

Desmond E. WALLING\*

### THE NEED

Contemporary geomorphological processes should clearly be included in any programme aimed at monitoring geosphere-biosphere processes and global environmental change. These processes, which reflect the fundamental mechanisms of landform development or land surface evolution through erosion, transport and deposition, represent an important component of landscape and ecosystem dynamics and they may be highly sensitive to changes in climatic conditions, land use and other man-impacted variables. Furthermore, disruption of the associated equilibrium may have serious and economic implications. Such implications are demonstrated in the case of accelerated soil erosion, where rates of soil loss exceed rates of soil formation. This leads to a reduction in soil depth, depletion of the soil resource and a consequent decline in crop productivity. The global significance of accelerated soil erosion is usefully illustrated by the following assessments:

*The world is now losing an estimated 23 billion tons of soil from croplands in excess of new soil formation .... At the current rate of excessive erosion, the global soil resource is being depleted at 0.7 percent each year, 7 percent each decade (Brown, 1984).*

*Crop productivity is reduced to zero or becomes uneconomic because of soil erosion and erosion-induced degradation on about 20 million ha each year (UNEP, 1980).*

The eroded sediment may cause further problems as it enters the river system and gives rise to increased sediment loads with their attendant problems. Again the following assessments usefully illustrate the wider significance of this problem:

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The annual off-site damage caused by sediment eroded from the land in the United States is estimated at more than 6 billion dollars (Clark et al., 1985).

In Pakistan, soil erosion and deposition have decreased the life expectancy of the 600 million dollar Mangla Reservoir, planned to last 100 years or more, to 57 years or less (El-Swaify et al., 1982).

Excess sediment is the major form of human-caused water pollution in the world today and exacts a heavier cost ...possibly more than all other pollutants combined (Eckholm, 1976).

DOCUMENTING CONTEMPORARY GEOMORPHOLOGICAL PROCESSES

A wide range of processes has been investigated by geomorphologists interested in contemporary landscape development and Table 1 summarises some of the most commonly studied processes and provides an indication of the typical rates encountered. These investigations have made use of a wide variety of measuring techniques of varying degrees of refinement, ranging from simple erosion pins measured at infrequent intervals to automatic water chemistry analysers and video recorders capable of providing a continuous record. Table 2 provides some examples of the techniques employed to monitor specific processes. These investigations have also involved considerable variation in terms of the scale addressed. In some cases the results refer to a single point or small plot, whereas in others they are representative of a larger area such as a drainage basin.

Table 1. Some contemporary geomorphological processes and their typical rates of activity.

Process	Typical Rates
Soil Creep	1-10 mm year <sup>-1</sup> linear movement
Solifluction	1-100 mm year <sup>-1</sup> linear movement
Surface Wash	0.001 - 1 mm year <sup>-1</sup> surface lowering
Chemical Weathering	0.001 - 0.1 mm year <sup>-1</sup> surface lowering
Landslides	0.5 - 5 mm year <sup>-1</sup> slope retreat
Slope retreat	0.01 - 1 mm year <sup>-1</sup> slope retreat
River Bank Retreat	1 - 1000 mm year <sup>-1</sup> linear retreat
Fluvial Denudation	0.01 - 1 mm year <sup>-1</sup> surface lowering

Any attempt to develop an integrated programme of global monitoring must select a process parameter and an associated measurement technique capable of providing representative and consistent information for a wide range of physiographic conditions. To ensure representativeness, the measurement technique should produce data integrated over an area, rather than for a single point, and it should be capable of being employed in a consistent way under a variety of conditions without the



Table 2. Some methods of monitoring contemporary geomorphological processes

Process	Monitoring techniques
Soil Creep	Young pits, inclinometers, buried rods cylinders, tubes and plates, surface markers, strain gauges
Solifluction	As above
Surface Wash	Erosion pins, Gerlach troughs, traps, erosion plots, measuring frames
Chemical Weathering	Buried rock tablets, water sampling, micro-erosion meters
Landslides	Erosion pins, traps, photogrammetric surveys, repeat surveys
Slope Retreat	Erosion pins, talus accumulation, repeat surveys, historical photographs
River Bank Retreat	Erosion pins, marker pegs, resurveying photogrammetric surveys, map evidence
Fluvial Denudation	Sampling of sediment and solute loads, reservoir surveys, lake sediment surveys

need for substantial technical support. Furthermore, the availability of some existing data or a means of reconstructing past records would afford a major advantage in any attempt to detect long-term trends and changes in the processes involved. In many situations it will be impossible to assess such trends if data are only available from a recently initiated programme of measurement.

#### A MONITORING STRATEGY

It is suggested that measurements of the suspended sediment yields from small- and medium-sized drainage basins fulfill most of these requirements and would provide the best index of contemporary geomorphological processes for inclusion in a global monitoring programme. Data on suspended sediment yields provide information on the total amount of fine-grained particulate material transported out of a drainage basin by the stream. This yield will reflect the rates of erosion and sediment production operating within the upstream catchment and therefore the rate of surface denudation. In providing results relating to a drainage basin, rather than a single point, the data are likely to be more representative of the areas from which they were derived. Furthermore, existing measurement techniques are

relatively easy to apply and already show a reasonable degree of uniformity in different areas of the world. It should therefore prove feasible to develop and apply the standard procedures necessary to ensure the consistency of a global monitoring network.

Sediment yield measurements have the further advantage of providing an index of contemporary geomorphological processes, which is applicable to almost all areas of the globe except for polar regions and arid deserts. Unlike measurements of dissolved load, they are only marginally affected by the pollution which now characterises so many of the world's water courses, and therefore provide a direct measure of the rates of erosion operating in the upstream catchment. At the global scale, values of mean annual suspended sediment yield documented from small- and medium-size drainage basins range over more than four orders of magnitude from about  $1.0 \text{ t km}^{-2} \text{ year}^{-1}$  to in excess of  $10,000 \text{ t km}^{-2} \text{ year}^{-1}$  (Table 3) and reflected control by climate and other physiographic variables (cf. Figures 1 and 2). In addition, suspended sediment yields have been shown to be extremely sensitive to disturbance of the natural equilibrium, such as that caused by land use change (cf. Table 4), and therefore offer very considerable potential as a barometer of global change.

Table 3. Maximum and minimum mean annual suspended sediment yields recorded in world rivers

River	Drainage Area ( $\text{km}^2$ )	Suspended Sediment Yield ( $\text{t km}^{-2}\text{year}^{-1}$ )
I. Maximum Values		
Huangfuchuan, China	3199	53500
Dali, China	96	25600
Dali, China	187	21700
Tsengwen, China	1000	28000
Perkerra, Kenya	1310	19520
Cilutung, Java	600	12000
Aure, New Guinea	4360	11126
Waiapu, New Zealand	1378	19970
Waingaromia, New Zealand	175	17340
Hokitika, New Zealand	352	17070
II. Minimum Values		
Queanbeyan River, Australia	172	1.7
Brindabella River, Australia	26.1	1.3
Pilica River, Poland	2544	0.7
Narew River, Poland	6880	0.7

Based partly on Walling (1987); data for Polish rivers from Branski (1985)

Table 4. Examples of the impact of land use change on suspended sediment yields

Catchment disturbance	Location	Resulted increase in sediment yield	Source
Clearfelling	New Zealand	x8	O'Loughlin et al. (1980)
Clearfelling	Oregon, USA	x39	Fredriksen (1970)
Forest clearance and cultivation	Texas, USA	x310	Chang et al. (1982)
Building construction	Maryland, USA	x126-375	Wolman & Schick (1967)

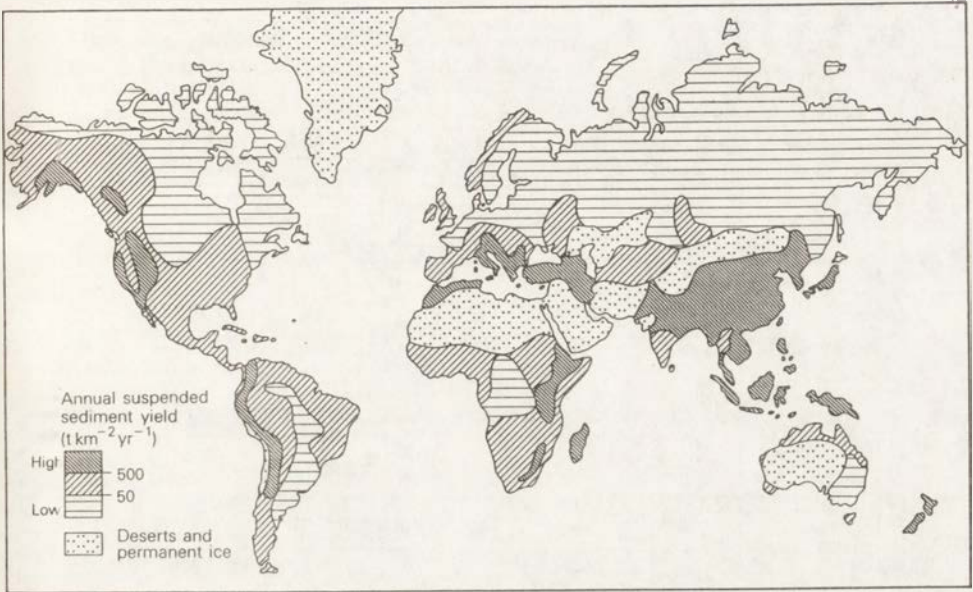
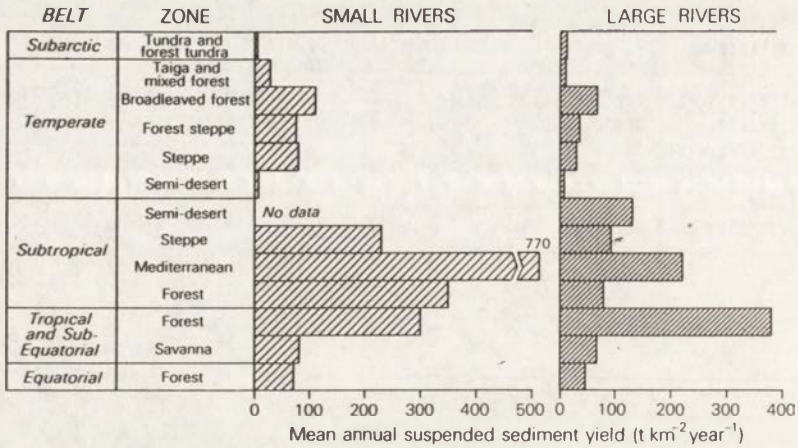


Fig.1 A generalised map of the global pattern of specific suspended sediment yield from drainage basins of 1000-10000 km<sup>2</sup>, based on data from over 1500 measuring stations

The availability of existing data for measuring stations in many areas of the world will increase the potential for assessing such change. For example, a valuable general indication of the magnitude of the changes experienced in recent years in Developing Countries as a result of land clearance and intensification of land use is provided by the work of Abernethy (1985). He was able to obtain estimates of the recent increases in suspended sediment yield for a number of drainage basins in



(a) PLAINS



(b) MOUNTAINS

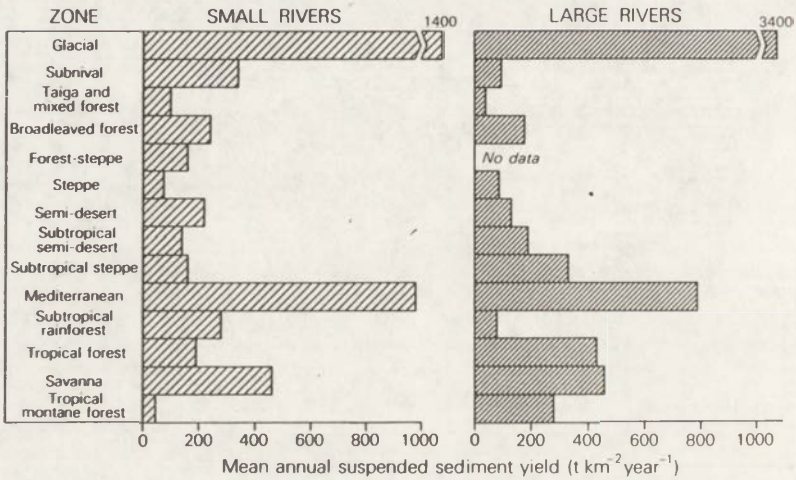


Fig.2 The global zonation of suspended sediment yields proposed by Dedkov and Mozzherin (1984)

Southeast Asia, and several examples of the results are shown in Figure 3. The individual drainage basins evidence annual rates of increase in mean annual sediment yield in recent years of between 2.5 and 6.0 percent. Abernethy (1985) has suggested that these increases closely paralleled the rates of population growth in the watersheds concerned, although the ratio of the rate of increase in sediment yield to that for the population was greater than unity (cf. Figure 3). Based on this evidence, he suggested that in many Developing Countries annual sediment yields are currently increasing at a

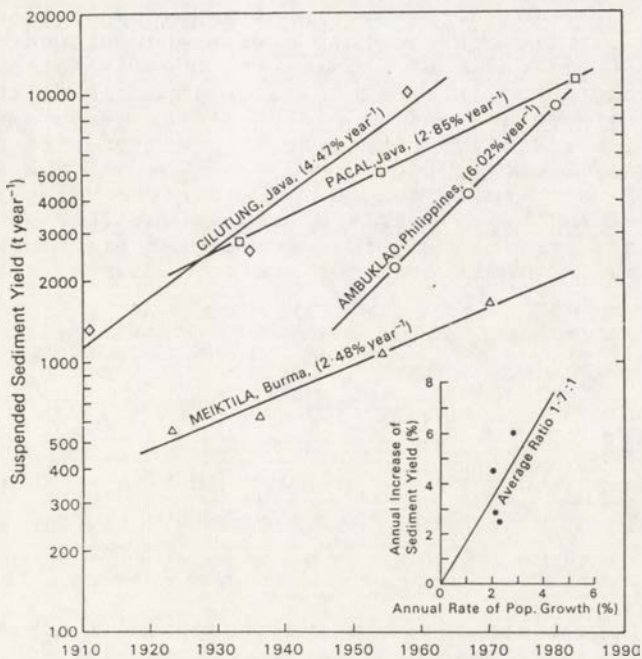


Fig.3 Trends of increasing sediment yields in selected reservoir catchments in Southeast Asia (based on Abernethy, 1985).

rate equivalent to 1.5 times the rate of population growth, and therefore by 5 percent or more per year, as a result of the accelerated soil erosion. Data on suspended sediment yields can provide information on global change of direct relevance to the problems of accelerated soil loss and the downstream impact of increased sediment loads highlighted in the introduction to this contribution.

### PLANNING THE MEASUREMENT PROGRAMME

#### Problems of data reliability

Considerable attention has been given to the sampling equipment and procedures necessary to obtain reliable estimates of suspended sediment transport and these are well-documented in the literature (cf. WMO, 1981; Ward, 1984, ASCE, 1975; Guy and Norman, 1970; ISO, 1976). However, the techniques documented in these manuals are primarily those associated with measurements of instantaneous suspended sediment load. In a monitoring programme it will be necessary to obtain estimates of longer-term (ie annual) suspended sediment yield and attention must be directed to the problems of measuring longer-term yields. These

problems, which essentially involve extrapolation or interpolation of point measurements, have been reviewed by Walling and Webb (1981) who have highlighted the limitations of traditional rating curve procedures and emphasised the need to consider the accuracy and precision of the measurement strategy employed. Figure 4 illustrates the accuracy problem by comparing the accurately known suspended sediment load of the River Creedy in Devon, UK, for the period 1972-9, derived using a continuous turbidity record, with nearly 60 equivalent load estimates that could have resulted from typical strategies of infrequent manual sampling coupled with various rating curve extrapolation procedures.

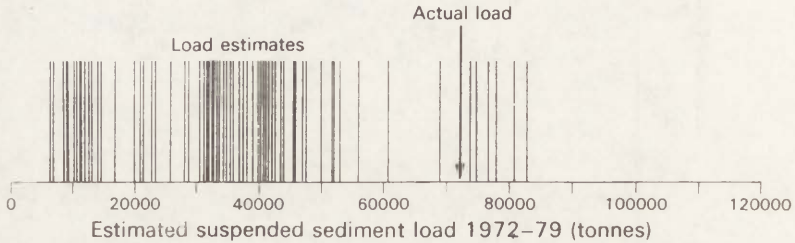


Fig.4 A comparison of the actual suspended sediment load of the River Creedy, Devon, UK, for the period 1972-79 with estimates obtained using rating curves based on data from typical sampling strategies

Underestimation by as much as 60% is common. For consistency, the values of suspended sediment concentration associated with potential manual sampling strategies were abstracted from the continuous record of concentration obtained from the turbidity monitoring equipment. The discrepancies between the load estimates and the 'true' loads must therefore be seen as a direct result of the use of infrequent samples and the rating curve procedures. Using the same example, precision problems can be demonstrated by the fact that replicate sets of samples collected using the same overall strategy of sampling frequency, but at different times, can produce substantially different load estimates. If a monitoring programme is to provide reliable estimates of sediment yield that will permit both meaningful comparisons between sites and the detection of trends at a single site, it is essential that the measurement strategy should be carefully designed in order to meet these requirements. This is likely to necessitate a programme of frequent sampling, capable of defining the continuous record of sediment concentration through time, rather than use of rating curve procedures. Furthermore, the procedures employed must be coordinated between different participants to ensure consistency and comparability of results. In addition, it is important to take account of these potential problems of data reliability when it is intended to make use of existing data to extend the temporal coverage of a monitoring programme in order to investigate long-



term trends. If the data are not consistent in terms of accuracy and precision, any evidence as to past trends may be illusory. A striking example of this potential problem is provided by recent work on the suspended sediment loads of New Zealand rivers by Griffiths (1979) and Adams (1980). Both workers used the same basic discharge and concentration data collected by the New Zealand Ministry of Works to estimate the mean annual suspended sediment load of the Cleddau River, which drains a basin of 155 sq.km in the southwest of South Island. Both used rating curve procedures, but their published loads of 13300 t km<sup>-2</sup> year<sup>-1</sup> and 275 t km<sup>-2</sup> year<sup>-1</sup> differ by nearly two orders of magnitude. Furthermore, it is easy to foresee a situation where improvements in sampling equipment and increased sampling frequency could result in records which gave the impression that sediment loads were increasing, whereas in reality no such trend might exist.

Although measurement of the total suspended sediment yield at the outlet of selected basins should represent the primary objective of the monitoring programme, consideration should be given to the potential for extending the scope of the programme to include other parameters. Such extension could usefully focus on three aspects. Firstly, investigation of the properties of the sediment constituting the total suspended sediment yield, secondly, elucidation of the overall sediment budget and, thirdly, reconstruction of past sediment yields from sedimentary evidence. These possibilities will be briefly considered.

#### Measurement of Sediment Properties

In addition to measurements of the total suspended sediment yield, it is useful to consider the physical and chemical properties of the transported sediment, since these can provide further information on the functioning of the environmental system under investigation and on perturbations induced by man-induced changes. As demonstrated in Figure 5, the suspended sediment loads of rivers exhibit substantial variations in their grain-size composition.

The median particle-size of the 10 distributions illustrated ranges over two orders of magnitude from fine sand (100  $\mu\text{m}$ ) to fine clay (<1  $\mu\text{m}$ ). This variability reflects control by the underlying geology, by climate and by the nature of the erosion and sediment delivery system. Thus, for example, where substantial deposition of eroded sediment occurs within the drainage basin it is likely that this will be associated with preferential deposition of coarse particles, resulting in a relatively fine sediment load at the basin outlet. Temporal changes in sediment source, such as might be associated with a shift in the relative importance of sheet and gully erosion, are also likely to produce changes in the grain-size composition of the suspended sediment. The organic matter content of suspended sediment will also reflect the dominant sources involved and the nature of pedogenic and biochemical cycling processes in the

(Figure 12). Hadley (1974) has suggested that the reduction in the annual sediment loads of the San Juan River which commenced in 1942 could be ascribed to the reduced grazing pressure which resulted from the Taylor Grazing Act of 1934. More detailed work by Graf (1985) has, however, cast doubt on this interpretation. Graf argues that the reduction in sediment loads in the Colorado and its tributaries which has occurred since the 1940's is due to a dramatic reversal in the behaviour of the alluvial valleys and channels upstream, whereby erosional or throughput channel conditions were replaced by a phase of aggradation. Much of the reduction in sediment yield which occurred after 1940 may therefore be the result of increased losses to channel storage. Butzer (1971) draws attention to the many similarities between the alluvial valley floors of Arizona and New Mexico, USA, and those of the Orange and Vaal Rivers in South Africa and it is interesting to note that the long-term record of sediment yield for the Orange River presented in Figure 12 demonstrates a similar reduction since 1936, to that evidenced by the San Juan River. This reduction in the sediment loads of the Orange River has been noted and discussed by Rooseboom and Von Harmse (1979), who ascribed it to a progressive exhaustion of erodible sediments following a period of accelerated erosion initiated by human activity. This is consistent with the analysis of the alluvial valley deposits reported by Butzer (1971), who suggested that the intensive human disturbance by burning and overgrazing which occurred during the period 1880-1930 and which corresponded to a run of dry years, increased surface runoff and resulted in a rapid dissection of the valley fill deposits. The decline in sediment yields post 1936 could therefore be interpreted as reflecting the completion of a "cut" cycle, whilst the further reduction apparent since 1954 may represent the initial stages of a "fill" cycle, since Butzer (1971) refers to recent alluviation in the major valleys.

## PERSPECTIVE

Suspended sediment yields provide a relatively easily measurable and valuable index of the rate of operation of contemporary geomorphological processes within the environment. Because they are highly sensitive to the impact of environmental change and they possess direct social and economic significance in terms of depletion of the soil resource, reduced crop productivity and downstream sedimentation, measurements of sediment yields from small- and medium-sized basins could provide an important component of a global monitoring programme. Such measurements would be directly applicable to a wide range of environments at the global scale, and the availability of existing records for some stations as well as the possibility of reconstructing long-term patterns from analysis of lake sediments and other sedimentary environments would considerably enhance the potential of such a monitoring programme for documenting environmental change. Existing measurement techniques could be readily adapted to a global monitoring programme, but

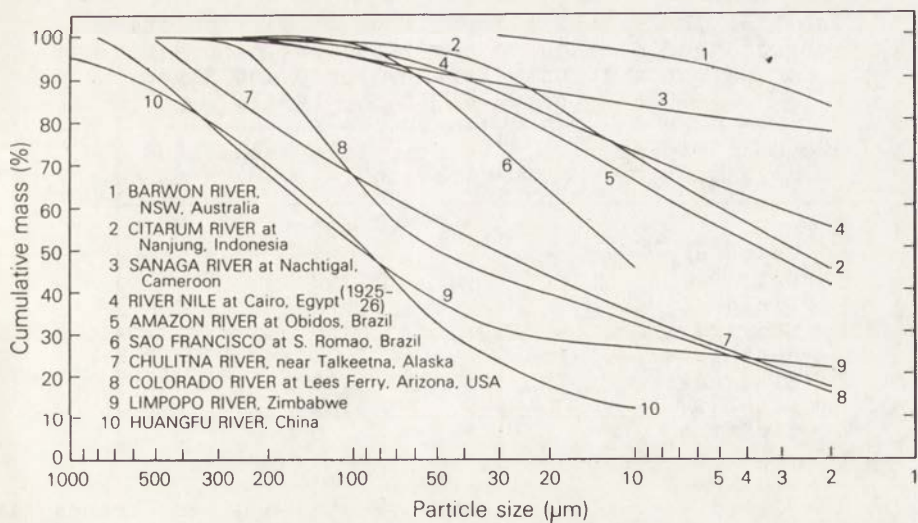


Fig.5 Global variation in the particle size composition of fluvial suspended sediment. The curves relate to typical distributions for individual rivers (based on Walling and Moorehead, 1989).

watershed, as well as indicating the significance of the sediment yield in depleting soil organic matter. For example, Burton et al. (1977) cite mean organic matter percentage of 30.6, 17.2 and 14.8, respectively, for sediment from forested-agricultural, suburban, and urban drainage basins in northern Florida, USA, whereas Skvortsov (1959) documents much lower values between 1.5 and 3.1% for the Rion River draining to the Black Sea in the USSR. Similarly, the nutrient content of suspended sediment can provide valuable information on the nutrient cycling processes operating in a drainage basin and in some basins the sediment-associated output of N and P may dominate the overall nutrient loads transported from the basin. For example, Schreiber et al. (1980) and Duffy et al. (1978) have calculated that the sediment phase accounted for 50% of the total N export and for 64-76% of the total P yield from five small forested watersheds in north-central Mississippi, USA. Equivalent results from agricultural areas by Schuman et al. (1976) indicate that sediment losses from small contour-cropped watersheds at Treynor, Iowa, USA accounted for 94 and 85% of the total discharge of N and P.

Recent work on the fluvial transport of contaminants (e.g. Allan, 1979, 1986) has also highlighted the important role of the sediment-associated phase in the transport of many contaminants such as heavy metals, agricultural pesticides and radionuclides. Table 5, for example, documents the relative importance of particulate-associated loadings in the transport of organic contaminants, primarily agricultural pesticides, to Lake



Table 5. The relative importance of particulate-associated loadings in the transport of organic contaminants to Lake Erie by the Grand River, 1976-77 (based on Frank, 1981).

Contaminant	Particulate-associated loading (%)
αBHC	100
Chlordane	91
DDT	68
Dieldrin	15
Endrin	0
Heptachlor epoxide	71
Lindane	100
PCBs	82
Simazine	0

Erie by the Grand River. Any attempt to monitor trends in environmental degradation and pollution could usefully include an assessment of the contaminant content of suspended sediment as well as the total yields.

#### Elucidating the Sediment Budget

Measurements of suspended sediment yield at the outlet of a river basin are essentially 'blackbox' in nature since they document what leaves the basin, rather than the processes operating within it. Any attempt to use sediment yield data to provide information on rates of erosion and catchment degradation must consider the complex relationship between on-site erosion and downstream sediment yield. This in turn involves consideration of sediment delivery processes and the overall sediment budget and the magnitude and relative importance of its sources and sinks. A relatively low suspended sediment yield at the outlet of a basin will commonly reflect low rates of erosion, but it could also reflect an inefficient sediment delivery system, wherein most of the eroded sediment was deposited before reaching the catchment outlet. Information on the properties of the suspended sediment can provide useful evidence as to the likely sources involved, but it is also important to consider the nature and relative importance of the sediment sinks or depositional zones. Figure 6 illustrates schematic examples of sediment budgets for a selection of drainage basins under different physiographic conditions.

In the case of Coon Creek, Wisconsin, and Oka River in the USSR, the sediment budgets evidence major losses to the sinks associated with slopes and the river valleys and only a small proportion of the eroded sediment reaches the basin outlets. This proportion increases in the case of the Arroyo de Los Frijoles, a small drainage basin in a semi-arid region of New

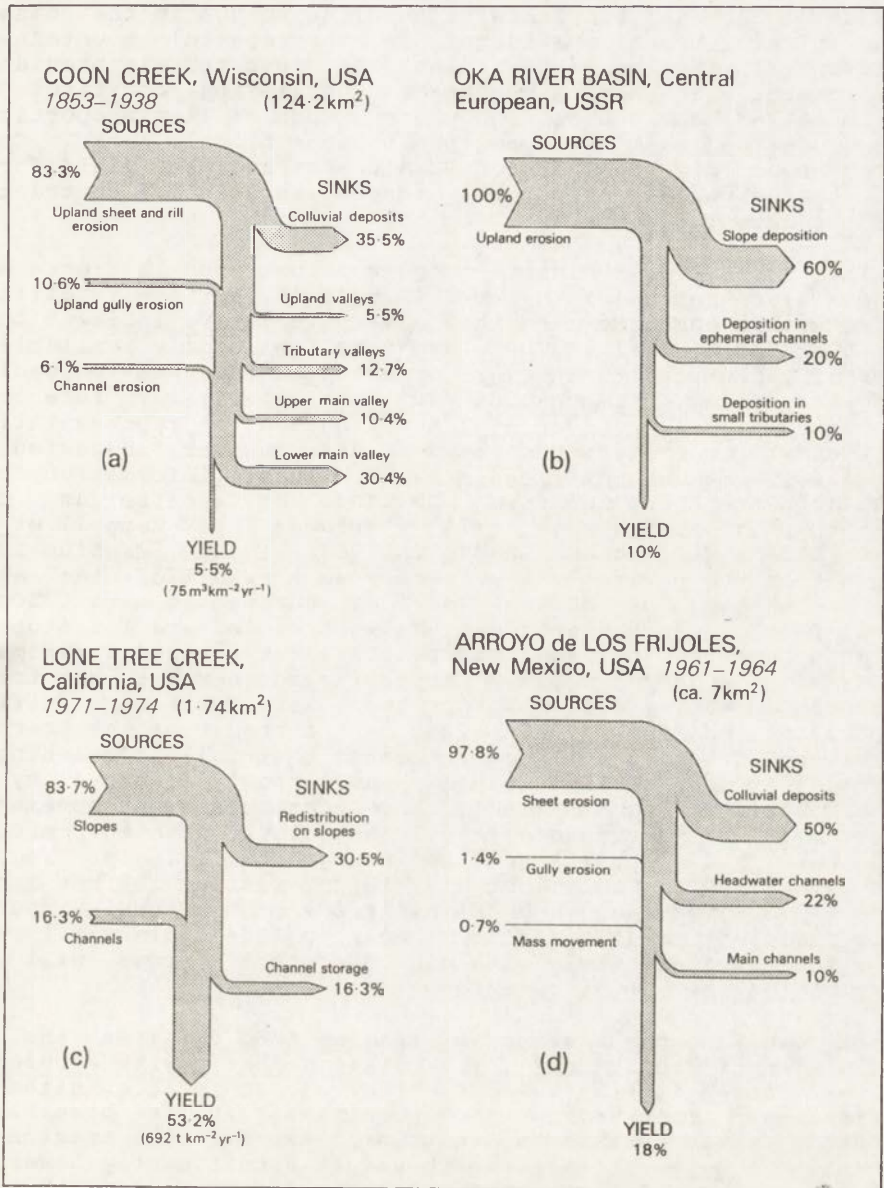


Fig.6 Examples of sediment budgets for a selection of drainage basins (based (a) on Trimble, 1981; (b) on Zavlavsky, 1979; (c) on Lehre, 1982; and (d) on Leopold et al., 1966).

Mexico, USA, and reaches a value close to 50% in the case of Lone Tree Creek, situated in the coastal mountains of California. In the latter case, the steep terrain provides an environment where mass movements and gulleying constitute the dominant sediment sources and where a much smaller proportion of the eroded sediment is deposited in depositional sinks. Consideration of only the individual values of sediment yield for the four basins would, therefore, conceal substantial contrasts in their sediment budgets.

The schematic sediment budgets illustrated in Figure 6 are essential conceptual in nature since it is extremely difficult to establish anything more than a very tentative sediment budget for a drainage basin. There are very few readily available and generally accepted techniques for establishing detailed sediment budgets and any attempt to do so must inevitably face major problems in terms of spatial sampling and the representativity of the data collected. Recent work has, however, suggested that caesium-137 measurements can provide valuable information on the spatial pattern and relative importance of erosion and deposition processes within small watersheds (cf. Campell *et al.*, 1986, 1988; Walling and Bradley, 1988, 1989). Caesium-137 is present in the environment primarily as a result of the atmospheric testing of nuclear devices during the late 1950s and early 1960s, and a significant fallout of this radioisotope was first documented in 1954. Rates of fallout reached a maximum in 1964 and declined rapidly after the nuclear test ban treaty, although in many areas of Europe there were further significant inputs of caesium-137 in 1986 as a result of the Chernobyl disaster. Existing evidence indicates that fallout reaching the surfaces of most soils is rapidly and strongly adsorbed by the upper horizons of the soil and that subsequent movement of caesium-137 is therefore generally associated with the erosion, transport and deposition of sediment particles (e.g. Rogowski and Tamura, 1972; Campell *et al.*, 1982). Caesium-137 has a half-life of 30.1 years and approximately 60% of the total input of this radioisotope since fallout began in 1954 could still remain in the environment, although Chernobyl inputs will have complicated the situation in some areas.

By comparing the caesium-137 loading ( $\text{mBq cm}^{-2}$ ) in the soil at different locations in a drainage basin with a reference value representing the fallout received at stable sites experiencing neither erosion nor deposition, it is possible to identify those areas in a catchment experiencing erosion over the past 25-30 years (i.e. with values significantly lower than the reference) and those evidencing deposition (i.e. with values significantly greater than the reference). Figure 7, based on the work of the author, provides an example of the application of the technique to a group of fields within the Jackmoor Brook, catchment in Devon, UK. In this case, no attempt has been made to quantify the magnitude of the rates of erosion and deposition involved but relationships between the amount of caesium-137 lost or gained are currently being refined for this purpose. If



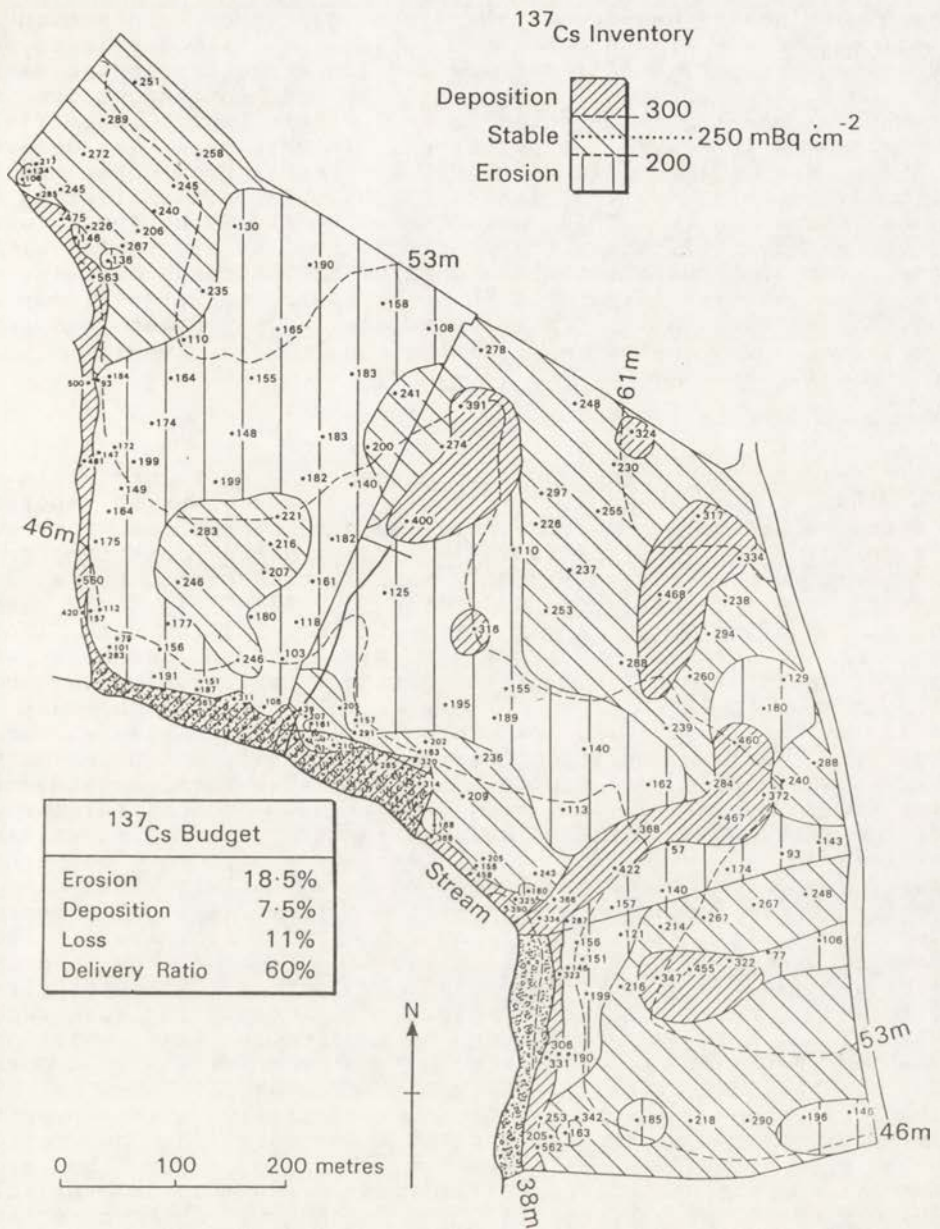


Fig.7 The spatial distribution of the caesium-137 content of the soil profile within a group of cultivated fields in Devon UK. Comparison of the individual sample values with the reference enables areas of erosion and deposition to be delimited and a tentative caesium-137 budget to be established.

such caesium-137 measurements are combined with information on sediment yields at the catchment outlet, it is possible to produce a tentative sediment budget for a small drainage basin. Figure 8, for example, represents the sediment budget for the Kackmoor Brook basin (8.8 sq.km) within which the fields referred to in Figure 7 are located. In this case the delivery ratios are higher than those encountered in Coon Creek and the Oka River basins (Fig. 6) indicating that depositional sinks are less significant. This accords with field evidence which provides no indication of significant valley alluviation within the Jackmoor Brook basin. The caesium-137 approach can also be extended to investigate such alluviation and also floodplain deposition in locations where these are an important component of the sediment budget (cf. Walling and Bradley, 1989).

## RECONSTRUCTING PAST SEDIMENT YIELDS

Documentation of trends and changes in sediment yield in response to environmental change must represent an important objective of any monitoring programme, but the scope for such investigations will be strictly limited where monitoring programmes have been extant for only short periods and where data series are in consequence of limited duration. In these cases, data from other measuring locations in the vicinity with longer periods of record may prove valuable, but in general it will prove impossible to document the drainage basin response under original undisturbed or wilderness conditions, which must be seen as the baseline against which subsequent changes should be measured. Recent investigations have, however, demonstrated the very considerable potential of lake sediments for reconstructing the sediment yield of inflowing streams over substantial periods of the past. Thomas (1988), for example, provides a valuable review of the wide range of circumstantial evidence concerning past erosion rates and the impact of human activity that can be derived from sediment cores retrieved from lakes. The work of Dearing *et al.*, (1981, 1987) and Souch and Slaymaker (1986), however, represents an important advance in that they have used lake sediment cores to reconstruct the actual sediment yields involved. There are four major requirements for such reconstruction. Firstly, there must be a suitable lake which has trapped sediment eroded from the upstream basin over a considerable period of time. Ideally the lake should have a high trap efficiency which has been essentially stable over the intended period of reconstruction. Secondly, dating methods capable of providing an absolute chronology for the sedimentation represented by the sediment cores must be available. Thirdly, and most importantly, a method of inter-core correlation is required, to enable the volumes of sediment stored between synchronous levels in the lake deposit to be calculated. Fourthly, it must be possible to distinguish the allochthonous inputs of sediment eroded from within the surrounding drainage basin, from autochthonous sediment originating within the lake itself. Radiometric dating techniques involving caesium-137,

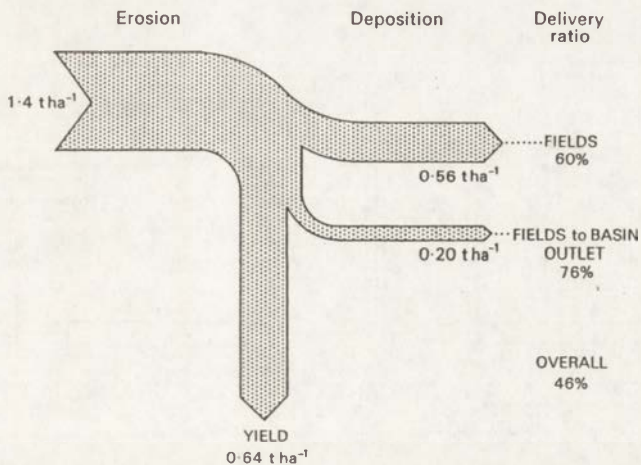


Fig.8 A tentative sediment budget for the Jackmoor Brook basin, Devon, UK, based on evidence provided by caesium-137 measurements undertaken at several locations within the basin. The fields illustrated in Figure 7 are located within this basin.

lead-210 and carbon-14 (cf. Campell, 1983; Oldfield and Appleby, 1984), palaeomagnetic dating methods (e.g. Thompson and Turner, 1979) and other dating procedures now provide a reliable means of obtaining absolute chronologies for sediment cores extending back for several thousand years. Continuous measurement of down-core magnetic susceptibility profiles, coupled with visual analysis of down-core stratigraphic changes (e.g. Bloemendal *et al.*, 1979; Dearing, 1986) have also been used to assist in establishing the necessary inter-core correlations.

Figure 9 illustrates the potential of lake sediment investigations for reconstructing records of sediment yield over both the relatively recent past and a period of several thousand years. In the case of Seeswood Pool, a small reservoir in the English Midlands constructed around 1765 and investigated by Dearing and Foster (1987), reconstruction of the sediment yield record the substantial increases that have occurred over the past 60 years, as a result of the removal of hedgerows and the introduction of intensive cultivation methods (Figure 9A). The reconstructed record derived for Lyn Peris in North Wales, UK, derived by Dearing *et al.* (1981) and illustrated in Figure 9B exhibits an almost order of magnitude increase in sediment yields over the past 150 years, which can be related to the erosional effects of mining, quarrying, overgrazing and recent construction activity in this upland catchment. In this case maximum and minimum values of sediment yield are shown for the individual periods, in order to take account of some of the uncertainties associated with the individual estimates. The ex-



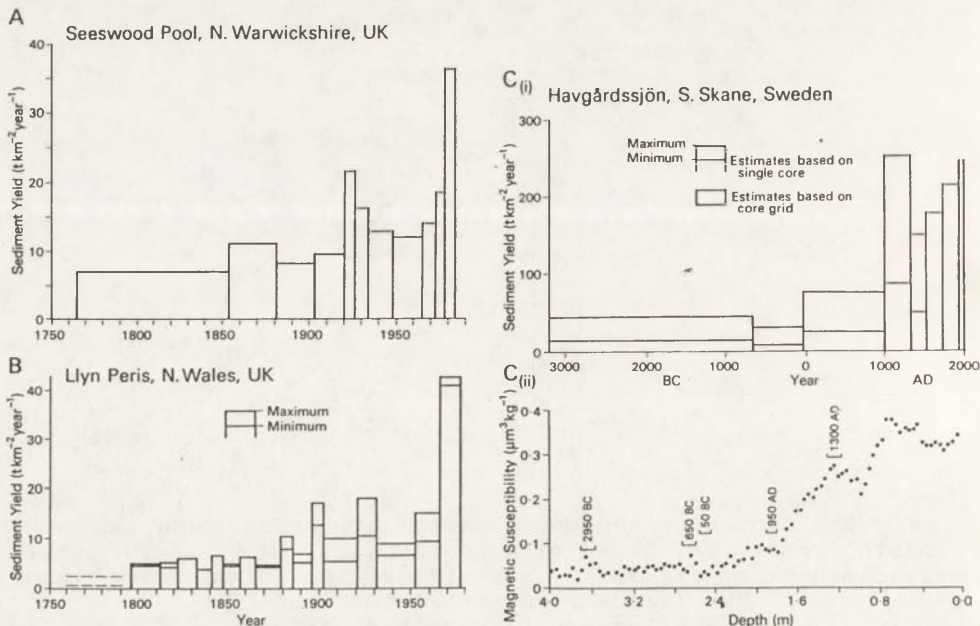


Fig.9 Examples of lake sediment-based reconstruction of sediment yields for three drainage basins, based on the work of Dearing and Foster (1987), Dearing et al. (1981) and Dearing et al. (1987).

ample from Lake Havgardssjon, illustrated in Figure 9C, relates to a small lake located in the hummocky moraine terrain of southern Skane, Sweden. In their study of this lake, Dearing et al. (1987) used a grid of cores to reconstruct the record since 1550, and evidence from a single core was used to tentatively extend the reconstruction back to 3050 BC. Based on this record it would appear that sediment yields in the period 3000 - 50 BC were of the order of 25 t km<sup>-2</sup> year<sup>-1</sup>, a level consistent with the essentially undisturbed woodland occupying the area at this time. After 50 BC sediment yields increased in response to land clearance and agricultural activity, and some of the fluctuations during the subsequent period can be related to variations in the intensity of agricultural activity.

In addition to providing evidence on past sediment yields, lake sediment investigations can also be coupled with recent work on sediment properties to provide information on changing sediment sources, if downcore changes in sediment properties can be linked to sediment influx from different sources or to a change in the relative importance of the sources involved. In the case of the Lake Havgardssjon study cited above, Dearing et al. (1987) measured the downcore changes in magnetic susceptibility of sediment from the 4m core (Figure 9C) and the

results were interpreted in terms of changes in sediment size and source. High susceptibility values were ascribed to the influx of coarser sediment, much of which have been derived from accelerated channel erosion within the basin.

These few examples highlight the potential that exists to assemble information on past sediment yields, in order to extend the scope of contemporary monitoring programmes and to attempt to define baseline conditions. Other sediment deposits and sedimentary environments may provide further opportunities for reconstructing past records and thereby elucidating long-term changes and trends.

#### INTERPRETING TRENDS AND CHANGES

In most situations, records of suspended sediment yield will provide a sensitive indicator of environmental change, but attempts to utilise such records to evaluate trends and changes within the environmental system must clearly take account of the accuracy and precision of the available data and the need to distinguish the more local effects of changes in catchment condition and land use (i.e. internal effects) from the more general influence of climatic change (i.e. external effects). Careful statistical analysis, which takes account of the reliability of individual values in a time series may be necessary to distinguish real changes and trends from spurious effects. Such problems will frequently be compounded by the difficulties of distinguishing trends and changes within a time series that exhibits substantial natural variability. Some of the latter difficulties are illustrated in Figure 10. This depicts the long-term record of suspended sediment yield for the Orange River at Upington/Prieska for the period 1937-1952 as documented by Rooseboom and Maas (1974) and a hypothetical record for the same river synthesised from this original record by assuming a progressive increase in sediment yields over the period of 5% per year. Although the latter record incorporates an overall increase in the sediment load over the period of 100%, this trend is far from clear since it is largely masked by the natural variability of the record. Attempts to decipher the trend could involve consideration of changing mean sediment concentrations, but in reality the increase in sediment loads could be largely the result of increased runoff volumes. Changes in the relationship between mean annual precipitation and sediment yield might afford clearer evidence of the change, but this would involve the assumption that there had been no change in the character of the precipitation. Furthermore, the non-stationary character of the sediment yield series could make it difficult to isolate the precise nature of the changing relationship and therefore the degree of change involved.

Figure 11 provides an example of the potential problems that may be associated with any attempt to distinguish changes driven by the internal and external causes referred to above. It

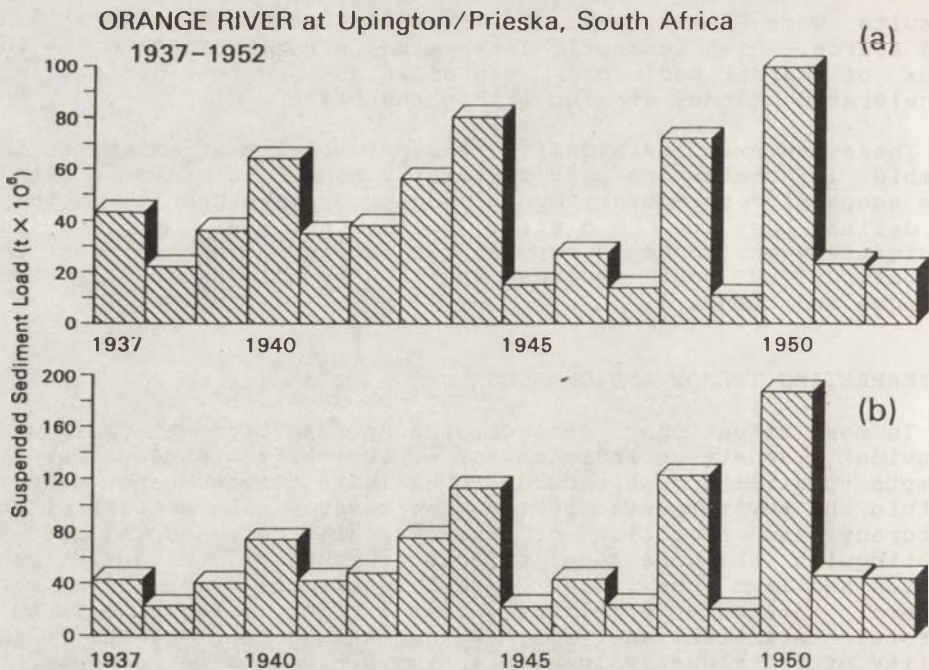


Fig.10 Problems of detecting long-term trends.

(a) depicts the record of annual suspended sediment yield for the Orange River at Upington/Prieska for the period 1937-52 documented by Rooseboom and Maas (1974). In (b) a hypothetical record for the same river involving a progressive increase in sediment yield of 5% per year has been synthesised using the annual yields depicted in (a). The natural variability of the record makes this synthesised trend difficult to detect.

illustrates the longer-term trend of sediment yield records for two neighbouring Kenyan rivers for the periods 1947-68 and 1957-76.

There is evidence of substantial land use change within this area over the period, which has in turn been related to increased sediment loads. However, this change occurred during a period of significant climatic change. Lamb (1966) used records of the water levels in East African lakes and other hydro-meteorological data to conclude that there had been a significant change in the atmospheric circulation, which caused increased rainfall in East Africa during the early 1960's, and the impact of this change is clearly evident in the sediment yield records presented in Figure 11.

When interpreting trends and changes in sediment yields at the outlet of a drainage basin in terms of the erosion processes



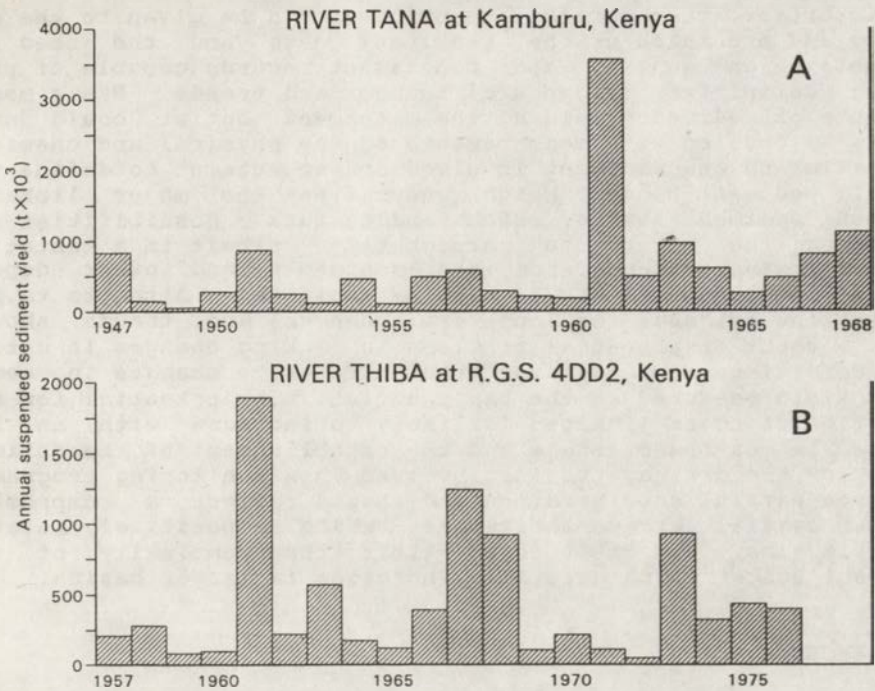


Fig.11 The long term variability of sediment transport demonstrated by two Kenyan rivers (based on Walling, 1984).

and rates operating within that basin, it is also important to recognise that any direct relationship between erosion and sediment yields may be obscured by changes in the functioning of the sediment budget. Trimble (1981), for example, cites the example of Coon Creek, Wisconsin, USA where the introduction of soil conservation and other sediment control measures within this severely degraded basin in the middle of the 20th century apparently had little effect on downstream sediment yields, since the reduction in upland erosion was effectively balanced by remobilisation of sediment previously stored in the valley bottoms. Another indication of the potential difficulties involved in interpreting the long-term sediment yield response of river basins to environmental change is provided by Fig.12. This presents sediment yield records for the period from the early 1930's to the early 1970's for the Orange River in South Africa and the San Juan River, a tributary of the Colorado River in southwest USA. Both drain large areas of semi-arid rangeland which were subjected to considerable grazing pressure during the latter part of the 19th and the early 20th centuries. Inspection of the long-term records provides some evidence of declining sediment yields which is clearly confirmed by double mass plotting of accumulated sediment yield versus accumulated runoff

is important that careful attention should be given to the accuracy and precision of the resultant data and the need to assemble high quality and consistent records capable of providing definitive evidence of changes and trends. Basic measurements of sediment yield at the catchment outlet could usefully be coupled with measurements of the physical and chemical properties of the sediment involved and an attempt to define the overall sediment budget which quantifies the major linkages between sediment source, sinks and outputs. Possibilities for extending the record back through time, albeit in a tentative manner, using evidence from lake sediments and other depositional environments should also be exploited. Attempts to interpret the evidence for long-term changes and trends should take account of potential problems in linking changes in catchment condition and associated erosion rates to changes in sediment yield measured at the basin outlet. The potential for attenuation of these linkages is likely to increase with an increase in catchment scale and the establishment of the optimum scale for the drainage basins involved in a monitoring programme requires careful consideration and should reflect a compromise between spatial representativeness, which is positively related to basin size, and the need to limit the complexity of the sediment budget which generally increases in larger basins.

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## LONG-TERM FLUCTUATION OF HYDROCLIMATE ELEMENTS IN NORTH-EASTERN EUROPE

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### INTRODUCTION

Water balance elements, such as atmospheric precipitation, air temperature (evaporation), river runoff and surface storage undergo the process of natural periodical changes in course of time. These can be daily, seasonally, yearly and long-term fluctuations due to rotary motion of the Earth, circulation of the Earth around Sun, and also because of the century-long changes in Sun's activity. Moreover, they are also liable to anthropogenic influence that can for example be referred to an increase in the content of dust in the atmosphere, absorption of radiation, water vapour condensation nuclei, carbon dioxide concentration (greenhouse effect) or yet other form of human activity (like e.g. water level regulations in reservoirs, land reclamation etc.).

The aim our research is to determine periodical changes that occur in water balance elements and to try to explain their causes. The anthropogenic component of their long-term trends has also been singled out and forecasts reaching until 2040 effectuated.

### EMPIRICAL DATA

Chronological data of water balance elements from the Polish and North-East European areas have been analyzed and recognized as reflecting the 18-20th Century changes. The following empirical values, varying in their length, have been examined: Sun activity (1700-1978), the Masurian Mamry Lake surface storage data (1846-1986), the Warsaw station atmospheric precipitation data, as well as those from Wrocław (1859-1979), Giżycko (1838-1986), Snieżka - Snow Hill (1885-1979); air temperatures from Warsaw (1779-1980) and Wrocław (1851-1979); as well as runoff of eight chosen rivers from North-Eastern Europe, like Łaba-Decin

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Fig.1 Hydroclimate date

(1856-1969), Niemen Smalininkai (1812-1979), Vistula-Tczew (1901-1980), Oder-Gozdowice (1901-1980), Neva-Saratovskaja-Leningrad (1858-1984), Göta-Älv (1807-1979), Kymijoki-Pernoo (1900-1979), and Kemijoki-Taivaalkoski (1911-1979) - (Fig. 1).

#### THEORETICAL APPROACH

Periodicity of the water balance elements has been examined using J. Boryczka's method (1984) which helps disclose the optimum periods. These optimum periods  $T$  in the secular changes are found by eliminating regression sine curves:

$$y = a_0 + b \cdot \sin \left( \frac{2\pi}{T} \cdot t + c \right) \quad /1/$$

from among  $T = 1, 2, 3, \dots, n$ , where  $n$  - number of measurements. The optimum periods  $T_j$  being looked after, as Stopa-Boryczka (1989) suggest, include local residual variance minima,  $\epsilon^2$  corresponding to the multiple correlation factor maximum

$$R = \sqrt{1 - \frac{\sum \epsilon^2}{S^2}} \quad /2/$$

where  $S$  is the  $y$  variable standard deviation.

The optimum period detection Model is being verified with the Fisher-Snedecor test  $F = \frac{n-3}{2} \cdot \frac{R^2}{1-R^2}$  with 2 and  $n-3$  degrees of freedom.

Pinpointing the hidden  $T_j - t_j$  period of the optimum sine curve boils down to developing the regression plane equation

$$y = a_0 + \alpha \cdot x_1 + \beta \cdot x_2 \quad /2/$$

in relation to variables

$$x_1 = \sin \left( \frac{2\pi}{T} t + c \right), \quad x_2 = \cos \left( \frac{2\pi}{T} t + c \right).$$

The amplitude of fluctuations ( $b$ ) of the hydroclimate element and phase shift ( $c$ ) are expressed with the formulae:

$$b = (\alpha^2 + \beta^2)^{1/2}, \quad \text{tg } c = \frac{\beta}{\alpha} \quad /3/$$

where angle  $c$  fulfills conditions  $\alpha = b \cdot \sin c$ ,  $\beta = b \cdot \cos c$ . The optimum period method can be used to determine the regression sine curve segment with its period longer than the measurement sequence ( $T > n$ ). It can also be used in the event of non-complete chronological trains (no observation data available as regards some of the years).

One drawback of the harmonic analysis so far in operation, according to which successive terms of the Fourier series (i.e. harmonics) have to be found, is the adoption of fictional periods:  $n, n/2, n/3 \dots$ . Periods in question, which are derived from an arbitrary division of the chronological train length into two, three and so on parts, do not come in line with the real ones.



The method proves unserviceable at all, if one wants to disclose periods with lengths within an  $n/2$  up to  $n$  years' time interval.

The same drawback can be found in the popular autocorrelation period detecting method. Autocorrelation factors between the primary sequence and sequences obtained from translations of 1, 2, 3, and more years tend to restrict its scope to periods shorter than  $n/2$ .

While knowing optimum  $T_j$  periods, we can try to establish the time-related trend of any hydroclimate element wanted from equation:

$$y = f(t) = a_0 + \sum_{j=1}^k b_j \cdot \sin \left( \frac{2\pi}{T_j} \cdot t + c_j \right) \quad /4/$$

by minimizing residual 
$$e^2 = \frac{1}{n} \cdot \sum_{i=1}^n [ Y_i - f(t_i) ]^2$$

the  $T_j$  periods are incommensurable. By extrapolating the time-related trend function  $f/t/$  of the analyzed variables one can complete their reconstruction ( $t < 0$ ) or obtain forecast ( $t > 0$ ) with any time advance desired.

So far, the time-related trend  $f/t/$  of hydroclimate elements has been used to be expressed with the Fourier series in which fictional periods functionally dependent on the length of a chronological sequence of precipitation (Kaczorowska, 1962, Ewert, 1984) or discharge (Mitosek, 1970, 1984) used to be introduced.

If we try to add a linear component  $\Delta y = a \cdot t$  to function  $y = f/t/$  which approximates periodic (natural) changes to result from the imposition of real cycles, the time-related model  $F/t/$  will go divided into two components:

$$y = f(t) = \underbrace{a_0 + at}_{\text{Linear component}} + \underbrace{\sum_{j=1}^k b_j \cdot \sin \left( \frac{2\pi}{T_j} t + c_j \right)}_{\text{Natural changes resulting from actual (optimum) changes } T_j} \quad /5/$$

Linear component with a lasting tendency of  $\frac{\partial y}{\partial t} = a = \text{const}$  may indicate the effect of the successively progressing changes of an anthropogenic nature. If the partial regression factor  $a > 0$ , the anthropogenic changes will show a rising tendency, and if  $a < 0$ , a falling tendency.

#### ATMOSPHERIC PRECIPITATION

The annual sums of precipitation in the localities under investigation are liable to periodical changes (Table 1). These are short half-period 5-8 yearly cycles, sun (10-14) year cycles, double (16-21) year cycles, tripple (26-34) year cycles,

quadruple (42-58) year and longer-secular cycles: Warsaw - 112 years, Wrocław - 73 years, Giżycko - 120 years.

Table 1. Atmospheric precipitation T cycles: Warsaw (1813-1980), Wrocław (1859-1979), Giżycko (1838-1986), Śnieżka (1885-1979); their amplitudes b and phase shifts c

Warsaw				Wrocław				Giżycko				Śnieżka			
T	b	c	F	T	b	c	F	T	b	c	F	T	b	c	F
6	28,0	-2,53	2,5	5	33,7	1,60	3,4	8	25,2	2,19	1,5	5	96,1	-0,30	3,0
12	22,4	-1,64	1,6	10	35,8	1,89	3,9	13	29,1	-0,20	2,1	10	110,1	0,09	4,0
16	35,6	1,48	4,1	16	28,9	1,57	2,4	19	25,0	-1,14	1,5	14	75,4	1,53	1,8
19	31,4	0,58	3,2	30	24,6	2,53	1,8	28	36,2	-0,78	3,2	21	78,8	-2,56	1,9
58	30,8	-3,04	3,1	42	35,4	2,74	3,8	46	46,4	0,88	5,8	28	100,6	1,99	3,2
112	29,7	-0,91	2,7	73	33,2	2,86	2,8	126	17,9	2,54	0,7	46	47,6	-3,05	0,7

The curves of annual precipitation for the time-related trend, with the account being also taken of the linear anthropogenic component, refer to Fig. 2. Their equations have been given below for Warsaw and Giżycko together with the assessment of their accuracy (R - multiple correlation factor, F - Fisher-Snedecore test):

Warsaw (R = 0,43, F = 2,64)

$$P = 563,7 + 0,0177 t + \\ + 27,46 \sin(2\pi t/6 - 2,493) + 22,94 \sin(2\pi t/12 - 1,483) + \\ + 31,61 \sin(2\pi t/16 - 1,564) + 28,08 \sin(2\pi t/10 + 0,598) + \\ + 27,33 \sin(2\pi t/58 + 3,121) + 26,36 \sin(2\pi t/12 - 0,740)$$

Giżycko (R = 0,42 F = 2,19)

$$P = 586,7 - 0,1669 t + \\ + 26,28 \sin(2\pi t/6 + 22,213) + 29,56 \sin(2\pi t/13 - 0,201) \\ + 22,11 \sin(2\pi t/19 - 1,227) + 23,97 \sin(2\pi t/28 + 0,145) \\ + 44,26 \sin(2\pi t/46 + 1,064) + 24,34 \sin(2\pi t/126 + 2,773)$$

The a regression factor values are, as follows: Warsaw - 1,8 mm per 100 years; Wrocław - 20,3 mm per 100 years; Giżycko - 16,7 mm per 100 years; Śnieżka - 3,5 mm per year. The rising tendency of annual precipitation sums for Warsaw and Wrocław may result from an increase in the content of dust (Condensation nuclei) in the urban atmosphere. The high increase tendency of precipitation at the Śnieżka is most probably an outcome of the straightline approximation over the sine curve section with a long unknown period, which period could not have been determined because of a short lasting measurement sequence. Moreover, we do not know what is likely to be the cause for a lasting drop in local precipitation at Giżycko.

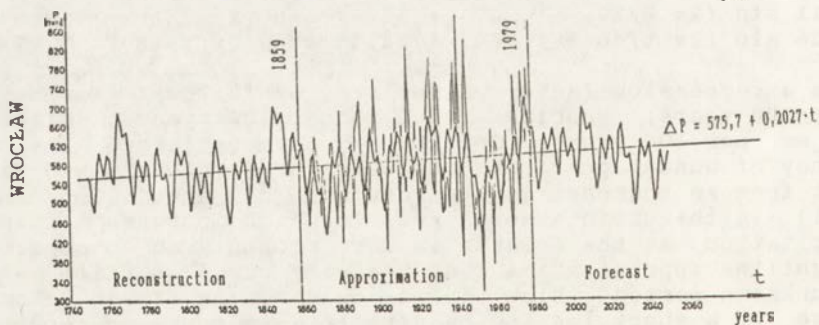
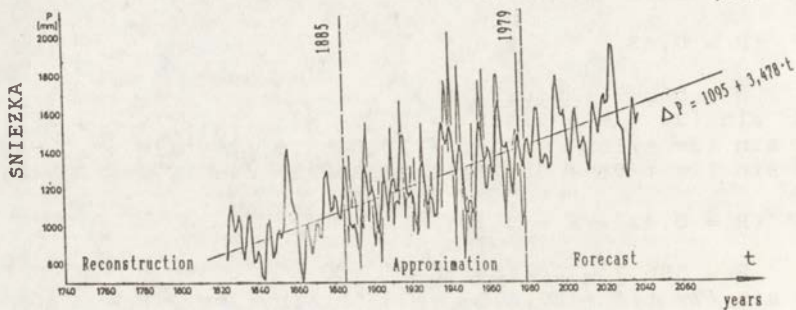
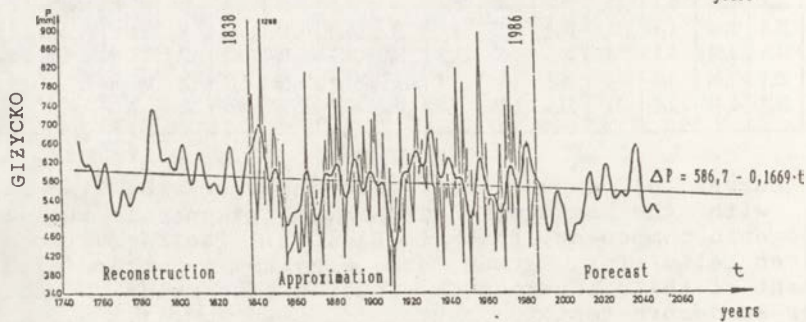
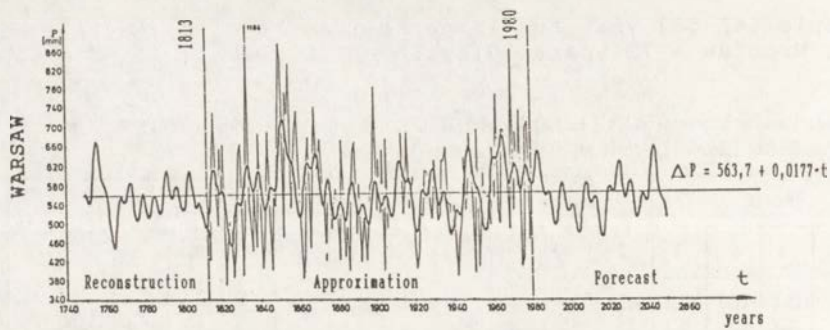


Fig.2 Long-term fluctuations of precipitation in the selected stations in Poland



## AIR TEMPERATURE

Air temperature results in evaporation which constitute one of the water balance components.

It is liable to periodical short-term and long-term fluctuations (Table 2, Fig. 3,4) which, as was shown in Boryczka's papers (1984, 1986), are synchronous with the short (11 and 12 year) and long (94 and 180 year) sun activity cycles. Two main air temperature cycles have been stated in Warsaw - 89 year and 217 year cycles with 0,5°C and 1,4°C amplitudes - which have been influencing the climate of Poland for more than two centuries. The absolute air temperature minimum in Warsaw occurred over the years featured by the smallest sun activity (1810-1811); the maximum was observed near the dates of the absolute sun-spot maximum (1957).

Table 2. Air temperature T cycles for Warsaw (1779-1979) and Wrocław (1851-1979) their amplitudes b and phase shifts c.

Warsaw				Wrocław			
T	b	c	F	T	b	c	F
4	0,16	1,12	1,3	5	0,12	-1,84	0,7
13	0,21	0,23	2,5	12	0,16	0,86	1,4
22	0,15	1,49	1,3	17	0,17	2,59	1,5
60	0,18	1,32	1,7	26	0,18	2,88	1,6
89	0,24	2,34	3,1	38	0,23	-1,85	2,7
217	0,57	-2,97	23,0	114	0,32	-2,03	6,1

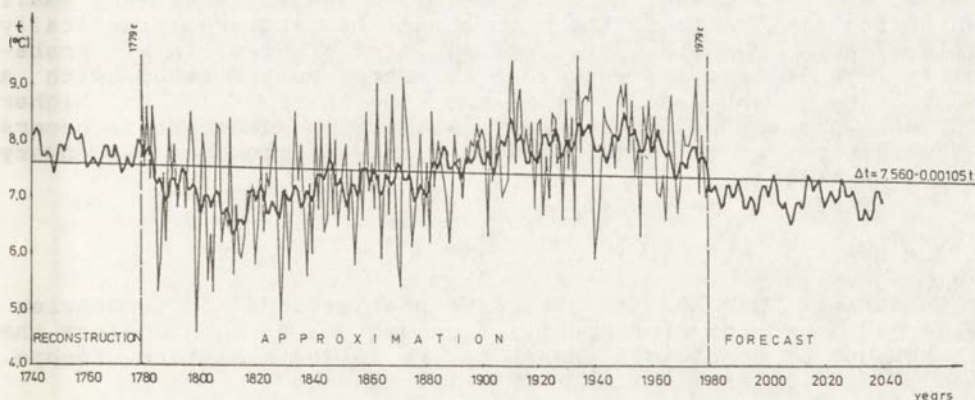


Fig.3 Long-term fluctuations of air temperature in Warsaw (1779-1979)

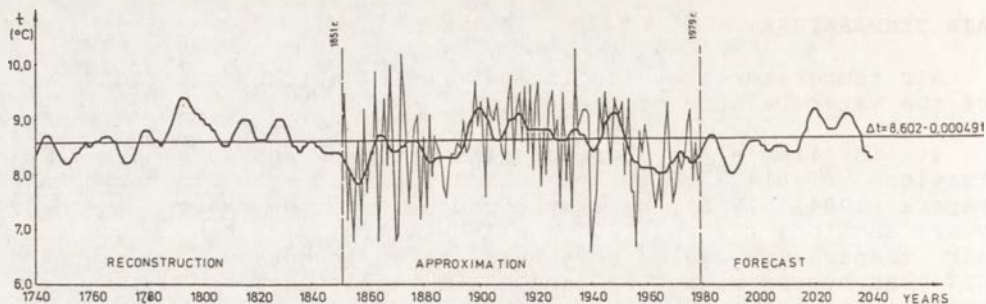


Fig.4. Long-term fluctuations of air temperature in Wrocław (1851-1979)

Below presented are functions of the mean annual air temperature trends in Warsaw and in Wrocław:

Warsaw (R = 0,49 F = 4,51)

$$T = \frac{7,560 - 0,001049 t}{+} + 0,1643 \sin(2\pi t/4 + 1,223) + 0,2015 \sin(2\pi/13 t + 0,2715) + 0,1307 \sin(2\pi t/22 + 1,593) + 0,1253 \sin(2\pi t/60 + 1,105) + 0,1378 \sin(2\pi t/89 + 2,501) + 0,5869 \sin(2\pi t/217 - 2,924)$$

Wrocław (R = 0,42 F = 2,25)

$$T = \frac{8,602 - 0,0004905 t}{+} + 0,1611 \sin(2\pi t/12 + 0,7683) + 0,1557 \sin(2\pi t/17 + 2,678) + 0,1420 \sin(2\pi t/26 + 2,759) + 0,1832 \sin(2\pi t/38 - 1,627) + 0,3049 \sin(2\pi t/114 - 2,118)$$

The anthropogenic linear components indicate a consistently diminishing air temperature tendency in Warsaw, by 0,1°C per 100 years, and in Wrocław, by 0,5°C per 1000 years. Those very small anthropogenic falls in the mean annual temperature (practically unimportant from the statistical point of view) in all probability result from the fact that in winter we are faced with a dominating greenhouse effect of the atmosphere (due to higher CO<sub>2</sub> contents in the atmosphere), whereas in summer there occurs an absorption of radiation by dust (derived from the secondary emission effect).

#### RIVER RUNOFF

An attempt was made to determine real periods and tendencies observed in Polish river runoff fluctuations as seen against the background of some eighth chosen rivers in North-Eastern Europe, and provide an explanation for their reason.

Table 3. Sun activity T cycles, their amplitudes b and phase shifts c

T	b	c	F
5	3,7	-2,82	0,6
11,1	28,1	-1,52	51,2
17	4,7	0,78	1,1
21,4	4,4	0,94	0,9
25	3,1	-2,62	0,5
29	5,4	2,44	1,4
33	3,2	2,43	0,5
38	4,6	-3,03	1,0
45	9,3	2,83	4,1
56	13,9	-1,91	9,7
95	18,2	-2,69	17,9
180	9,9	-1,32	4,8

The runoff of all rivers under investigation are found to have been liable to periodical high-amplitude fluctuations between more or less 95 or 90% levels (Table 4, Fig. 5a,b). The largest amplitude cycles of such Polish rivers as the Vistula - 13, 20, 55 and Oder - 10, 19, 54 years, resemble sun activity cycles with 11, 21-22 and 56 sun activity years. The long cycles of river runoff have attracted the attention of Krasnodębski and Gadkowski (1978), as well as Stachy (1970).

Table 4. River runoff T cycles: Łaba (1851-1964), Oder (1901-1980), Vistula (1901-1980), Niemen (1812-1979), Neva (1859-1984), Göta (1807-1979), Kymijoki (1900-1979), Kemijoki (1911-1979), their amplitudes b and phase shifts c.

Łaba				Oder				Vistula				Niemen			
T	b	c	F	T	b	c	F	T	b	c	F	T	b	c	F
5	38,8	0,75	5,9	5	42,4	0,16	2,0	8	68,6	0,98	1,8	8	27,6	-0,03	3,7
10	27,2	2,60	2,8	10	67,8	2,76	5,5	13	70,9	0,96	1,6	13	24,1	-0,12	2,8
15	48,3	0,96	9,9	13	68,3	1,02	5,7	20	71,8	2,16	2,0	17	23,3	-1,67	7,9
22	26,6	0,85	1,7	19	53,6	0,24	3,3	29	72,2	-2,18	2,1	27	33,1	-1,15	5,4
30	20,2	0,95	1,5	54	54,9	-1,47	3,4	55	112,8	-1,00	5,0	67	22,8	2,40	2,4
47	24,4	2,29	2,1												
101	27,4	-2,71	2,8												
Łaba				Oder				Vistula				Niemen			
8	12,8	3,09	2,9	7	35,5	2,64	5,3	8	33,9	-2,60	3,8	11	58,1	1,71	5,5
11	15,8	1,60	4,6	11	25,3	1,11	2,6	10	37,4	-1,66	4,7	15	54,4	-2,80	4,9
20	90,4	-0,82	1,4	17	29,6	-1,32	3,6	15	15,0	0,24	8,6	36	42,7	-0,93	2,7
29	321,3	-1,32	23,8	32	33,6	2,52	4,7	29	40,9	1,41	5,8				
43	101,1	-0,42	1,8	43	31,4	-2,20	4,1								
132	126,7	-0,18	3,0	87	18,0	-0,91	1,3								



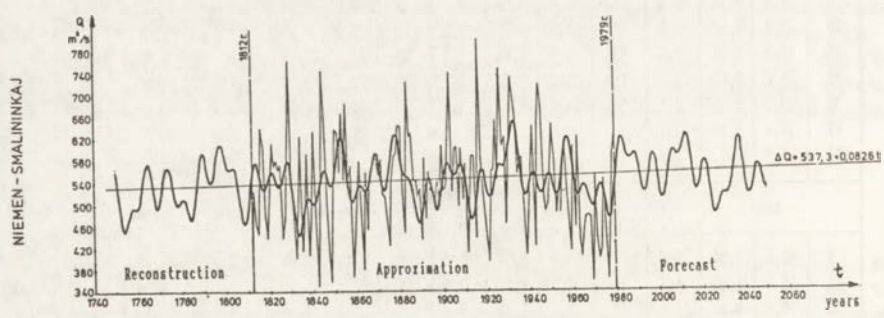
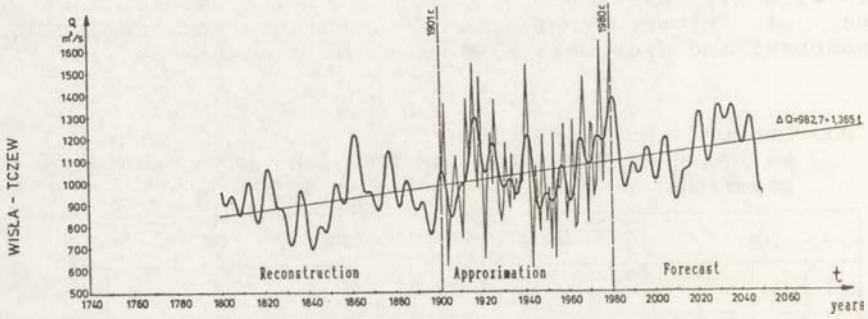
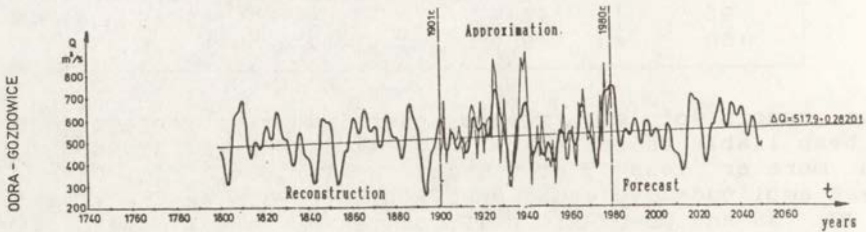
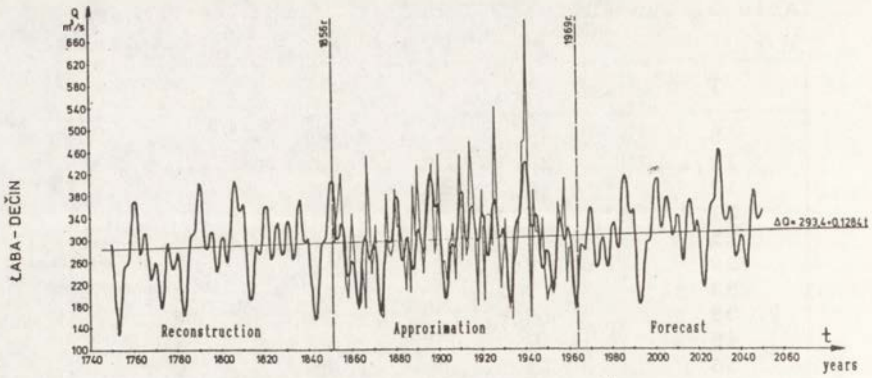
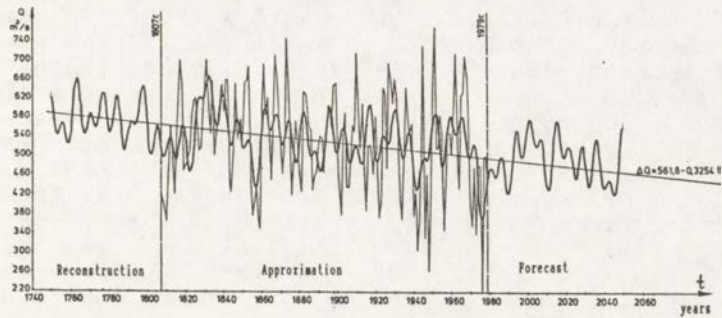
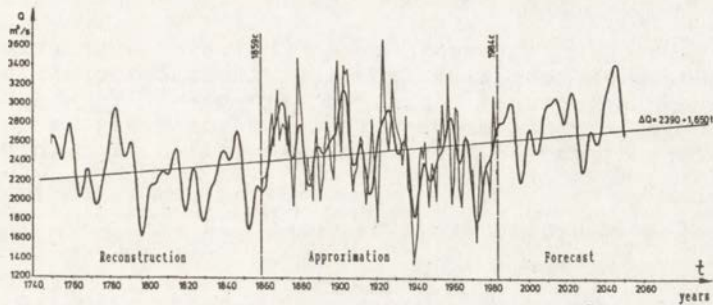


Fig.5a Long-term fluctuations of runoff of selected rivers in Norden-Eastern Europe

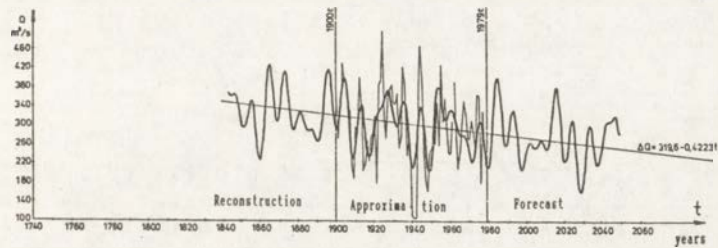
GÖTA - ÄLV - Vänersborg



NEVA - LENINGRAD



KYMIJOKI - PERNOO



KEMIJOKI - TAIVALKOSKI

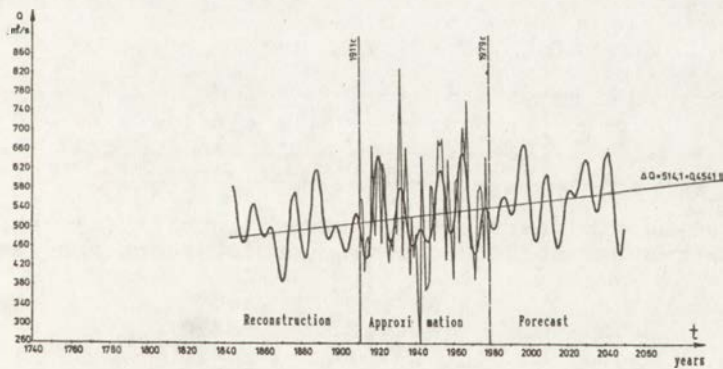


Fig.5b Long-term fluctuations of runoff of selected rivers in Norden-Eastern Europe

The runoff of 8 large rivers feature short 5-8 year and 10-15 year periods, approaching a little the 11-year sun activity cycle. A somewhat longer cycle, 17 to 22 years, is noticeable in the runoff of 6 rivers, i.e.: the Łaba, Oder, Vistula, Niemen, Neva, Göta. The tripple Brückner cycle of 27-22 years occurs in the case of 7 rivers, with the exception of Oder. The longest cycles disclosed so far are: Neva - 132 years, Łaba - 101 years, Göta Alv - 87 years, Niemen - 67 years. Two from among the found long cycles: Łaba - 101 years, Göta - 37 years, and those quoted in the Stachy (1970) publication, i.e: Veltava - 86 years, Niemen - 82 years, Łaba - 85 years, Dniepr - 88 years, are more or less in line with the 94-year centurylong sun activity cycle.

Of a particular interest seem the time-appropriated river flow tendencies resulting from the linear component  $a_0$  + at imposing upon the natural - periodical cycles, in which one can easily trace the anthropogenic influence (Fig. 5). Equations covering trends quoted have been exemplified for three rivers: the Vistula, Göta and Niemen.

Vistula (R = 0,54 F = 2,58)

$$Q + \frac{982,7 + 1,365 t +}{+ 74,60 \sin (2\pi t/5 + 0,833) + 72,77 \sin (2\pi t/13 + 0,689) + 57,28 \sin (2\pi t/17 + 0,508) + 35,11 \sin (2\pi t/27 - 1,156) + 20,46 \sin (2\pi t/67 + 2,619)}$$

Göta (R = 0,49 F = 3,33)

$$Q = \frac{561,8 - 0,3254 t +}{+ 34,80 \sin (2\pi t/7 + 2,680) + 23,96 \sin (2\pi t/11 + 1,033) + 26,56 \sin (2\pi t/17 - 1,279) + 25,08 \sin (2\pi t/32 + 2,369) + 26,59 \sin (2\pi t/43 - 2,331) + 12,36 \sin (2\pi t/59 - 1,551) + 11,86 \sin (2\pi t/87 - 1,306)}$$

Niemen (R = 0,41 F = 2,91)

$$Q = \frac{537,3 + 0,0826 t +}{+ 27,78 \sin (2\pi t/8 - 0,040) + 25,13 \sin (2\pi t/13 - 0,140) + 54,31 \sin (2\pi t/17 + 0,508) + 35,11 \sin (2\pi t/27 - 1,156) + 20,46 \sin (2\pi t/67 + 2,619)}$$

Anthropogenic increments in river runoff (a) expressed as cubic metres per sec. calculated per 100 years are, as follows:

Łaba	12,8	Neva	165,0
Oder	28,2	Göta	-32,0
Vistula	13,6	Kymijoki	-42,2
Niemen	8,3	Kemijoki	45,4

The runoffs of 6 rivers exhibit a rising tendency ( $a > 0$ ), those of the two Scandinavian ones - a diminishing tendency ( $a < 0$ ). The Scandinavian rivers of Kymi and Göta with their negative flow tendency are characterized by a high retention level which



results from the number of lakes within their basin area, exceeding 15% (Vattenforing 1979, Discharge ... 1987).

The relative 100-years anthropogenic influence increments  $\Delta Q/\bar{Q}$  and  $Q/\Delta Q^*$ , when compared with the mean discharge  $\bar{Q}$  and with the scope of natural changes  $\Delta Q^* = \sum_{i=1}^k Q_j$  expressed in percent are, as follows:

	$\frac{\Delta Q}{\bar{Q}}$	$\frac{\Delta Q}{\Delta Q^*}$		$\frac{\Delta Q}{\bar{Q}}$	$\frac{\Delta Q}{\Delta Q^*}$
Laba	4,3	6,6	Neva	6,6	17,2
Oder	5,3	9,8	Göta	-6,1	-19,8
Vistula	1,3	3,8	Kymijoki	-14,1	-32,4
Niemen	1,5	5,1	Kemijoki	8,5	33,2

The highest anthropogenic influence increments are found to be those of Kymi and Kemi. They constitute 14,1% and 8,5% of the average runoff these rivers have on their record, the percentage of which constitutes 1/3 of their natural (periodical) variation.

The constantly increasing tendency of the Vistula runoff may be the consequence of the volume of mine pumping waters inflow into this river, or of some other anthropogenic influences.

#### SURFACE STORAGE

Surface storage of lakes has been characterized by reference made to the sequence of the Masurian Mamry Lake water levels. The storage of waters in that lake is liable to undergo periodical fluctuations and resembles cycles observed in the precipitation, air temperatures, as well as runoff of the Polish and other North-East European rivers (Table 5, Fig. 6). Cycles mentioned (13, 18, 28 years) resemble cycles of the single and double sun activities. The 26, 34, 47 years show cycles of

Table 5. The Mamry Lake surface storage T cycles (1846-1986), their amplitudes b and phase shifts c

T	b	c	F
8	4,77	1,47	2,6
13	4,78	-2,24	2,7
18	4,59	-0,48	2,4
26	8,56	0,92	9,3
34	6,18	0,98	4,7
47	8,11	0,42	8,3
75	3,12	0,63	1,2

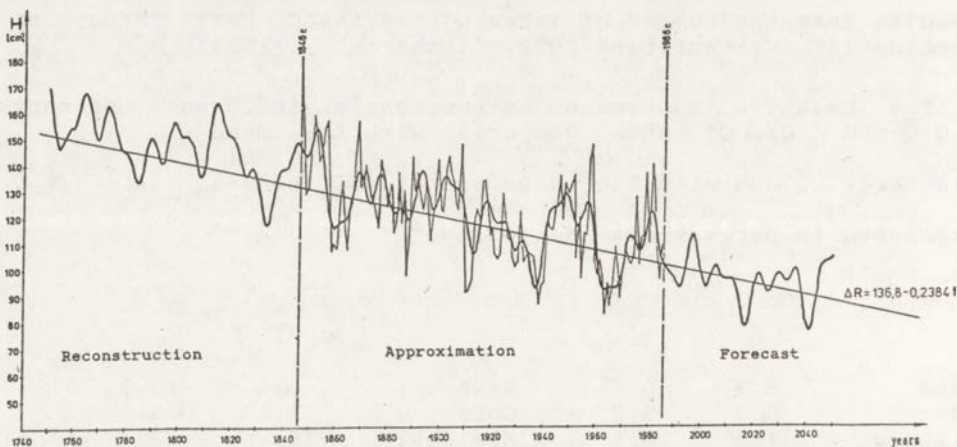


Fig.6 Long-term fluctuation of surface storage in Mamry Lake

highest amplitude. They prove essential on the 99% confidence level (acc. to Fisher-Snedecore test). Moreover, there is also a 34-year and a longer 73-year Brückner's cycle approaching in its appearance the Wrocław precipitation cycle.

The time trend function of the surface storage levels is expressed by the following equation:

$$R + 136,8 - 0,2384 t + 4,501 \sin (2\pi t/8 + 1,522) + 5,615 \sin (2\pi t/11 - 2,454) + 2,633 \sin (2\pi t/18 - 0,800) + 7,980 \sin (2\pi t/26 + 1,128) + 4,987 \sin (2\pi t/34 + 1,279) + 5,221 \sin (2\pi t/47 + 0,437) + 2,457 \sin (2\pi t/75 - 2,594)$$

featuring the highest (from among chronological series under investigation) multiple correlation factor (0,78) and an  $F = 13,06$  Fisher-Snedecore characteristic. In this chronological series, the most clearly "recorded" natural and anthropogenic changes are the storage changes.

Recession of lake water level due to the anthropogenic factors comes as a  $= -24$  cm per 100 years. This represents  $H/H$  nearly almost 20% of an average water level of lake ( $H = 120$  cm for this lake in the 1846-1986 time interval). This lake may dry out completely after 500 years (recording from 1846 on), if the linear component  $H = a \cdot t$  fails to approximate the sine curve segment of an unknown longer interval cycle.

The progressive lowering of the Great Masurian Lakes water level has long been attracting Mikulski's attention (1966). In Mikulski's opinion, the adverse storage trend of the lakes is an outcome of natural changes in water circulation and a man-controlled water level activity.

## CONCLUSIONS

To sum up, one could conclude that such hydroclimate variables, as atmospheric precipitation, air temperature, river runoff, and surface storage are liable to periodical high-amplitude (statistically essential) changes. Both the single 10-13 year, double and triple Brückner cycles having been disclosed, as well as some longer ones, are found to be synchronous with the sun activity cycles. Sun activity is of particular importance as regards basic natural changes of the water balance elements.

The long, secular cycles are most easily distinguishable in the air temperature and certain river runoff processes.

The annual precipitation, as well as the yearly mean air temperature undergo a process of cyclic changes, the anthropogenic components of their trends being nevertheless quite negligible, i.e. statistically unimportant. This, in all probability, results from an adverse effect the anthropogenic factors tend to exert in winter (CO<sub>2</sub> domination) and in summer (domination of radiation being absorbed by dust).

The century-long anthropogenic river runoff increments are significant for they can represent from several to more than a dozen per cent of their average century-long levels.

River runoff and surface storage is what remains most severely influenced by anthropogenic factors. Runoffs from a high inertia basin, like storage itself, show a diminishing trend most probably due to land reclamation or hydro-engineering development projects etc.

The problem as such calls for some further more meticulous investigations on the basis of not only annual but also monthly empirical sequences.

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## LITTER MASS-LOSS RATES IN A CLIMATIC TRANSECT IN NORTH-WESTERN EUROPE - EFFECTS OF CLIMATE AND SUBSTRATE QUALITY

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### SUMMARY

The present paper presents a study in progress on litter decomposition along a climatic transect. The analysis presented here is based on data from three out of the 16 sites that are under study along a transect ranging from northern Finland to mid-Holland. The analysis focuses on Scots pine and lodgepole pine needle litters, but an attempt is made to extend the findings to several deciduous leaf litters.

Two main approaches are made, namely;  
- the influence of estimated soil temperature and moisture on litter decomposition rate.  
- the changing influence of substrate quality with respect to different climates. This section also contains an analysis of different indices of substrate quality.

Site-specific soil climate was estimated using a mathematical model, SOIL, driven by standard meteorological data. Expected decomposition rates of unified litter were calculated using simulated soil temperature and moisture and using response functions with estimated coefficients from one site. Data of actual decomposition from the three sites gave similar correlations with the climatic response functions but a higher sensitivity for changing climatic conditions was obtained for the southern site.

The concentrations of lignin increased in litter as decomposition proceeded and had a rate-retarding influence, which was investigated at five sites, including the three sites along the climatic transect. In all cases the rate-retarding effect of

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lignin influence was statistically significant. The influence of lignin on mass-loss rate varied among the sites with the strongest influence at the warmest and wettest site. Lignin and a holocellulose-lignocellulose quotient as indices for predicting mass-loss rates were compared for several litter types.

## INTRODUCTION

When plant litter is shed each litter type has a different chemical composition as regards both nutrients and organic-chemical compounds. During the process of decomposition the chemical composition of a given litter changes. The more easily degradable compounds are decomposed first and the more resistant compounds thus become more concentrated (Berg et al., 1982). In addition, as a result of the synthesis of recalcitrant compounds many litters show an increase in absolute content of polymerized lignin-like compounds during decomposition. Studies using high-resolution  $^{13}\text{C}$ -NMR using litter of different decomposition stages have indicated that no really new compounds are being synthesized during decomposition. Several studies have reported that the increasing levels of lignin and related compounds in decomposing litter have a retarding effect on litter decomposition rate (McClaugherty and Berg, 1987; Berg et al. 1987). Based on the progressive increase in recalcitrance it has been possible to estimate a final rate for litter/humus decomposition at a given site and under given climatic conditions (Berg and Ågren, 1984).

Soil climate, including soil moisture and soil temperature, has a strong influence on litter decomposition rates and in early stages of decomposition the influence may be estimated (Jansson and Berg, 1985). The interaction between rate-regulating factors, such as the litters' chemical components (contents of nutrients and lignin) and soil temperature and moisture have been investigated only to a limited extent. Very few investigations seem to exist as regards the late stages of litter decomposition in relation to soil moisture and temperature.

Flanagan and Veum (1974) made a study on respiration rates from some different litter types of different ages under a variety of temperature and moisture regimes. Their study indicated that the effect of temperature and moisture on respiration rate was less pronounced in the older, more recalcitrant litter than in fresh litter. Meentemeyer (1978) compared the effect of a climatic factor "actual evapotranspiration" (AET) and the litter's lignin concentration on decomposition rate and Dyer et al. (199X) described some relations for mass-loss rate as compared to AET and concentrations of nitrogen and lignin. These investigations did not discriminate between early and late stages, however. Even if some studies in this area exist, the possible interaction between the rate-regulating factors of soil temperature and moisture and the litter's concentration of lignin in late stages of decomposition appear to have been very



little studied, and probably not at all in field studies.

Litter decomposition was studied in the climatic range constituted by a transect from Northern Finland to mid Holland (Olofsson, 1988; Berg et al., 1986). The soil climate was estimated and litter decomposition rate was both measured and estimated, and at three sites in northern, central and south Sweden the rate-retarding effect of lignin on mass-loss rate was more intensively studied. These three sites have been selected for a more thorough presentation in this paper. At these sites and at two sites outside the climatic transect the effect of the changing substrate quality on mass-loss rate in late stages has been studied. With late stages we here mean decomposition stages above 20 percent accumulated mass loss. We have given the late stages more attention since it appears that the litters often come into the late stages quite early and that these stages thus encompass the main part of the litter/humus decomposition. The aim behind this study was to combine the effect of climate and the effect of substrate quality on litter mass-loss rate.

#### SITE DESCRIPTIONS

Four of the sites (Nos 2, 6:51, 8, and M) had Scots pine monocultures. Three of them, namely Harads, Jädraas and Nennesmo (sites Nos 2, 6:51 and 8) were located on nutrient-poor, sandy sediment soil. The understory varied between the Harads site (No 2) in the north and the Nennesmo site (No 8) in the southern part of Sweden. The understory in site No 2 was mainly cowberry (*Vaccinium vitisidaea* L.) and lichens. The Jädraas site (No 6:51) in central Sweden had, in addition bilberry (*Vaccinium myrtillus* L.), heather (*Calluna vulgaris* Hull) and mosses. Site No 8 had an understory similar to that of No 6:51 except that lichens were absent. All these sites had typical mor soils. For reference to more complete site descriptions see Table 1.

The numbers of the sites are those published in a report (Berg et al., 1986) with the exception of the sites called "M" and "B.I." (below).

Site M, situated in west-central Sweden, includes three similar subsites, situated close to each other. These sites which had monocultures of Scots pine and lodgepole pine were more nutrient rich than those above and had an understory of mosses and bilberry. The three subsites of site M correspond to sites numbered 17, 18, and 19 in a description by Berg et al. (1986). For a further site description see Berg and Lundmark (1987).

Site B.I. located on Blackhawk Island in south central Wisconsin, USA was different from the above sites since it was a mixed deciduous forest with a mull soil. The dominant vegetation was sugar maple (*Acer saccharum*) and with very little understory.

Table 1. Overview of site locations and climatic data for three sites in the climatic transect and two additional sites

Site name	Ref. no.	Long/Lat	Alt. (m)	Annual mean		Site descr. by
				prec. (mm)	temp. (°C)	
Haradas	2	66°08'N 20°53'E	58	650	+1.3	[1]
Jädraas	6:51	60°49'N 16°30'E	185	609	+3.8	[1, 2]
Nennesmo	8	58°16'N 13°35'E	155	930	+6.2	[1, 3]
Malung	M:17	60°33'N 13°44'E	375	450	-	[4]
	M:18	60°38'N 13°37'E	400	450	-	[4]
	M:19	60°35'N 13°34'E	435	450	-	[4]
Blackhawk Island	B.I.	43°38'N 89°47'E	280	799	+7.6	[5]

[1] Berg et al. (1986); [2] Axelsson and Brakenhielm (1980); [3] Holmen et a. (1976); [4] Berg and Lundmark (1987); [5] McClaugherty and Berg (1987).

The site was relatively nutrient rich. A further site description is given by Pastor et al. (1982).

The size and the shape of the plots varied. Site dimensions were, No 2 10mx30m; No 6:51 100mx300m; No 8 40mx40m; B.I. 20mx50m and each of the plots of site M 30m x 30m.

## MATERIALS AND METHODS

### Needle collection, storage and sample preparation

#### Sites Nos 2, 6:51, and 8

Brown needle litter was taken at abscission from the branches of Scots pines, which were approximately 15 years old, by gently shaking the branches. This "unified" litter was collected at the research site of the Swedish Coniferous Forest Project (Jädraas, site 6:51; Table 1) in late September. All trees sampled were located in an area less than 50 m x 50 m. Green Scots pine needles were collected in the same area and taken at wintertime

as 2 and 3 year-old needles. Experimental Scots pine needle litter was collected at abscission from trees in a fertilization optimization site. The collection and decomposition of these litters has been described earlier by Berg et al. (1987).

The leaf litter of white birch and of grey alder was sampled at the same plot as the unified litter above and described by Berg and Wessen (1984) and by Berg and Ekbohm (199X).

#### Site M

The sampling of litter at site M (lodgepole pine and Scots pine) was made as above (see also Berg and Lundmark 1987).

The sampled litter was air-dried and stored dry at room temperature until sample preparation took place. Before weighing, the needles were dried further at room temperature to a constant moisture level, approximately 5-8 percent. The largest difference in moisture within a set of samples was less than +/-0.5 percent-units from the average as determined by 20 samples. The unified Scots pine needle litter used in this study has been described earlier from the point of view of chemical composition and decomposition dynamics (Berg et al., 1982). Since this litter was collected from one site it was relatively uniform between years (Appendix 1). The main rate regulating chemical components in early decomposition stages (nitrogen, phosphorus, and water solubles) had a certain variation among the years which probably influenced decomposition rates somewhat in early stages, a possibility that may be overlooked in the present analysis.

The litter bags, measuring 8 cm x 8 cm, were made of terylene net with a mesh size of 1 mm. Each litter bag enclosed about 0.8 g of needle litter (weighed with 3 decimals) and a piece of plastic tape giving the mass of the needles. The bags were fastened to the ground by 10-15 cm long metal pegs made of stainless steel.

#### Site B.I.

The procedure used at the Blackhawk Island site has been described by McClaugherty and Berg (1987). Litter was collected at Blackhawk Island during the period of leaf fall from a number of 1m x 30m fiberglass screens placed on the forest floor. Litter was dried at room temperature to a constant mass. Air dried samples weighing 4.0 g were placed into polyester litter bags, which had a mesh opening of 0.1 mm. The bags were held in place on the ground by a nylon cord.



## Experimental design, incubation and mass loss determination

At all Sweden sites litter samples were incubated in a randomized block design at 25 spots within each plot. Each incubation spot measured about 1 m x 1 m. At all sites the samples were placed on the Aoo layer and incubation time was up to five years with samplings normally 2-3 times a year. Wisconsin samples were randomly located along one of 50 transects within the plot. Samples were collected on 13 different dates over a five-year period.

When collected (one sample from each spot) the samples were transported directly to the laboratory and cleaned of mosses, lichens and other remnants of ingrown plants. After the removal of plant remains, the loss of dry mass of the needles was determined by drying the samples to a constant mass at 85°C (Wisconsin samples at 50°C). Mean values of mass loss were calculated for each sampling (n=20 or 25; n=4 to 10 in the Wisconsin samplings) and used in regression analysis. After this the samples were combined for chemical analysis.

Because of their high ash contents, all Wisconsin data for mass loss and chemical composition are expressed on the basis of ash-free dry mass.

## Chemical analyses

Samples of the sites No 2,6:51,8, and M. The combined samples were ground in a laboratory mill equipped with a screen allowing particles of less than 1 mm to pass. The amounts of water soluble and ethanol soluble substances were determined by sonicating the milled sample three times in a sonicator bath and weighing the samples after filtration and drying. The analyses for Klason lignin in the needle litter samples were carried out according to Bethge et al., (1971) (see also Berg et al., 1982). Nitrogen was determined by a semi-micro-Kjeldahl method using a flow-injection analysis apparatus (Bifok FIA 05, Tecator, Höganäs, Sweden) with gas diffusion and using phenol red as an indicator (Svensson and Anfält, 1982). For analysis of phosphorus, sulfur, magnesium, calcium, potassium, and manganese samples were digested for 2 days in a 2.5:1 (v/v) mixture of nitric and perchloric acid. The analyses were performed by plasma atomic emission spectrometry ICP-AES (Instrumentation Laboratory IL P-200, Andover, Massachusetts, USA).

## Samples of site B.I.

Analytical methods of the Wisconsin samples were similar to those above and have been previously described (McClagherty et al., 1985). Reanalysis of a range of Wisconsin samples using Swedish methods yielded essentially identical results

(McClaugherty and Berg, 1987). Ash determination was made by incineration at 450°C for 8 h.

### Soil climatic measurements

Soil climatic measurements were made at sites Nos 2,6;51, and 8 during short periods to obtain the necessary information for using a simulation model described below.

### The soil water and heat model

To estimate daily means of soil temperature, water tension and water content in the uppermost soil layer and evapo-transpiration at the different sites, we used a numerical model based on physical equations for water and heat flows. This model, SOIL, has been described in detail by Jansson and Halldin (1980) and simulations using the model in a context similar to the present one were reported by Jansson and Berg (1985).

### Site characteristics used in the SOIL model

At each site some site characteristics were collected. These were:

- canopy cover by the Cajanus-tube method (Lindroth and Pertu, 1981).
- soil texture at the levels 0-10 and 10-30 cm depth in the mineral soil.
- organic matter thickness.

In addition the used sites had some basic characteristics in common, such as flat ground, sediment soil and low understory. These site specific data are given by Berg et al. (1986;1989)

### Parameterization of the SOIL model

The driving variables used by the SOIL model were standard meteorological data obtained from national meteorological institutes. The driving variables required by the SOIL model are: air temperature (°C), vapour pressure (Pa), wind speed ( $\text{m s}^{-1}$ ), precipitation ( $\text{mm day}^{-1}$ ), global radiation ( $\text{J m}^{-2} \text{day}^{-1}$ ) and cloudiness (fraction).

Starting conditions for each run of the SOIL model were selected to be a uniform water tension soil profile with the value of 50 cm water and likewise a uniform temperature profile with a value which roughly corresponds to the annual mean soil temperature of each site. Initially no ground water was assumed to exist in the profile and deep percolation was calculated from the unsaturated conductivity of the lower boundary and a unit gradient of water potential caused by the gravitational forces. Each run, specific for each site was started in the spring or in

the autumn prior to the start of litter decomposition measurements. This was done to minimize errors because of uncertainties in initial conditions.

#### Calculation of actual evapotranspiration

Actual evapotranspiration was calculated as the sum of transpiration and evaporation of intercepted water. Both transpiration and evaporation calculations originate from potential rates given by the Penman-Monterth equation assuming a certain roughness of the forest and different values of surface resistances for transpiration and evaporation. The reduction of potential transpiration to actual transpiration depends on soil temperature, availability of soil water, and evaporation of intercepted water. Evaporation of intercepted water takes place with the potential rate until the whole interception storage is depleted. Detailed descriptions of the mathematical formulation are given by Jansson and Halldin (1980).

#### The litter decomposition model

Coupling of simulated soil variables and litter decomposition values have been made by using the climatic response functions developed by Jansson and Berg (1985).

The effect of temperature on litter decomposition rate was tested with the commonly used  $Q_{10}$  equation:

$$D_t = Q_{10}^{((T - T_n)/10)} \quad /1/$$

where  $D_t$  is a multiplicative factor for decomposition,  $Q_{10}$  is the steepness in the temperature function,  $T$  is the soil temperature and  $T_n$  is the temperature for which  $D_t$  equals one.

The effect of soil moisture on litter decomposition was expressed either as soil water content,  $D_\theta$  (eq. 2) or as soil water tension  $D_\psi$  (eq 3);

$$D_\theta = 1^{(\theta/\theta_0)^a} \quad \theta \leq \theta_0 \quad /2/$$

$$\theta > \theta_0$$

$$D_\psi = 1^{(\psi_0/\psi)^b} \quad \psi \geq \psi_0 \quad /3/$$

$$\psi < \psi_0$$

where  $\theta$  is the volumetric water content, and  $\theta_0$  is the threshold water content,  $\psi$  is the soil water tension expressed in cm water,  $\psi_0$  is the threshold value of soil water tension for optimum decomposition rate and  $a$  and  $b$  (Table 2) are empirical constants. In the present case the values for  $T$ ,  $\theta$ , and  $\psi$  are calculated for a organic layer of 4 cm thickness.



Table 2. Parameters and coefficients used in the functions of the SOIL model in the runs presented

Parameter/coefficient	numerical value
$Q_{10}$	2.0
$T_{nor}$	19°C
Soil water content ( $\theta_0$ )	28 volume percent
a	1
b	1
Soil water tension ( $\psi_0$ )	250 cm water

#### Adaptation of the litter decomposition model (DECOMP)

The above functions require driving variables from the SOIL model *i.e.* daily means of soil temperature, soil water content, and soil water tension in the upper layer of the soil organic material (0-4 cm). Linear correlations between the above response functions and litter mass-loss rates were made. In addition, linear correlations were made between simulated actual evapotranspiration and litter mass loss rates.

#### CONDITIONS FOR SELECTING DECOMPOSITION DATA

##### Data for the litter decomposition model

Climate data from sites No 2,6:51, and 8 were used for the model calculations and only decomposition data from unified litter.

For the present analysis only decomposition values up to 45 percent accumulated mass loss were used to calculate the daily average mass loss. At greater mass losses decomposition rates become increasingly dependent on lignin concentration as compared to climate, and a substrate quality effect may be noticeable. It must be emphasized, though, that this limit was taken arbitrarily.

##### Data for substrate quality analysis in late decomposition stages

We used only decomposition data from litter that was in a late decomposition phase, namely in a stage where the concentration of lignin ruled the litter mass-loss rate (Berg and Staaf, 1980; Berg et al., 1987). For all litters we thus

used only decomposition values for litter that had lost at least 20 percent (accumulated mass loss) of its initial mass.

#### Initial chemical composition of the litters used

The unified Scots pine needle litter had a certain variation in chemical composition among years (Appendix 1). Thus nitrogen concentrations ranged from 3.4 to 10.4 mg g<sup>-1</sup>. This latter value appears to be exceptional when comparing to the relatively stable level in the other years. The levels of phosphorus also varied between years, from 0.18 to 0.30 mg g<sup>-1</sup>. These two chemical components have been found to be rate regulating in early decomposition stages. However, an extreme nitrogen concentration like that mentioned above (10.4 mg g<sup>-1</sup>) had no effect on decomposition rate in that specific sampling of litter - phosphorus being the rate regulating factor (cf Berg et al., 1987). Concentrations of water soluble substances varied between 92 and 213 and lignin between 223 and 286 mg g<sup>-1</sup>.

At site M the local Scots pine needle litter had nitrogen and phosphorus concentrations similar to those of the unified litter, whereas lignin concentrations were clearly higher and in the range from 265 to 300 mg g<sup>-1</sup> (Appendix 2). At the same site the lodgepole pine needle litter had similar nitrogen levels, whereas the phosphorus levels were significantly higher and concentrations of water solubles significantly lower than for the needle litter of Scots pine (Berg and Lundmark, 1987). The lignin concentrations which ranged from 357 to 391 mg g<sup>-1</sup> were significantly higher than for Scots pine needles.

The experimental litters incubated at site 6:51 had a considerable variation in chemical composition among them. The Scots pine needle litter from fertilized plots (Berg et al., 1987) thus ranged from 4.4 to 8.1 mg g<sup>-1</sup> in nitrogen concentration, and in phosphorus concentrations from 0.30 to 0.42 mg g<sup>-1</sup>. There was no difference in water solubles or lignin concentrations. The deciduous leaves used were relatively different and nitrogen concentrations ranged from 30.7 mg g<sup>-1</sup> in grey alder leaves to 7.6 mg g<sup>-1</sup> in white birch leaves. Phosphorus concentration was highest in one sampling of white birch leaves with 2.40 mg g<sup>-1</sup>, and lowest in cowberry leaves with 0.73 mg g<sup>-1</sup>. Also water solubles varied strongly - from 321 mg g<sup>-1</sup> in birch leaves to 207 mg g<sup>-1</sup> in cowberry leaves. Lignin concentrations, on the other hand varied relatively little, from 330 mg g<sup>-1</sup> in white birch leaves to 264 mg g<sup>-1</sup> in grey alder leaves.

The litters incubated at the Blackhawk Island site also varied in initial chemical composition. Thus had white oak leaves 8.4 mg g<sup>-1</sup> of nitrogen and red maple wood 0.9 mg g<sup>-1</sup>. Phosphorus concentrations ranged from 0.20 mg g<sup>-1</sup> in red maple wood to 1.50 mg g<sup>-1</sup> in white oak leaves. The variation in lignin concentration ranged from 121 mg g<sup>-1</sup> in sugar maple leaves to 248 in red oak leaves.

The ash contents varied considerably among litter types. In the unified Scots pine needle litter the concentrations were low varying from 12 to 26 mg g<sup>-1</sup>. Initial ash content of six foliage litters collected at the B.I. site, ranged from 113 mg g<sup>-1</sup> of dry mass for sugar maple leaves to 38 mg g<sup>-1</sup> for white pine needles. Red maple wood contained only 3 mg g<sup>-1</sup> of ash.

## RESULTS AND DISCUSSION

### Overview to the study

In the present analysis we used site-specific climatic data to simulate soil climate at each of three sites. We then examined the relationship between soil climate and decomposition rate within a single site and across the three climatically different sites (Nos 2,6:51, and 8) and its effect on litter decomposition rates. The effect of a changing substrate quality has, in addition, been investigated at sites M and B.I. We also examined the effects of litter chemical composition on the rate of decay at the three sites and some additional sites. This examination provides a basis for evaluating the interaction between climate and substrate composition as regulators of decomposition rates. Within each component of the study (climatic effects, substrate quality effects, and interactive effects) we proceeded by first verifying the significance of simple effects (e.g. the effect of climate on decomposition rate of a single litter type). Second, we compared the rate-regulating effects of climate on litter quality for several sites or several litters. Third, we attempted to discern the relative importance of climate and litter quality as rate regulating factors and their potential interaction across a range of sites and litters. In addition, to support our study of the role of litter quality in regulating the rate of decomposition, we compared the utility of two indices of litter quality as predictors of decay rate.

### Climatic regulation of decomposition rates

Of the three climatically different sites, one (site No 6:51) was previously investigated by Jansson and Berg (1985). The effects of climate on decomposition rate at this site can now be compared to the climatic effects at edaphically and floristically similar sites located in climatically different regions.

The comparison was made by linear regression and by plotting the values for measured litter decomposition versus the simulated values of soil temperature, soil water content and soil water potential for the same period. The relationships between mass-loss rates were examined both separately and combined using simulated climatic variables (Table 3).



Table 3. Coefficients of determination ( $r^2$ ) for the linear relationship between observed and predicted decomposition rates of Scots pine litter. Decomposition rates were predicted by a decomposition model (DECOMP) and were based on input of estimated soil climatic data from the SOIL model which used several soil climatic variables. All the relations were highly significant.

Site No	T	$\theta$	$\psi$	T* $\theta$	T* $\psi$	AET	n
2	0.45	0.42	0.40	0.51	0.50	0.44	37
6:51	0.46	0.24	0.29	0.50	0.50	0.50	57
8	0.48	0.38	0.46	0.60	0.55	0.56	23
sites combined	0.41	0.48	0.47	0.45	0.50	0.49	117

T - calculated soil temperature in the uppermost 4 cm of organic soil ( $^{\circ}$ C)

$\theta$  - calculated soil water content in the uppermost 4 cm of organic soil (volume percent)

$\psi$  - calculated soil water tension in the uppermost 4 cm of organic soil (cm water)

T\* $\theta$  - combined functions for T and  $\theta$  (-)

T\* $\psi$  - combined functions for T and  $\psi$  (-)

AET - actual evapotranspiration (mm day $^{-1}$ )

When single climatic factors were investigated, soil temperature was more important than soil moisture as a limiting factor for litter decomposition rates. This observation was general for each individual site and for all sites combined. However, the combined factors of soil temperature and moisture always improved the value of the coefficient of determination ( $r^2$ ). Only small differences were found among the relationships depending on whether soil moisture was expressed as water content ( $\theta$ ; eq 2) or water potential ( $\psi$ ; eq 3). It was also worth noticing that AET (which also integrates temperature and moisture - here on a daily basis) gave similar values for the coefficient of determination to those obtained when using the combined variables.

The same response function coefficients (a and b; Table 2; eqs 1-3) were used for all sites which means that a given value in the response functions corresponds to a given climatic value independent of site.

Previously, Olofsson (1988) made a preliminary and similar comparison of 16 sites and found some tendencies that are found also among the three sites selected for this presentation. Thus it appeared that the nutrient-poor site located in the coldest region (site No 2) had consistently lower decomposition rates for a given value of the response function (Fig.1) than the more

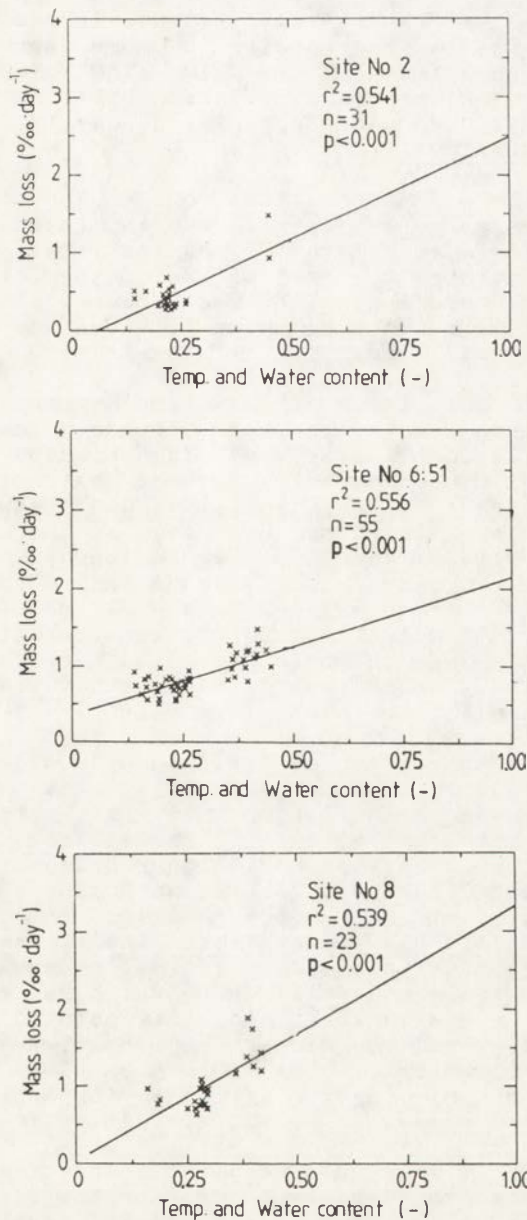


Fig.1 Litter mass-loss rate as dependent on calculated soil temperature and moisture (water tension) at three climatically very different sites.

(A) Site No 2 – the northernmost site. (B) Site No 6:51 in central Sweden. (C) Site No 8 – the southernmost site.

nutrient-rich sites (Nos 6:51 and 8) located in a warmer climate, and for site No 8 also a more wet climate. For example, at given climatic index value ( $T^* \theta$ ) of 0.25, which is in the range of overlap for all three sites predicted decay rates were 0.51, 0.80 and 0.85 o/oo day<sup>-1</sup> for sites Nos 2, 6:51, and 8 respectively.

The sensitivity of decomposition rate to the modelled climate appeared to vary among the sites as indicated by different slopes among the sites of the regression lines. However, the slopes were not related to the position of the site along the overall climatic gradient; the northernmost site (No 2) had a slope with was intermediate to those of sites Nos 6:51 and 8, which were wetter and warmer.

Some observations in other systems support that there are differences in mass-loss rates and responses among sites in climatically different locations. Thus Linkins et al. (1984) observed that cellulose degrading enzymes extracted from soil organic matter had different  $Q_{10}$  values between arctic and temperate ecosystems depending on a more southern or northern location of the site of sampling. In a study on humus respiration Bringmark (pers. comm.) found that when humus samples from climatically different areas in a transect were respired under standardized temperature and moisture conditions, the relative respiration rate increased from southern samples having lower respiration rates towards the north, where the samples showed higher respiration rates.

It is possible that regional difference in climate may result in different responses in decay rate at a certain  $T^* \theta$  value. It has been shown (Jansson and Berg, 1985) that water is limiting the mass-loss rate at site 6:51 and a first condition for a change in response would then be a higher soil water level. It has actually been observed that in natural systems which have both higher nutrient and moisture levels the sensitivity increases (Olofsson, 1988). Three Scots pine systems located very close to each other (within a 100m radius) showed increased decomposition rates along a soil catena which had changes in soil texture, nutrient availability and water holding capacity. The more mesic sites had a higher decomposition at a particular value of  $T^* \theta$  than the drier ones (Olofsson 1987). In another study irrigation only (system irrigated for more than 7 years) increased measured mass-loss rates (evaluation to be published).

The differences in slope among the transect sites are relatively small. When the data from all three sites were considered together, the correlation coefficient obtained was similar to that for each site alone and the slope of the regression equation for the combined data was not significantly different from any of the slopes from individual sites.



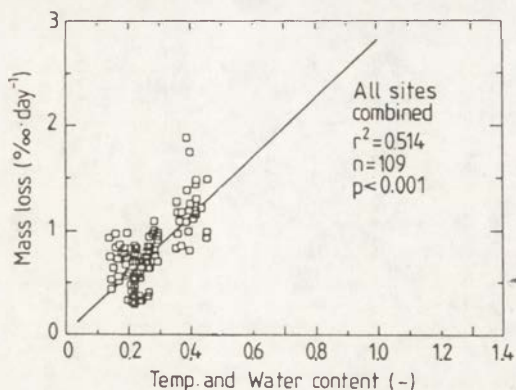


Fig.2 Litter mass-loss rate as dependent on calculated soil temperature and moisture (water tension). The three sites No 2, No 6:51 and No 8 combined into one model.

#### THE REGULATION OF LITTER MASS-LOSS RATE AS DEPENDENT ON SUBSTRATE QUALITY AT SOME CLIMATICALLY DIFFERENT SITES

##### Early stages of decomposition

It has been noted earlier that high concentrations of nitrogen, phosphorus (Berg et al., 1987) and water solubles (Berg and Lundmark, 1987) initially promote a high rate of decomposition. In the present paper no evaluation of these early stages will be made.

##### Late stages of decomposition

In the decomposition process there is an enrichment of lignin (Berg et al., 1987; Berg et al., 199X). Being a recalcitrant compound it is decomposed at a much lower rate than the other organic-chemical components. The result is an increasing concentration of lignin in the litter which can be approximately described as a straight line versus the accumulated mass loss (Fig 3).

Ten sets of decomposing litter were followed at site 6:51. Linear regressions revealed that there was very little difference among slopes for lignin concentrations versus accumulated mass loss. The difference between the different sets of incubated litter was rather in the intercept. The slope for all the combined data points was 2.970 with a standard error of 0.114; n=104 (B.Berg, C.McClaugherty, G.Agren and M.B. Johansson, to be published). It thus appears possible to calculate the concentration of lignin at each decomposition level fairly accurately for a given site, as well as litter type once we know the litter's initial concentration of lignin.

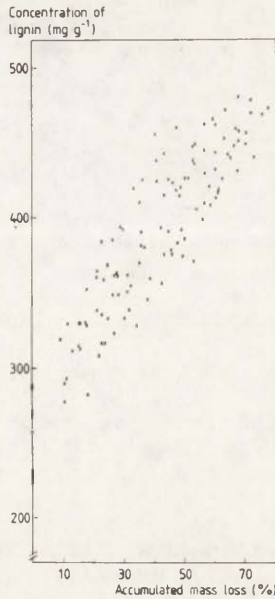


Fig.3 Increase in lignin concentration in Scots pine needle litter as compared to accumulated mass loss. The incubation took place at site 6:51.

We compared the effect of lignin concentration on litter mass-loss rates for three climatically different sites and could see that for the three sites investigated in two cases the slopes and in all cases the intercepts were clearly different (Fig 4).

We were careful to use similar intervals of lignin concentrations in the linear regressions among the sites (site 2; 343 - 475, site 6:51; 315 - 442, and site 8; 302-460 mg g<sup>-1</sup>). A linear regression was, in addition, run with the purpose to compare the slopes at sites Nos 6:51 and 8 using an interval for lignin concentration that was exactly the same. No change in slope was seen even if the correlation coefficient obtained a somewhat lower value. The steepest slope (about -0.211; Fig 4) was that of the litter at site No 8 which was a site with a high precipitation and a relatively high annual mean temperature and consequently a high decomposition rate. The slope at site No 8 was significantly different from those of the other two sites.

Sites Nos 2 and 6:51 had similar slopes. Although site No 2 is located more to the north, it has a somewhat higher mean annual precipitation than has site No 6:51 (Table 1). The main difference between sites, was in intercept, the difference reflecting higher overall mass-loss rate. These data indicate that lignin concentration had a stronger effect on decomposition

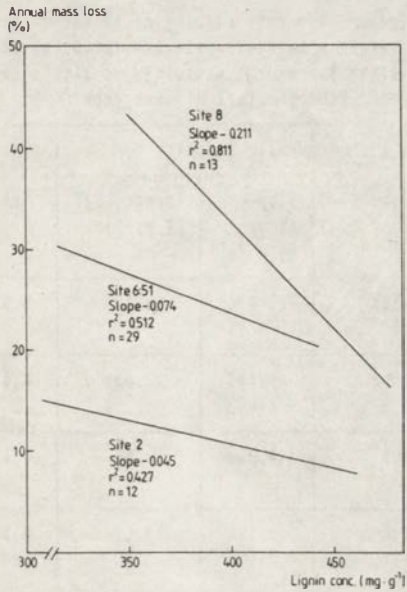


Fig.4 Linear relations for annual mass loss as dependent on lignin concentration at the start of each one-year period at three climatically different sites.

rate under warmer and more moist conditions. The observation that lignin regulation was stronger under conditions promoting a higher decomposition rate is strengthened by a similar observation from litter decomposing in an irrigation and fertilization experiment (B.Berg, unpubl.).

#### REGULATION OF LITTER MASS-LOSS RATE AS DEPENDENT ON SUBSTRATE QUALITY AT A SINGLE SITE.

To investigate for possible variation within litter incubations of the same species at the same site (No 6:51), two different sets of data of incubated Scots pine needle litter were compared (Table 4).

The two sets had initially different nutrient composition and similar initial organic-chemical composition. The unified litter gave a slope of  $-0.074$  and a set of experimental litter (Berg et al., 1987; Berg and Ekbohm, 199X) gave a slope of  $-0.085$ , thus indicating that the relation may be similar among litters with similar lignin contents but varying nutrient contents. At the same site deciduous leaves behaved differently and gave a lower slope.

At site M two sets of pine needle litter, namely from Scots pine and lodgepole pine, each of the sets incubated in its own



Table 4. A comparison of the rate regulating effect of lignin in some sets of chemically different pine needle litters incubated at the same site. Linear regressions for annual mass loss vs lignin concentration at the start of each year.

Site name	Litter sp.	Equation		r <sup>2</sup>	n	lit. ref.
		slope (% yr <sup>-1</sup> /mg g <sup>-1</sup> )	interc. ref. (% yr <sup>-1</sup> )			
No 6:51	Scots pine (local)	-0.074	53.59	0.512	29	[1]
No 6:51	Scots pine (exper)	-0.085	58.63	0.633	18	[1]
No 6:51	Deciduous leaves	-0.058	39.50	0.123	12	[1,2]
No 6:51	Deciduous and conf. litter	-0.128	73.92	0.537	19	[2]
M	Scots pine needles	-0.190	103.95	0.801	14	[3]
M	Lodgepole pine needles	-0.189	106.59	0.371	14	[3]

[1] Berg et al. (1991); [2] Berg and Ekbohm (1991); [3] Berg and Lundmark (1987).

forest system, gave very similar slopes (-0.190 and 0.189; Table 4). The slopes had higher values than those of site 6:51, which may be expected since this site (M) had climatic conditions promoting a higher mass-loss rate.

#### SOME COMPARISONS OF THE EXPRESSION FOR SUBSTRATE QUALITY.

In late stages of decomposition, lignin has been suggested as a main rate-regulating factor. In an attempt to have a more precise index, McLaugherty and Berg (1987) suggested the use of the quotient holocellulose/(holocellulose + lignin), and called it HLQ, thus using only the insoluble organic substances of the litter to index rate regulation. The intention also was to develop an index that was based on the different potentials for major classes of organic compounds to provide the energy for the microbial processes, especially the holocelluloses should provide more energy than lignin.

A comparison between these two indices reveals somewhat better regression coefficients when using the HLQ-index (Table 5). At site No 6:51 the use of this index was tested using Scots

pine needle litter both from the site as well as experimental Scots pine needle litter from another one. The two indices were compared for litters of different chemical compositions. Further, several leaf litters and lodgepole pine needle litter were tested.

Table 5. A comparison of two indices for substrate quality. The site given is that where the litter was incubated.

Site No	Litter sp	Coeff. of determin.		n	Lit.ref.
		Lignin	HLQ		
No 6:51	Scots pine (unified)	0.512	0.499	29	[1]
No 6:51	Scots pine (exper.)	0.633	0.648	18	[1,6]
No 6:51	Lodgepole pine (green+brown)	0.520	0.622	6	[2]
No 6:51	Deciduous leaves	0.123	0.141	12	[1,2,4]
No M	Scots pine (local)	0.801	0.830	14	[3]
No M	Lodgepole pine (local)	0.371	0.409	14	[3]
No B.I.	Deciduous and coniferous litter	0.396	0.692	6	[5]

[1] Berg et al. (199X); [2] Berg, and Ekbohm (199X); [3] Berg, and Lundmark (1987); [4] Berg, and Wessen (1984); [5] McClougherty and Berg (1987); [6] Berg, et al. (1987).

At site M the sets of local litter (Scots pine and lodgepole pine needle litter) were incubated at a more nutrient-rich site, also of a mor type. The decomposition indices were compared, and found to follow the same pattern as above. Also the indices of some different coniferous and deciduous litters incubated at a mull site in a mixed deciduous forest (site B.I.) had a similar behaviour with HLQ, providing a better index of decomposition than lignin.

In almost all the cases (six out of seven) there was an improvement of the coefficient of determination when HLQ was used as compared to lignin as an index. The exception was for the unified litter at site No 6:51 where the HLQ index gave a somewhat lower coefficient of determination. In most cases the improvement was relatively small and the maximum improvement was as high as from 0.396 to 0.692 in the  $r^2$ -values.

When the deciduous litters incubated at site 6:51 were investigated as a separate group, none of the relations was even significant (birch, cowberry and alder leaf litter) and to compare the effect of lignin and HLQ was thus less meaningful. The reason to this is not known but may depend for example on very differing ash concentrations in the litters (Bogatyrev et al., 1983). Thus alder litter has a considerably higher ash concentration than birch leaves and both are quite higher in ash than Scots pine and lodgepole pine needle litter.

In a study at the B.I. site, ash contents were analysed and we could thus investigate the effect of ash on the determination of mass-loss rate. The effect of ash correction on mass loss estimates was relatively small (Table 6). Even for sugar maple leaves, which after five years of decomposition had 81 percent accumulated mass loss and contained 266 mg g<sup>-1</sup> of ash, the effect of correcting for ash was only 2.5 percent units of accumulated mass loss.

Table 6. Effect of ash correction on mass loss determinations for three litters incubated at the Blackhawk Island site.  
Amount of ash expressed as mg g<sup>-1</sup> initial dry mass.

Litter type	Concentration of ash (mg g <sup>-1</sup> )		Remaining ash after 5 yrs (mg g <sup>-1</sup> )	Mass remaining after 5 years (mg g <sup>-1</sup> )	
	initial	after 5 yrs		ash corr.	uncorrected
Red maple wood	3	98	16	168	184
White pine needles	38	170	47	279	314
Sugar maple leaves	113	266	49	186	212

In contrast, if lignin concentration is used to estimate mass-loss rate, the effects of correcting for ash can be substantial. Although the difference in concentration of lignin may be only a few percent (Table 7) this difference can be important when comparing the lignin and mass-loss dynamics of litters.

A thorough analysis of ash contents of the lignin fraction was conducted on litter samples after one year of decomposition and revealed that not accounting for ash could result in an overestimate of the lignin content by as much as 40 mg g<sup>-1</sup> in sugar maple leaves. As regards calculation of linear regression for lignin concentration versus accumulated mass loss, the effect of not correcting for ash was to increase the slope of overestimate of the lignin content by as much as 40 mg g<sup>-1</sup> in



Table 7. Effect of ash correction on estimates of concentration of lignin in three litters incubated at Blackhawk Island. Values are for litters incubated for one year.

Litter type	Total ash (mg g <sup>-1</sup> )	Ash in lignin (mg g <sup>-1</sup> )	Lignin conc. after 1 yr. (mg g <sup>-1</sup> )	
			ash corr.	uncorrected
Red maple wood	12	27	221	227
White pine needles	78	61	341	362
Sugar maple leaves	195	113	350	390

Table 8. Effect of ash correction on linear regressions of lignin concentration as dependent on accumulated mass loss, Blackhawk Island site. Standard errors within paranthesis.

Litter type	Intercept	Slope	r <sup>2</sup>	n
Red maple wood	- ash corr. 148.3 (24.9)	3.17 (0.30)	0.909	13
	- not corr. 152.3 (25.1)	3.35 (0.31)	0.912	13
Sugar maple leaves	- ash corr. 130.4 (21.0)	3.77 (0.25)	0.955	13
	- not corr. 144.3 (24.1)	4.40 (0.30)	0.952	13

sugar maple leaves. As regards calculation of linear regression for lignin concentration versus accumulated mass loss, the effect of not correcting for ash was to increase the slope of the relationship. The effect was small in low ash materials but can be significant for high ash materials (Table 8).

It thus appears that even if there is a general relationship between litter mass-loss rate and lignin concentration in litter, the relation which has been seen to vary depending on litter species, may be the result of differences in ash concentrations - at least partly (Table 4).

It is reasonable to conclude that the variation in influence of lignin on mass-loss rate was caused both by litter properties and site factors at each site. The reason for this variation in lignin regulation can only be speculated about. In an earlier paper Berg and Ekbohm (199X) showed that at a given site with identical climatic conditions for all litter types (No 6:51) the faster the decomposition in the earlier stages the slower the decomposition in the later phase. A high initial decomposition

rate may thus promote chemical changes that may make the lignin or the whole complex of cellulose and lignin more resistant. Such an explanation could fit the present experiment. In some cases the fixation of ammonia to organic material (review by Nömmik and Vahtras, 1982) and the chemical reactions that follow have been suggested to give rise to more recalcitrant compounds. A higher initial mineralization rate may thus have supplied an increased amount of nitrogen required to give a higher level of fixation and thus a later incorporation that may cause this effect.

Another possible explanation is the interaction of rate regulating factors. The lack of available water is limiting litter decomposition rate to a high degree (Jansson and Berg, 1985). At more moist sites where access to water is less limited the regulation by lignin can be expressed more strongly.

#### CONCLUDING REMARKS

When considering what would be the most important variables to measure in decomposition studies in forests over a broad geographical range, two principal factors emerge: climate and substrate quality. These two rate-regulating factors interact with the result that both are needed in order to predict patterns and rates of decomposition at a particular site. Although the effects of both climate and substrate quality (in the present case lignin concentration) can be generalized, neither is sufficient when used alone to predict decay across a range of climates or litter types. The interaction between these two rate-regulating factors (climate and lignin concentration) may vary with climate and it is possible that in very late stages of litter decomposition (humus-near stages) the rate regulating effect of lignin dominates over that of climate.

The variable concentration of ash among litter types appears to be a factor worth consideration when comparing decomposition rates among litters, as well as when using lignin concentration as a rate regulator.

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Appendix 1. Initial chemical composition of the unified Scots pine needle litter collected at the same site annually in a 14-year period. n.d. stands for "not determined".

Collection year component and site	Concentration of component (mg g <sup>-1</sup> )										
	water solub.	ethanol solub.	lignin	N	P	S	K	Ca	Mg	Mn	Ash
site No 6:51											
1973	92	120	223	3.8	0.19	0.42	0.73	6.5	0.38	1.55	23
1974	145	84	270	4.2	0.22	0.29	0.71	5.4	0.49	n.d.	24
1975	172	107	238	3.4	0.20	0.32	0.61	4.7	0.39	n.d.	19
1976	151	89	255	4.0	0.21	0.36	0.53	4.9	0.42	n.d.	n.d.
1977	202	102	224	4.1	0.19	0.38	0.87	6.0	0.42	1.02	n.d.
1978	164	96	257	3.8	0.21	0.33	0.62	5.5	0.55	1.00	20
1979	129	95	286	10.4	0.29	0.78	0.97	2.3	0.39	0.31	12
1980	180	102	246	3.8	0.18	n.d.	1.72	6.1	0.53	0.77	17
1981	213	94	231	3.9	0.28	0.61	1.02	7.1	0.58	1.17	23
1982	164	113	231	4.8	0.33	0.55	1.07	4.4	0.49	0.79	19
1983	178	112	229	3.8	0.30	0.45	0.90	5.9	0.39	1.08	26
1984	82	116	288	3.7	0.21	n.d.	0.82	6.3	0.44	0.12	22
1985	182	94	241	n.d.	0.19	0.45	0.52	4.8	0.38	1.24	18
1986	170	89	257	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	20
1987	162	100	250	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
1988	165	94	247	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

Appendix 2. Initial chemical composition of some coniferous and deciduous leaf litters used in the study.  
The site denomination used is for the site of collection. n.d. stands for "not determined".

Litter type and site	Concentration of component (mg g <sup>-1</sup> )										
	water solub.	ethanol solub.	lignin	N	P	S	K	Ca	Mg	Mn	Ash
Site 6:51											
White birch leaves	241	57	330	7.7	1.05	0.80	4.66	11.84	3.30	1.23	n.d.
" " " 1	222	57	322	17.4	1.80	1.32	6.95	5.56	1.99	0.36	n.d.
" " "	321	56	263	7.6	2.40	n.d.	4.30	11.5	2.60	2.60	n.d.
Grey alder "	254	39	264	30.7	1.37	6.12	15.6	12.3	2.3	0.10	n.d.
Cowberry "	207	33	366	8.2	0.73	1.73	2.53	5.2	0.82	1.64	n.d.
Scots pine needles <sup>1</sup>	180	90	220	15.1	1.31	1.13	4.67	2.77	0.82	0.26	n.d.
" " " (exp)	150	100	256	4.4	0.32	0.45	0.91	4.7	0.57	n.d.	n.d.
" " " (exp)	170	90	251	4.4	0.30	0.43	0.98	4.6	0.67	n.d.	n.d.
" " " (exp)	140	90	269	7.0	0.34	0.53	1.06	4.3	0.58	n.d.	n.d.
" " " (exp)	150	80	268	8.1	0.42	0.64	1.36	4.5	0.54	n.d.	n.d.
Site M											
Scots pine needles	79	81	285	4.1	0.23	n.d.	0.50	6.30	0.45	1.66	n.d.
" " "	74	95	293	3.6	0.23	n.d.	0.38	6.42	0.56	1.48	n.d.
" " "	159	78	265	4.4	0.37	n.d.	1.38	5.32	0.67	1.43	n.d.
" " "	106	76	300	4.6	0.32	n.d.	0.58	6.91	0.74	1.76	n.d.
" " "	212	90	243	4.7	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Lodgepole pine needles.	69	46	389	3.4	0.31	n.d.	0.40	6.8	0.88	2.19	n.d.
" " "	67	44	391	3.8	0.31	n.d.	0.50	5.62	0.85	2.33	n.d.
" " "	109	47	366	4.0	0.44	n.d.	0.52	9.07	1.06	3.07	n.d.
" " "	119	42	357	3.7	0.46	n.d.	0.93	5.68	1.06	2.17	n.d.
" " "	127	58	365	4.2	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
" " " 1,2	147	36	346	10.5	0.82	1.17	3.84	3.99	0.93	0.82	n.d.
" " " 2	103	42	381	3.9	0.34	0.62	0.56	6.35	0.95	1.79	n.d.
Site B.I. <sup>3</sup>											
White pine needles	166	162	225	4.4	0.58	n.d.	n.d.	n.d.	n.d.	n.d.	38
Aspen leaves	169	142	214	8.3	1.40	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Sugar maple leaves	336	112	121	8.3	1.0	n.d.	n.d.	n.d.	n.d.	n.d.	113
Hemlock needles	206	181	177	8.3	0.78	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
White oak leaves	247	77	202	8.4	1.50	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Red oak leaves	210	90	248	8.2	1.20	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Red maple wood	22	48	125	0.90	0.20	n.d.	n.d.	n.d.	n.d.	n.d.	3

<sup>1</sup> green needles; <sup>2</sup> incubated at site 6:51; <sup>3</sup> all analyses from the B.I. site are on ash-free mass.



## SEARCH FOR RRCs PROGRAM IN ECOSYSTEM ECOLOGY

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Using the privileges of editor, who can add some comments at the last minute, I would like to consider for a while the position of an ecosystems ecologist in the subject under discussion. Where is our place in this programme, so imposing in its space and time scale? How can ecosystems react, and consequently, what should be observing in them? I should add that ecosystem is defined here as such an ecological system in which the organic matter produced within this system (or partly coming from outside) is transformed at successive trophic levels according to known and described pattern of matter and energy cycling. The transformations of matter occurring in a set of functioning trophic levels are called basic (main) ecosystem processes. The sequence of basic ecosystem processes included in the functional definition of ecosystem is necessary for the self-restoration of an ecosystem and for its theoretically unlimited duration.

Limits of ecosystem capacity on stress (rapid climate change, contamination) are set up (estimated) as the limits on stress of main ecosystem processes (Brey Meyer 1981). These processes can obviously be intensified or reduced and the proportions among production and destruction can vary in each ecosystem. However, the processes must continue. If any of them disappear, the ecosystem, according to the definition, no longer exists. The disappearance of ecosystem processes is measurable, so the capacity of an ecosystem can be measured, too (Brey Meyer 1981). If we add that in IGBP we are to register relations between ecosystems and geosphere (including climate) on a global or at least regional scale, then ecology of ecosystems will be in a very difficult situation. Ecosystem processes which - as has been stated in the above definition - constitute a condition for ecosystem existence, should be controlled in the IGBP on large areas. What can thus be suggested now, today?

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It seems that the programme of ecosystems control may for the time being be based on their zonal and phenological changeability. Zonality, occurring both on plateaus, from the equator towards the poles, and on mountainous areas to a certain extent repeating the plain zonality going upwards, is a feature easy for registering with the help of remote photography technologies. Borders between ecosystems are easy to define thanks to a changing of producers, i.e. plant species creating an ecosystem. Particularly borders between tree, shrubby and herbaceous ecosystems may be registered by remote techniques in a very detailed way and so their eventual shifting can easily be documented. Certain aspects of a phenological changeability of ecosystems may also be registered from the air; in this case I am thinking above all about registering falling down of litter, an ecosystem process which ought to undergo changes with changes of climate. Let us consider some examples of new results in this matter (Breymer, in prep.).

Conditioning of litter fall by climatic factors is known from older literature and present studies (Fig.1). In a broad, global scale the pattern is very clear, but a more careful analysis of some smaller regions does not show such a distinct correlation.

Let us analyse two examples of changeability of litter fall with changing climate, mainly temperature. Majority of data used comes from our current studies. They were not published yet and only very preliminary statistics was applied for their elaboration.

The first example shows the relationship between climate and grasslands productivity - mortality rate - Tab.1. Two mountain transects, the granitic and the calcareous one were studied in Polish Carpathians; the method of Wiegert and Evans (1964) was used for sampling of dying and green grass. In the case of grassy ecosystems the plants mortality can be treated as the measure of litter fall. Changes of temperature and grass mortality in both transects are shown in Tab.1. The index of mortality per 1°C shows very clear tendency: mortality is growing with warming of climate. It is probably the result of growing productivity in lower altitudes as well as increasing rate of mortality processes.

The second example deals with litter fall in North-South transect of coniferous forests - Tab.2. The stands selected in Sweden and Poland ranges from 68° to 52° North; there are very distinct differences in mean yearly temperatures measured on these sites (accidentally their range is very similar to this analysed in the mountain transect - Tabs.1 and 2). Litter fall is growing with warming, but different litter fractions behave differently: it seems that the share of woody fraction is larger in cooler climates and it decreases with warming. Probably the "green production" i.e. production of needles and leaves responses stronger to warmer climate; woody parts do not react so simply or they react with some delay. This can be the reason

of more "woody litter fall" in more northern locations and more "soft litter fall" in the southern sites.

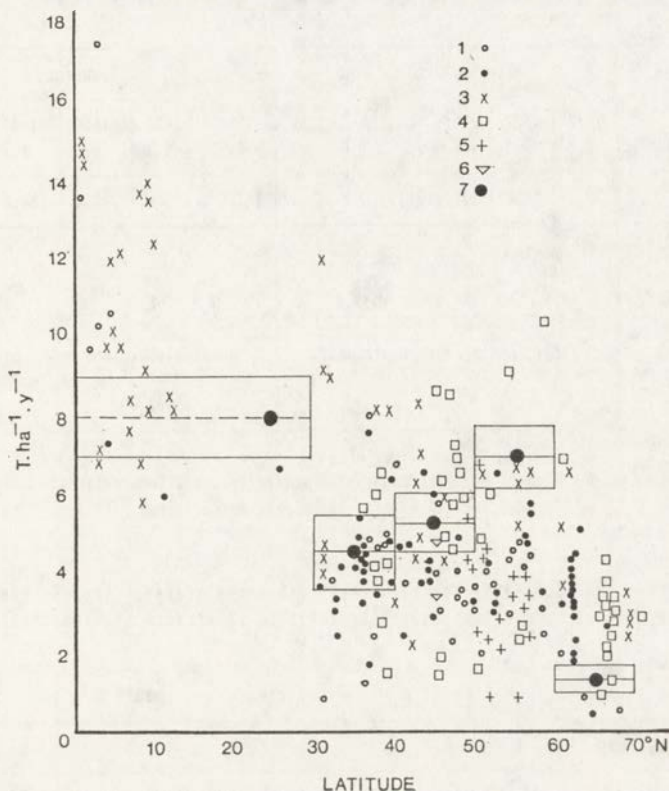


Fig.1 Annual litterfall in relation to latitude. 1-Bray and Gorham 1984, 2-IBP Woodland Data Bank after Reichle 1981, 3-Vogt et al. 1986 broadleaved forest, 4-Vogt et al. 1986 needle forest, 5-unpublished data Breymeyer et al., 6-Alvera 1980, 7-wood production (means and standard errors) according to Woodland Data Bank. Vogt et al. data are collected for northern and southern latitudes, the others for northern only.

In both transects the measurements of decomposition rates were carried in a parallel way. It was found that litter fall responses stronger than decomposition to the climate change.

It seems that after conducting appropriate calibrations on the ground it will be possible to evaluate on the basis of aerial photography not only the time of litter fall but also its quantity.

Considering the remote technics and the grasslands, it can be expected that on large areas situated within central parts of



Table 1. Measurements of plant mortality in mountain grasslands laying along altitudinal transect in Polish Tatras. Granitic (G) transect sampled in years 1982, 1983, 1984, calcareous (C) transect during 1986 only. Annual sum of precipitation for both transects ranges from 1350 to 1620 mm and increases in higher elevations. After Uba and Breymeyer in prep.

	Transect G					Transect C					
Altitude m asl	1970	1820	1680	1520	1200	1940	1830	1650	1480	1340	1100
Temp. mean annual °C	-0.8	0.3	0.9	2.4	3.3	-0.8	0.2	1.1	1.9	2.7	3.4
Mortality g.m <sup>-2</sup>	30.2	90.6	122.1	223.2	346.6	187.6	191.4	247.0	184.0	252.2	397.2
Index: mortality per 1°C growing temp. For all stands <sup>1</sup>	54.9 52.5 77.7 137.1					3.8 61.7 85.2 181.4					
Divided by timber line <sup>2</sup>	above timber line below t.l.					above timber line below timber line					
	28.5 137.1					31.2 130.1					

<sup>1</sup> Calculated as ratio of differences between consecutive mortalities and temperatures:  $\frac{m_2 - m_1}{t_2 - t_1}$

<sup>2</sup> Calculated as ratio of differences between extreme temps. and mortalities.

Table 2. Litter fall in coniferous forests, north-south transect from northern Sweden (Tornetrask and Jdraas) to central Poland (Mierzvice and Kampinos).

Geogr. Position	68°14'N	60°2'N	52°2'N	52°2'N
Yearly mean temp. °C	-0.7	3.8	7.2	7.8
Stand name, years and points of sampling	Tornetrask (1; 1986,87)	Jdraas (1; 1986,87)	Mierzvice <sup>1</sup> (6; 1988)	Kampinos <sup>2</sup> (2; 1975)
Litter fall G m <sup>-2</sup> y <sup>-1</sup>	55.3; 61.5	112.6; 199.1	197.9-369.3	231.7; 244.6
In this:				
% needles and leaves	47.0; 63.4	47.5; 46.3	59.0-71.9	63.9; 54.2
% woody parts	48.0; 37.0	52.5; 53.0	20.2-30.0	26.5; 29.5

<sup>1</sup> After Breymeyer, not published

<sup>2</sup> After Józefaciukowa, 1975

continents, covered by steppes and prairies, it is easy to register very characteristic phenological aspects of spring changeability; it may be expected that both the long lasting and the sequence of those aspects will change under the influence of climatic transformations.

The two types of variability, in space (zonality) and in time (phenology) may easily and surely be interpreted on the basis of

current knowledge concerning the functioning of ecosystems, and certain general scenarios of biosphere function transformations may be established. It seems that ecosystem ecology in the IGBP may commence with such programmes in the RRC's network. It would be of immense interest if we could collect such data on the global scale.

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## TEN YEARS OF CLIMATE OBSERVATIONS AT THE ARCTOWSKI AND BELLINGSHAUSEN STATIONS (King George Is., South Shetlands, Antarctica)

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The Ice Cap of King George Island plays an important role in influencing the climate of the islands SE shore and for this reason Arctowski region differs from the one at Bellingshausen. In the last decade the mean air temperature has increased, and precipitation and pressure decreased. Simultaneously, an intensive deglaciation process has been observed in the Arctowski area.

### INTRODUCTION

King George Island is a unique place in the world, with a net of most closely spaced meteorological stations (Fig. 1). In 1988, eight such stations were active within a 13 km radius. The Soviet Bellingshausen meteorological station has been active the longest time, since 1969, while the Polish Arctowski base has worked since 1977. Both stations are registered in the World Meteorological Organization and both make eight observations per 24 hours using the same recording methods. In the years 1948-60, a British meteorological station, Admiralty Bay, had worked in the vicinity of today's Arctowski Station.

The climatic characteristics of this area, based on data from the Arctowski station, have been recorded for the years 1977 and 1978 by Zubek (1980) and Nowosielski (1980), and for the period 1978-84, by Marsz and Rakusa-Suszczewski (1987). A comparison of results of meteorological observations between the two neighbouring stations allows us to assess the effect of orography on the local climate as well, perhaps to detect any tendencies in the long-term climatic changes of the area of the South Shetland Islands. According to Kaufeld (1988), no long-term climatic trends can be detected in this area during the last decade.

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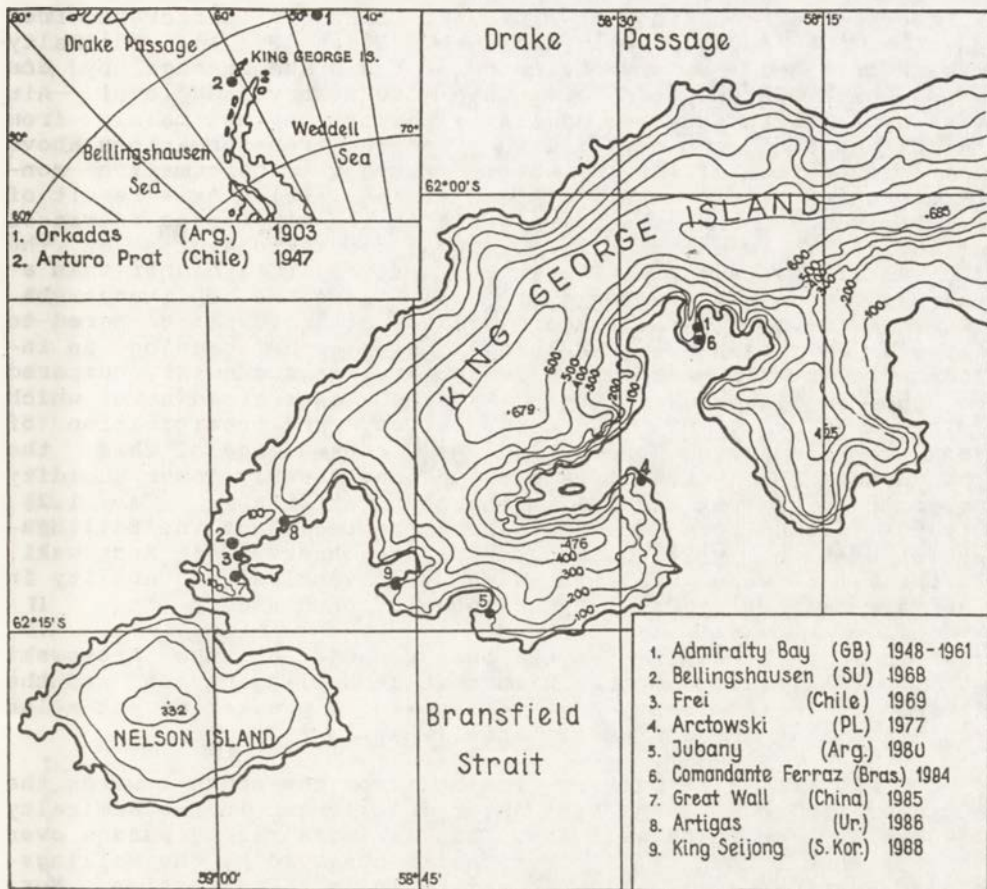


Fig.1. Climatological observation area (1-9 distribution of meteorological stations and the years of the beginning of work)

Rakusa-Suszczewski (1988) stated that the first half of the nineteen eighties at Arctowski Station had been distinctly warmer compared with earlier decades.

## RESULTS AND DISCUSSION

King George is the largest island in the South Shetlands group. The climate of this region is mainly under the influence of cyclonic systems generated in the SE part of the Pacific Ocean, and moving generally in an easterly direction. During winter, the air masses which originate in the western part of the Weddell Sea (van Loon and Shea 1988) also move into this area.

The area surrounding the Arctowski base is different from that at the Russian Bellingshausen Station (Fig.1). Admiralty Bay is isolated from any influence of the Drake Passage by ice caps which extend to more than 600 m above sea level. Air masses travelling towards Admiralty Bay are moving mainly from the NW and SW directions, and they undergo transformations above the cold surface of the ice sheet. Further transformation continues when the air masses descend to sea level. As a result of adiabatic processes, the temperature of the air masses increased slightly. The mean monthly and annual air temperatures at the Arctowski base are a few tenths of a degree (C°) higher than at the Bellingshausen Station (Tab. 1.1). Also the amplitudes between extreme temperatures are greater at Arctowski compared to these at Bellingshausen. An additional factor causing an increase in the air temperature in the area of Arctowski, compared to the Bellingshausen area, is the lower cloud cover which arises as a result of cloud accumulation, and precipitation of snow and rain above the ice cap. As a consequence of this, the area around the Arctowski base has a considerably lower humidity compared to that at the Bellingshausen Station area (Tab. 1.2). Stratus clouds are dominant above the region of the Bellingshausen station, while Cumulus types are observed at Arctowski. In the latter case, this is evidence of vertical instability in the air masses caused by catabatic processes.

Much lower precipitation has been recorded at the Arctowski station (Tab. 1.2) compared with that at Bellingshausen, and the shores of the Admiralty Bay are exposed to greater direct solar radiation than the shores of Maxwell Bay.

In winter, air masses flowing from the south towards the south-east (Tab. 1.3 and 1.4) may remain longer in the Admiralty Bay region than in Maxwell Bay. This air mass rarely passes over the ice sheet, but it is occasionally observed at the Bellingshausen Station. Generally, it drifts in an ESE direction. More northerly and northwesterly winds are observed at Bellingshausen. The greatest effect of these is an increase in the air temperature and a decrease in precipitation at the Arctowski base. North-westerly winds are associated with the transfer of cyclones and these, in turn, are associated with a decrease in air pressure (Tab.1.5 and 1.6). Low pressure observed in the Bellingshausen Station area is indicative of the changes which have occurred in the atmospheric circulation in the region of the South Shetlands during the last decade. According to Kaufeld (1988), who analysed pressure anomalies for the period 1957-1985, fluctuations lasting longer than one year are very weak.

Calculations of the correlation coefficients between the mean monthly air temperatures at Arctowski, Bellingshausen, Admiralty Bay and Arturo-Prat have allowed us to propose hypothetical ten-year air temperature means for the Arctowski region for the period 1948-1987 (Tab.2). During the last decade there has been a mean temperature increase from 0.2 to 0.6°C as compared to the previous decades. It appears that as a consequence it has resulted in the process of deglaciation on land, which has been

Table 1. Climatological data for Arctowski (AR) and Bellingshausen (BL) stations  
(Summary for period 1978-1987)

Table 1.1.

Air Temperature (°C)							M.S.L. Pressure (mbar) 900 + P			
Month	Daily Mean		Extremes				Daily Mean		Extremes	
			Lowest		Highest				Lowest	Highest
	AR	BL	AR	BL	AR	BL	AR	BL	AR	BL
I	2.2	1.5	-4.9	-5.7	16.7	12.4	91.0	91.5	62.6	114.5
II	2.1	1.6	-3.8	-3.4	9.1	9.3	88.7	89.3	59.2	117.8
III	1.1	0.4	-8.4	-7.6	11.4	7.5	91.3	91.8	52.5	117.8
IV	-0.9	-1.6	-16.8	-15.9	10.0	5.5	90.6	91.8	48.4	123.4
V	-3.6	-4.0	-24.0	-24.0	7.6	4.3	96.9	97.0	61.4	127.8
VI	-5.1	-5.3	-27.3	-21.5	7.0	3.6	93.5	93.8	51.6	127.0
VII	-7.1	-7.2	-32.3	-27.4	8.8	5.0	93.4	93.7	57.2	131.0
VIII	-5.6	-6.3	-25.3	-20.9	6.6	2.8	91.0	91.5	38.3	123.0
IX	-3.6	-4.5	-29.0	-25.8	5.8	4.5	91.5	92.1	49.9	122.0
X	-1.9	-2.9	-16.4	-17.3	9.2	5.0	88.6	89.6	41.9	123.3
XI	-0.4	-1.4	-11.0	-15.0	9.8	5.0	86.6	87.4	50.3	120.4
XII	1.6	0.5	-6.7	-6.0	12.7	7.4	89.9	90.5	53.2	118.4
Year	-1.8	-2.4	-32.3	-27.4	16.7	12.4	91.1	91.6	38.3	131.0

Table 1.2.

Month	Total Cloud 1/10		Humidity (%)		Precipit. mm		Wind Speed (m/s)			
	AR	BL	AR	BL	AR	BL	Daily	Mean	Extremes	
							AR	BL	AR	BL
I	8.2	9.3	82.6	89.0	33.9	45.5	6.3	6.6	26	34
II	8.2	9.0	83.2	89.2	62.3	67.9	6.6	6.8	32	33
III	7.9	9.0	82.0	88.4	68.9	74.4	7.5	7.1	30	38
IV	7.9	8.9	81.9	87.7	58.3	61.8	7.8	7.6	60	36
V	7.7	8.9	82.7	89.4	31.5	63.0	6.7	7.7	28	38
VI	7.5	8.7	81.6	88.1	37.0	47.0	7.1	7.9	28	35
VII	7.1	8.3	81.8	88.5	33.8	53.8	7.2	7.6	30	36
VIII	7.0	8.5	81.8	88.9	27.1	60.9	7.6	7.7	36	44
IX	7.4	8.8	81.9	88.9	48.5	61.3	8.0	7.9	45	36
X	7.6	8.8	80.7	88.5	35.0	48.2	8.0	7.9	36	33
XI	8.1	9.2	81.7	88.2	46.0	47.6	7.6	7.3	35	36
XII	8.1	9.2	81.8	89.8	41.8	53.1	6.4	6.7	38	32
Year	7.7	8.9	81.9	88.7	512.9	681.2	7.2	7.4	60	44



Table 1.3.  
Analysis of wind

Seasonal frequency of wind direction (%). AR									
Month	N	NE	E	ES	S	SW	W	WN	Variable
I	10.8	5.8	12.7	14.6	7.4	15.1	14.2	11.2	8.2
II	12.8	6.0	10.8	11.9	5.6	15.0	13.0	14.6	10.3
III	10.5	6.4	8.9	10.1	6.1	21.6	13.6	14.2	8.6
IV	8.1	6.3	14.5	6.3	6.6	24.9	13.2	11.1	9.0
V	8.9	6.5	17.2	10.2	7.5	17.8	9.4	10.4	12.1
VI	8.8	6.0	12.7	9.2	8.3	20.8	12.5	9.6	12.0
VII	7.5	6.2	8.4	7.7	6.5	19.4	13.4	11.8	19.4
VIII	9.7	3.5	7.5	6.1	6.8	25.7	13.2	13.7	13.7
IX	12.5	5.3	7.0	6.4	5.2	24.6	11.9	15.8	11.3
X	9.3	2.7	8.2	7.8	4.4	28.8	16.3	14.4	8.2
XI	9.7	5.4	9.9	7.7	5.4	26.5	15.4	13.4	6.6
XII	10.1	4.6	8.7	10.7	6.0	19.7	18.0	12.4	9.7
Year	9.8	5.2	10.6	9.1	6.3	21.7	13.5	12.9	10.9

Table 1.4.

Seasonal frequency of wind direction (%). BL									
Month	N	NE	E	ES	S	SW	W	WN	Variable
I	21.2	6.5	11.1	10.6	3.7	2.7	16.6	20.4	1.2
II	21.3	6.9	8.6	13.7	4.6	4.1	16.8	23.5	0.5
III	20.1	5.5	8.5	11.8	4.4	4.3	19.1	24.8	1.5
IV	16.4	4.9	9.3	13.7	3.6	6.5	21.0	22.0	2.6
V	17.1	5.9	11.3	20.3	4.6	4.1	15.8	17.7	3.2
VI	13.9	4.0	13.3	17.0	3.9	5.7	20.4	17.8	4.0
VII	11.8	4.0	9.3	16.3	5.3	7.1	20.1	20.4	5.7
VIII	20.0	3.1	6.0	11.3	4.0	7.4	19.5	23.6	5.1
IX	19.2	3.5	5.6	9.7	3.8	7.5	21.4	26.7	2.6
X	18.7	2.8	7.0	9.6	2.7	6.5	26.8	23.9	2.0
XI	19.3	2.8	7.1	10.6	2.3	5.1	24.6	25.8	2.4
XII	21.5	4.4	8.9	12.8	3.2	3.8	21.9	22.9	0.6
Year	18.4	4.5	8.8	13.6	3.9	5.4	20.3	22.5	2.6

Table 1.5.

Mean wind speed and direction (m/s) AR											
Month	N	NE	E	ES	S	SW	W	WN	Var.	speed m/s	direct Dec.
I	5.8	5.8	5.9	6.0	5.5	6.2	5.8	8.7	0.5	0.8	258
II	7.4	5.3	6.4	6.1	5.5	7.0	7.6	8.7	0.7	1.4	293
III	6.9	5.3	6.7	7.5	6.0	7.4	7.3	9.8	0.3	1.8	268
IV	8.2	6.5	8.7	6.5	5.6	8.0	7.8	9.9	0.1	1.4	258
V	7.4	6.2	8.5	6.3	5.5	7.2	6.9	8.0	0.2	0.2	167
VI	7.4	5.8	7.6	7.8	5.0	8.2	8.7	10.1	0.1	1.4	249
VII	9.0	6.9	8.1	5.4	5.6	8.8	8.6	10.6	0.2	2.1	276
VIII	7.8	5.4	6.8	5.8	6.0	9.3	9.1	10.7	0.3	3.2	263
IX	9.1	5.8	8.1	6.0	5.5	8.4	8.1	11.5	0.1	2.8	285
X	8.3	5.5	6.9	7.5	6.0	8.9	9.4	11.2	0.3	3.5	263
XI	7.6	5.7	6.8	6.6	6.6	8.0	9.1	10.2	0.4	2.5	264
XII	6.3	5.0	6.2	5.6	5.2	6.8	8.0	8.5	0.4	2.1	267
Year	7.6	5.8	7.2	6.4	5.6	7.8	8.0	9.8	0.3	1.9	268

Table 1.6.

Mean wind speed and direction (m/s) BL											
Month	N	NE	E	ES	S	SW	W	WN	Var.	speed m/s	direct Dec.
I	6.6	6.3	5.9	7.2	4.1	3.6	5.8	6.4	0.0	1.6	354
II	6.7	7.4	6.3	7.6	5.0	4.5	6.5	6.3	0.0	1.8	340
III	7.0	6.2	6.4	7.2	4.0	5.0	6.9	7.3	0.0	2.4	326
IV	7.2	5.5	5.7	7.2	4.0	5.7	7.6	7.8	0.0	2.2	312
V	7.3	7.6	7.6	8.2	3.7	6.0	7.1	7.0	0.0	1.0	012
VI	7.6	6.8	7.8	7.4	4.6	7.2	8.3	7.6	0.1	1.2	317
VII	8.2	8.1	6.8	6.9	4.2	7.0	8.4	8.1	0.1	2.4	296
VIII	7.7	5.6	7.0	7.0	4.1	6.4	8.5	7.8	0.0	3.0	311
IX	8.0	7.0	4.7	6.7	3.6	6.0	8.5	8.3	0.0	3.7	310
X	7.7	7.0	7.2	7.6	3.5	5.9	8.5	8.0	0.0	3.4	307
XI	7.1	5.3	5.5	7.0	4.4	6.0	7.2	7.4	0.0	3.0	311
XII	7.1	6.1	6.0	7.2	4.0	4.3	6.2	6.4	0.1	2.2	329
Year	7.4	6.6	6.4	7.3	4.1	5.6	7.5	7.4	0.0	2.2	319

Table 2. Calculated theoretical mean temperatures for the Arctowski station in the periods shown, based on actual data collected at the station 1978-1987

Month	1948-1960	1960-1967	1968-1977	1978-1987	1984-1987
I	1.4	1.7	1.4	2.2	1.6
II	1.6	1.6	1.5	2.1	1.7
III	-0.2	-1.2	0.0	1.1	0.0
IV	-1.7	-2.1	-1.1	-0.9	-1.4
V	-5.2	-4.1	-4.3	-3.6	-4.4
VI	-6.1	-5.2	-6.3	-5.1	-5.7
VII	-9.5	-6.7	-6.7	-7.1	-7.7
VIII	-6.8	-6.6	-6.7	-5.6	-6.4
IX	-4.1	-3.4	-3.7	-3.6	-3.8
X	-1.8	-2.1	-1.6	-1.9	-1.8
XI	-0.5	-0.7	-0.3	-0.4	-0.5
XII	3.2	0.6	0.9	1.6	1.8
Year	-2.1	-2.4	-2.0	-1.8	-2.0

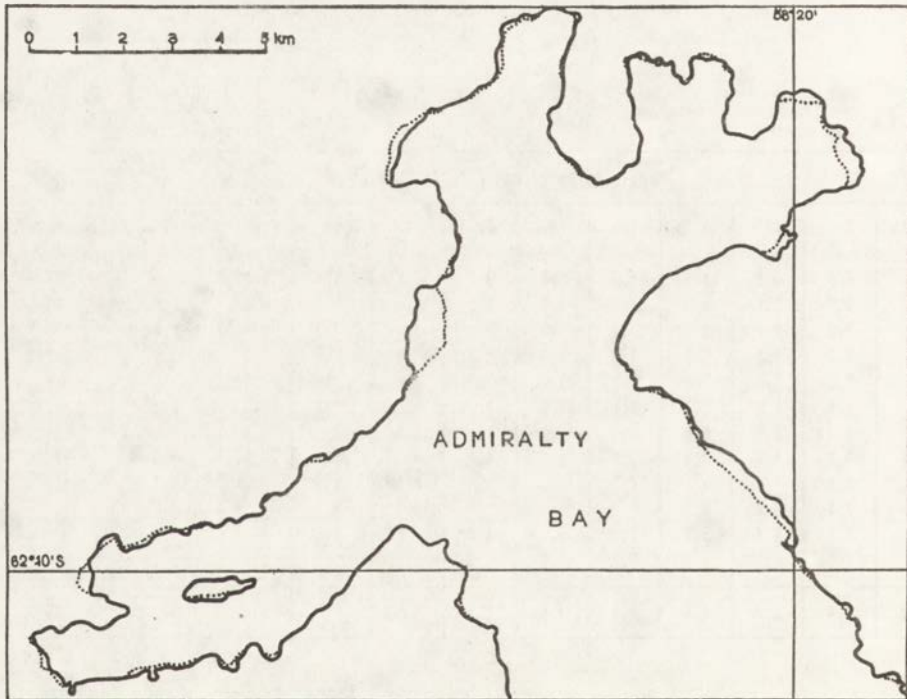


Fig.2 Comparison of ice-shore line in Admiralty Bay area between 1959 - dotted line, photo. by British Hunting Aerosurveys Ltd., and 1979 - continuous line, aerial photo. by Institute of Ecology, Polish Academy of Sciences.



evident during the last ten years. It has also caused a regression of the ice barriers forming parts of the shores of Admiralty Bay (Fig.2).

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## WHERE SHOULD CLIMATE MONITORING STATIONS BE?

C.R. MARGULES and L. BELBIN \*

Using climate monitoring in Australia as an example, a numerical method is described for classifying a region into climatic zones and identifying a geographic location which best represents each zone. These would be the ideal locations for monitoring stations. This ideal network can be compared to the existing network and the loss in monitoring efficiency can be assessed. In some climatic zones, existing monitoring stations record a similar climatic profile as a new station if it was established at the ideal location. In others, no existing station records a similar climatic profile to that climatic zone so a new station would be recommended. Scientific priorities for establishing new stations then can be assessed relative to the costs involved.

### INTRODUCTION

The 10 (or so) Regional Research Centres (RRC's), which it is planned will be established around the globe will have a major role in managing regional data sets to monitor trends in global change. It is envisaged that RRC's will link existing networks of monitoring stations and other data collection stations to provide the multidisciplinary data base required to meet IGBP objectives (Report of WG2, 10-12 May, 1989).

The criteria for selecting regions for RRC's include geographical coverage, ecosystem coverage or representation and coverage of geo-political groupings. Criteria for identifying actual RRC sites within regions include the nature and extent of any existing research infrastructure, the potential to involve local scientific and governmental institutions and the possibilities of logistical support. Inevitably, there will be gaps in existing networks regardless of the willingness and ability of local research and other institutions to participate. These gaps must be identified and their relative importance assessed so that the IGBP can set priorities for filling them.

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There are three questions that should be asked of any monitoring program: what to monitor, where to monitor and when to monitor? The question of what to monitor will depend on the specific objectives of the monitoring program and the identification of key variables that will best indicate changes and trends for these objectives. Examples relevant to global change might be species of extreme environments, species of restricted environments, edges of ecosystems or biomes, migratory species such as insects and birds, entities which are detectable in the fossil record, or the frequency of extreme climatic events. The question of when to monitor depends on the processes relevant to the responses of the entities or events being monitored. For species, monitoring might be appropriate during each season, whilst for extreme climatic events it might be when such events are expected (e.g. winter for frosts) and for ecosystems it might be regularly but not necessarily often.

It is the second of those questions, where to monitor, that is the subject of this paper. Using climate monitoring in Australia, we describe a procedure for classifying a region into climatic zones and identifying a location which best represents each zone. Then the existing network of monitoring stations can be compared with the 'best' network, and inadequacies can be identified. Priorities for establishing new monitoring stations can be set according to the scientific priorities of IGBP. For example, if cold, high altitude environments were accorded scientific priority because they are likely to experience change early, and there was no monitoring station in a region which adequately represented that environment, establishing a new one might be given a high priority.

## METHODS

### The Data Base

The data used for this exercise are the 24 climate variables listed in Table 1. These data were supplied by H.A. Nix from his BIOCLIM data base, which is a set of continuous mathematical surfaces fitted to meteorological data (Nix, 1986; Busby, in press). Note that, for this study, there are 15 temperature variables and nine precipitation variables so the resulting classification described below is weighed towards temperature. Some of the variables are also strongly correlated. The purpose here is to describe a procedure, not derive the 'best' climatic classification of Australia. Any future analysis should give equal weight to temperature and precipitation, and consider using solar radiation, for which there are parameters in the BIOCLIM system. The problem of cross correlation also can be addressed.

### The Analysis

Values for each of the 24 variables in Table 1 were assigned to 45,249 grid points, derived from an eighth of a degree grid



Table 1. The climatic variables used to classify Australia into 100 climatic types.

#### TEMPERATURE

1. ANNUAL MEAN TEMPERATURE
2. ANNUAL MEAN MAX. TEMPERATURE
3. ANNUAL MEAN MIN. TEMPERATURE
4. MAX DIURNAL RANGE  
max (monthly(max-min))
5. MEAN TEMPERATURE OF WARMEST MONTH
6. MEAN TEMPERATURE OF COLDEST MONTH
7. MEAN SEASONAL RANGE (5-6)
8. ISOTHERMALITY (4/12)
9. MAX. TEMPERATURE OF WARMEST MONTH
10. MIN. TEMPERATURE OF COLDEST MONTH
11. ANNUAL RANGE (10-11)
12. MEAN TEMPERATURE OF WETTEST QUARTER
13. MEAN TEMPERATURE OF DRIEST QUARTER
14. MEAN TEMPERATURE OF WARMEST QUARTER
15. MEAN TEMPERATURE OF COLDEST QUARTER

#### PRECIPITATION

1. ANNUAL PRECIPITATION
2. PRECIPITATION OF WETTEST MONTH
3. PRECIPITATION OF DRIEST MONTH
4. RANGE (2-3)
5. SEASONALITY (4(1/12.0))
6. PRECIPITATION OF WETTEST QUARTER
7. PRECIPITATION OF DRIEST QUARTER
8. PRECIPITATION OF WARMEST QUARTER
9. PRECIPITATION OF COLDEST QUARTER

across the continent of Australia, using the surface fitting algorithms of Hutchinson (1984, 1987). An application of these surface algorithms can be found in Adomeit et al. (1988). Then, the grid points were classified into 100 groups using a non-hierarchical allocation routine (ALOC) from the PATN software package (Belbin, 1988). This algorithm compares the similarity of all grid points based on shared values of the climate variables and generates a smaller number of groups (defined by the user) which consist of grid points which share similar values. The Gower metric (Gower, 1971) was used as the measure of association between grid points. An earlier continental classification by Laut et al. (1975), an arid zone classification by Austin & Nix (1978) and a more recent continental classification by Mackey et al. (1989) suggested that an order of magnitude 100 would be appropriate for Australia, but more or fewer groups can be obtained readily. There would be a practical advantage in working with fewer groups, but the disadvantage would be an increase in within group heterogeneity and an increased probability of missing small groups which might be significant climatic zones.

Each group can be considered a hypersphere with the centre, or centroid, the point which best represents that group in multivariate (24 variable) space. The nearest grid point (in multivariate space) to the centroid is the geographic location which best represents each group. The distance (in multivariate space) from the centroid to the nearest climate station is an indication of how well that climate station represents that group. The closer it is to the centroid, the better it represents the group. This distance varies between 0 and 1 with 0 distance meaning the station is identical with the centroid. Currently, there is no rigorous test to determine the length of this distance which would make it unacceptably different from the centroid. One problem is that the distance to the boundary of the hypersphere is not known accurately. A conservative estimate of this distance can be obtained by taking half of the distance from a centroid to the closest neighbouring centroid because as a consequence of the allocation routine it can be assumed that the boundaries of adjacent hyperspheres are half way between their centroids. This assumes, in turn, an even or random distribution of gridpoints in the multi-dimensional climate space. Thus, the distance from the nearest climate station to the centroid was divided by half the distance to the next nearest centroid. In this way, the position of the nearest climate station to the centroid of each group could be expressed as a proportion of its distance to the boundary of each group.

This approach permitted a preliminary evaluation of the extent to which a climate station represents the climatic zone. An alternative approach was attempted on three groups as examples. The distances from the centroid to all grid points allocated to a group were calculated and drawn as a histogram. The position on that histogram of the nearest climate station to the centroid was determined. A test of the closeness of the nearest climate station to the centroid was that it should fall in a distance class close to the centroid.

## RESULTS

Figure 1 is a map showing the 100 climatic zones recognized by the classification. As expected, large areas of uniform climate occur across much of the continent, with the clear latitudinal zonation largely reflecting the weight given to temperature. Along the east coast and in Tasmania, however, this zonation is confounded by considerable local relief and the climate is far more heterogeneous. There are many geographically small climatic zones compared with the rest of the continent.

Table 2 gives the distances, for all 100 climatic zones, or groups, from the centroid to the nearest climate station, from the centroid to the next nearest centroid and the distance from the nearest climate station divided by half the distance to the next nearest centroid, expressed as a percentage. Thus, the nearest climate station to the centroid of group 1 in multivariate space is 0.0209 (in the range 0-1). The distance to the



Fig. 1. A map of Australia showing  
 the 100 climatic zones recovered  
 by the allocation routine



1	2	3	4
43	0.0097	0.0645	0.3008
44	0.0107	0.0483	0.4421
45	0.0156	0.0505	0.6189
46	0.0119	0.0633	0.3762
47	0.0179	0.0388	0.9243
48	0.0085	0.0263	0.6477
49	0.0231	0.0509	0.9056
50	0.0179	0.0460	0.7782
51	0.0204	0.0698	0.5840
52	0.0177	0.0534	0.6631
53	0.0189	0.0753	0.5018
54	0.0058	0.0309	0.3759
55	0.0232	0.0585	0.7932
56	0.0219	0.0460	0.9535
57	0.0474	0.1056	0.8982
58	0.0199	0.0678	0.5868
59	0.0142	0.0348	0.8153
60	0.0221	0.0643	0.6874
61	0.0078	0.0523	0.2986
62	0.0183	0.0527	0.6942
63	0.0153	0.0624	0.4897
64	0.0148	0.0539	0.5483
65	0.0257	0.0523	0.9823
66	0.0129	0.0454	0.5691
67	0.0166	0.0418	0.7940
68	0.0105	0.0494	0.4254
69	0.0192	0.0718	0.5348
70	*		
71	0.0269	0.0561	0.9587
72	0.0204	0.0452	0.9031
73	0.0159	0.0403	0.7893
74	0.0147	0.0399	0.7372
75	0.0130	0.0660	0.3941
76	0.0366	0.0587	1.2465
77	0.0578	0.0972	1.1897
78	0.0222	0.0660	0.6726
79	0.0155	0.0517	0.5993
80	0.0143	0.0399	0.7170
81	0.0168	0.0422	0.7962
82	0.0390	0.0537	1.4520
83	0.0270	0.0465	1.1607
84	*		
85	*		
86	0.0397	0.0523	1.5177
87	*		
88	0.0084	0.0422	0.3985
89	0.0374	0.0600	1.2478
90	0.0121	0.1071	0.2257
91	*		
92	0.0268	0.0531	1.0094
93	0.0141	0.0520	0.5428
94	0.0143	0.0520	0.5504

1	2	3	4
95	0.0364	0.0529	1.3762
96	0.0225	0.0467	0.9645
97	0.0503	0.1058	0.9507
98	0.0144	0.0519	0.5551
99	0.0277	0.465	1.1911
100	0.0244	0.0588	0.8304

The fourth column is a conservative estimate of the distance of the nearest climate station to the boundary of each climatic zone. Thus the nearest climate station to zone 1 is 0.6045, or 60.45% of the way to the multi-variate boundary of that zone. See the Methods section for all details.

next nearest centroid is 0.0691 and therefore the nearest climate station to the centroid of group 1 is estimated to be 60.45% of the way to the boundary of that group. In some cases, the nearest climate station to the centroid of a group lies outside the boundary of that group, but is still closer to its centroid than to the centroid of any other group. Thus, values of more than 100% appear in the fourth column of Table 2. Clearly, those 15 climate stations represent their groups, or climatic zones, very poorly. Further, there are five groups (designated a \* in Table 2) for which no climate station was closer to their centroids than to any other centroid. Three of these are from the wet tropics of northern Queensland and the other two are from sub-tropical coastal areas, also in Queensland. Only five groups, or climatic zones, have existing climate stations within 30% of the group radius and only another 23 have existing climate stations within 50% of the group radius.

Figure 2 shows histograms of the distances from the centroid to all grid points allocated to three groups, numbers 18, 22 and 65. Group 18 is semi-arid climatic type in eastern Australia with an annual mean temperature of 15.72 degrees celcius and an annual mean rainfall of 429.74 mm. Group 22 is the coldest climatic type with an annual mean temperature of 6.73 degrees celcius and an annual mean precipitation of 1544.92 mm. Group 65 has a Mediterranean climate with an annual mean temperature of 22.01 degrees celcius and an annual mean rainfall of 696.68 mm.

The histograms are highly skewed with most grid points being close to the centroid. In the case of groups 18 and 22, the distance from the centroid to the nearest climate station falls within the first class of distances from the centroid. It seems reasonable to assume that those climate stations are good representatives of those climatic zones. In the case of group 65 the climate station is further from the centroid, though still not out in the tail of the skewed distribution and still within a standard deviation of the mean. However, with the strongly skewed distribution, the mean is further out in the fourth class away from the centroid and therefore unlikely to

represent the typical climate indicated by the first two classes where 156 of the 267 grid points allocated to group 65 lie.

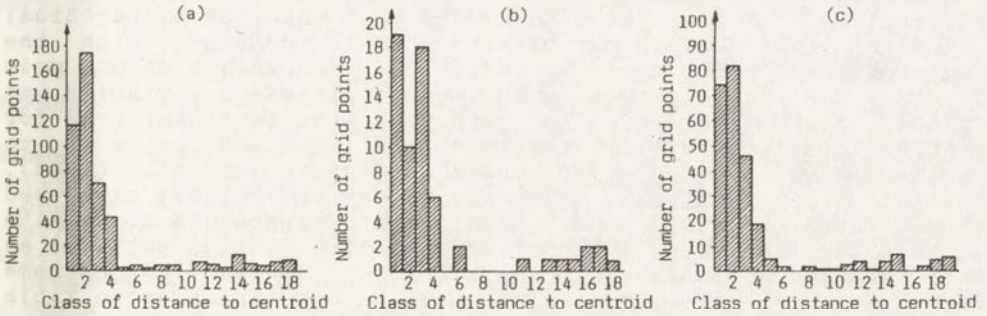


Fig.2 Histograms of the distances of all grid points to the centroid of climatic zones 18(a), 22(b) and 65(c). The location of the nearest climate station is shown thus; Classes along the y axis are in units of 0.056 varying from 0 to 1, from the Gower metric (Gower 1971). See text for explanation.

DISCUSSION

Most discussions on monitoring global change, or on monitoring in general, centre on the question of what to monitor. Of equal importance though are the other two questions of where to monitor and when to monitor. There is little point in attempting to monitor entities or events where or when they do not occur. In this paper, one method of identifying the most appropriate locations for climate monitoring stations, and assessing the efficacy of the existing network of climate stations has been described. An evaluation of alternatives and possible methodological improvements is still required, particularly in two areas.

The first is on the stratification itself: the climatic classification. There are alternative classification methods to numerical classification which should, perhaps, be evaluated. Land system mapping (Christian & Stewart, 1986) or phyto-geomorphology (Howard & Mitchell, 1985) involves the integration of a range of environmental features such as landforms, soils and vegetation in one map unit. The same approach might be suitable for climate classification. It has been used to provide rapid appraisals of land resources at a low cost and has the advantage that the holistic approach may lead to more realistic assessments of land use options and constraints because major environmental variables appear together (Margules & Scottt, 1984). Disadvantages include the implicit assumptions of correlations between variables and the extrapolation of those assumed correlations to unsampled sites.



Alternative numerical classifications include hierarchical agglomeration and division, but they are unsuitable for analysing very large data sets. Belbin (1987) compares a widely used hierarchical classification with the non-hierarchical classification used here and concludes that this non-hierarchical algorithm gives equal or better results combined with the computational efficiency necessary to accommodate 45,000 grid points. The possibility of using more appropriate variables was raised earlier and this is perhaps a most important area for further investigation. It involves the question of what to monitor as well as where to monitor. Austin et al. (1984), Austin et al. (in press) and Margules et al. (1987) have used annual mean rainfall and annual mean temperature along with lithological substrate to model species distribution patterns as well as patterns in tree species richness. However, if extreme events are most likely to signal change, then variables in Table 1 such as maximum or minimum temperatures of the warmest or coldest months, or precipitation in the wettest or driest months might be used. In addition, variables not included in Table 1 might be considered, especially solar radiation variables because they might reflect changes in the patterns of cloud cover. These questions are being followed up in Australia currently.

The second area relates to how similar or different an existing climate station is to the climatic zone it should be monitoring. It is difficult to interpret the meaning of the distance of a station from the centroid of its group as given in Table 2. Is 65% of the way to the boundary insufficient or not? A more meaningful evaluation is illustrated in Figure 2 where the position of the nearest climate station relative to all distances between the centroid and all grid points defining the group is shown. In general, the closer the climate station is to the centroid, the more likely it is to represent that climatic type adequately. Occurrence in the first class is within the first 5.6% of all distances from the centroid to all points. Occurrence in the third class is only within 16.8%, which is clearly inadequate. However, an unambiguous test still is not available so further research is required.

Climatic variables are continuous so the definition of a climatic zone is arbitrary. Species, on the other hand, are discrete entities. Margules et al. (1988) and Pressey & Nicholls (1989) have developed an algorithm for identifying the minimum set of sites in a region, which sample all species. They have used this algorithm to address the question of where nature reserves should be located, arguing that a network of reserves should sample all species. The same or a very similar algorithm could be used to identify a minimum set of sites necessary for monitoring species' responses to climate change.

Whilst the procedure described still requires research and development to make it applicable routinely, it does offer an explicit solution to the problem of where climate monitoring stations should be at any desired level of resolution. The

identification of the best locations for monitoring sites and an assessment of the extent to which the existing network of monitoring sites covers those locations, should be an integral part of any program designated to monitor global change.

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## CLIMATE AND VEGETATION OF CENTRAL EUROPE IN PAST WARMER PERIODS

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The deep cores from the ocean sediments and permanent ice caps provide a continuous record of biotic and climatic changes throughout the whole Quaternary, indicating at least 17 climatic cycles from cold to temperate-warm and again to cold conditions. The driving forces behind those changes are the fluctuations of insolation at the top of the atmosphere, connected with periodical variations in the Earth's orbital geometry (COHMAP Members, 1988).

According to independent different pieces of evidence, the cold stages lasted 50.000 to 100.000 years, and warmer periods in between were no longer than 10.000 to 20.000 years. For the most part of Quaternary, global temperatures were lower and the areas covered by permanent ice-sheets - larger than today. Thus, as commented by Birks (1986) the Quaternary is in its nature a cold period, with short interglacial disruptions only.

The climate patterns of cold and warm stages seem to be different. The evidence provided by the oxygen isotope ratio ( $^{16}O/^{18}O$ ) suggests a cold stage with long-lasting gradual slow cooling proceeding since its onset, with minor oscillations all the way, and a maximum of cold temperatures accompanied by the maximum extent of ice-sheets during the late phase of the stage. Such was the pattern of the last Vistulian glaciation, which began around 110.000 years ago, but its coldest phase, starting around 30.000 yrs ago, reached its maximum development between 20.000 and 18.000 yrs only. The following warming progressed already since 14-13.000 yrs, opening a new interglacial cycle.

To the contrary, during the warm periods, the maximum summer-time solar radiation was normally reached at the beginning of a

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This paper contains the ideas of many of my colleagues, authors of the papers on paleobotany together with my own interpretation of the state of art.

cycle.

However, the induced climatic changes would develop meta-chronously in different areas, depending on such factors, as latitudes, the ocean/continent situation, the distance to permanent ice-caps and albedo.

The ecological processes typical of an interglacial cycle were expressed by Iversen (1958) as a simple model of four phases, described for north-west Europe, but valid for central Europe as well, which can be shortly characterized as follows:

#### CRYOCRATIC PHASE

which is an initial phase in vegetational development. The climate is still cold, dry and continental. The pioneer open herb vegetation includes arctic-alpine and steppe elements and also ruderal plants. The soils are shallow, skeletal and basic.

#### PROTOCRATIC PHASE

starts with a rapid rise in temperature. The insolation is high, and climate very continental, differing from recent climates by different temperature, precipitation and circulation patterns, and different seasonality. The great vegetational succession commences. The light is ample, so many shade-intolerant herb, shrub and tree species of very diversified affinities immigrate and, they because of abundance of space and nutrients, expand rapidly forming species rich grasslands, shrubs and open woodlands. The competition is still low. The soils are fertile, unleached, with a low humus content.

#### MESOCRATIC PHASE

The climate was similar or warmer than in the protocratic phase, with a high insolation causing high summer temperatures, and metachronous. The thermic optimum. The vegetation was characterized by the development of mixed deciduous forests dominated by shade-demanding and shade-tolerant species, and by the high and continuously increasing competition eliminating the light demanding plants. The dominant soils were mature, fertile, rich in humus, e.g. brown soils.

#### TELOCRATIC (SENSU IVERSEN 1958), OR OLIGOCRATIC (SENSU ANDERSEN 1964) PHASE

It is the last, retrogressive phase of an interglacial cycle. Inversen (l.c.) tried originally to explain its development by the temperature fall as an initiating factor. However, Anderson found out that the deterioration of soil conditions, proceeding

independently from the temperature decline was the primary factor for this change. The change of climate used to happen definitely later within the phase and involved undoubtedly also the increase of humidity. Due to the progress of leaching processes the soils become infertile with the abundance of raw acid humus resistant to decomposition. This in turn caused the gradual elimination of nutrient-demanding mesocratic vegetation, and development of oligotrophic open forests with dominant conifers (mainly *Pinus* and *Picea*), and some less demanding deciduous trees (e.g. *Quercus robur*, *Betula*).

The above-described natural cycle of vegetational succession can be traced in detail in pollen diagrams from the interglacial sediments. The last Eemian interglacial shows in its duration and the sequence of vegetational development most similarities to the recent Holocene interglacial. The comparison of those two sequences is very instructive; it shows what could the natural Holocene succession be like if the interference of man, growing enormously in its importance since the later part of mesocratic phase, did not deviate and change the natural trends.

To understand what happened we should look at the climate-soil-vegetation relationships of the mesocratic phase in more detail (Fig.1). The protocratic phase of rapid, fast changes was quite short in the Holocene - no more than ca. 1000 years, and was not substantially longer, as correlations show, in the Eemian interglacial either. However, the mesocratic phase was rather long-lasting in the Holocene at least ca. 4000 years (ca. 9000-5000 BC). The Oxygen-isotope curves obtained from the ice-cores (Bradley 1985), as well as from the carbonate lacustrine sediments of Europe, including from Poland (Róžański 1987; Fig.2), show that the main rapid temperature increase occurred already during the protocratic phase. According to the longest Polish sequence, the temperature may have reached values close to the maximum ones already by the end of the protocratic phase. Thus, the mesocratic phase developed, since its onset, in favourable climatic conditions.

The early mesocratic phase was characterized by animated migration processes of deciduous tree taxa coming from the refugia of different location. The time and areas of their expansion were the combined effects of many factors such as the distance from the refugium and the landscapes to cross, the individual migration rates and individual ecological attributes. The competition for space and resources, still rather low in this early phase, would gradually grow stronger, inhibiting the migration rates of more delayed taxa.

In different interglacial cycles these were different trees taking part in the earliest expansions. Predominantly, however, the moderately shade tolerant/light demanding and rather fast reproducing taxa like *Corylus*, *Ulmus*, but sometimes also *Quercus* species (Eemian), were first to spread during the early mesocratic phase. *Tilia* and *Fraxinus* migrations were usually slower, and expansions - later.



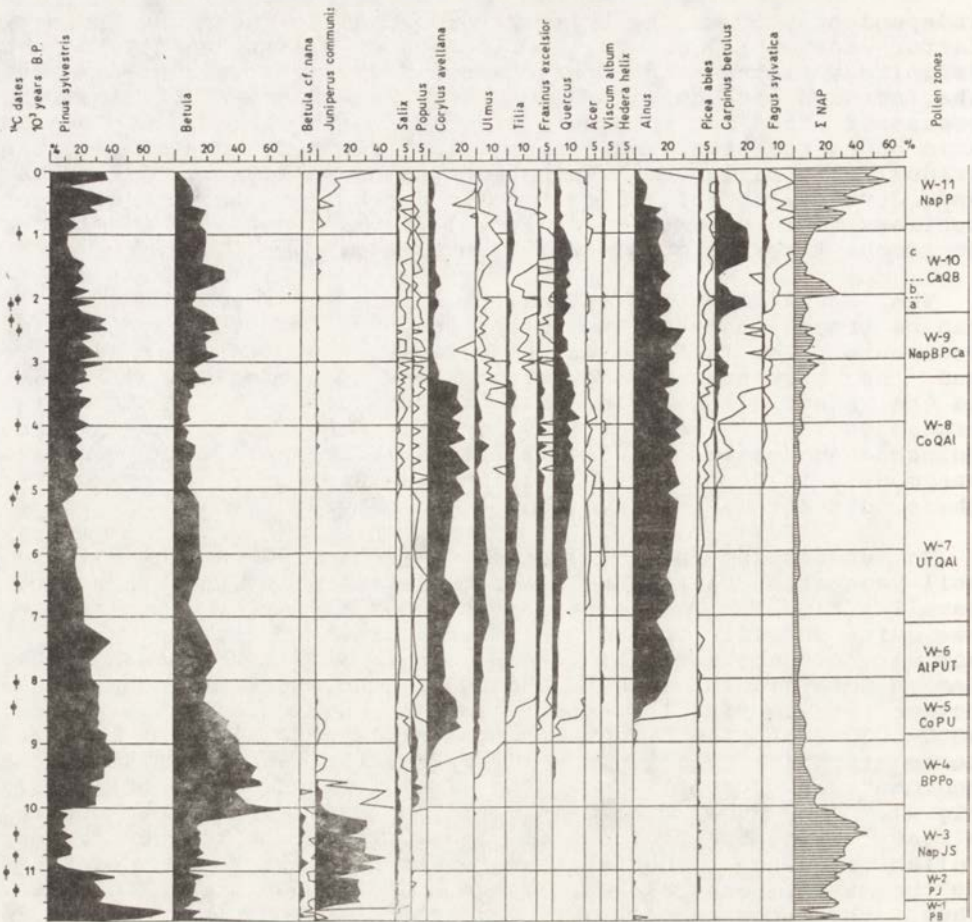


Fig.1 The simplified pollen diagram from Woryty, central lake districts of Poland, showing the typical holocene forest development (after M.Ralska-Jasiewiczowa 1989)

During the later mesocratic phase the central Europe was occupied by dense multispecies deciduous forests. There existed, of course, differences in the composition of forests in both, the regional scale, resulting from such factors as geology, climate, altitudes etc., and also the local scale, forming fine variation patterns and forest mosaics in response to soil - moisture and nutrient supply, local altitudes and exposures, and other phenomena like e.g. natural disturbances by storms, disease or fire (Birks 1986). Such disturbance gave chance to the light-demanding trees, shrubs and herbs to form temporary populations within the prevailing dense forest of maximum shade,

formed by shade tolerant taxa only. Otherwise, the heliophilous vegetation was then confined to extreme habitats, such as dunes, cliffs, shallow stony soils, very steep slopes, gorges etc. In the above described way, the broad-scale competitive balance within the vegetation was formed.

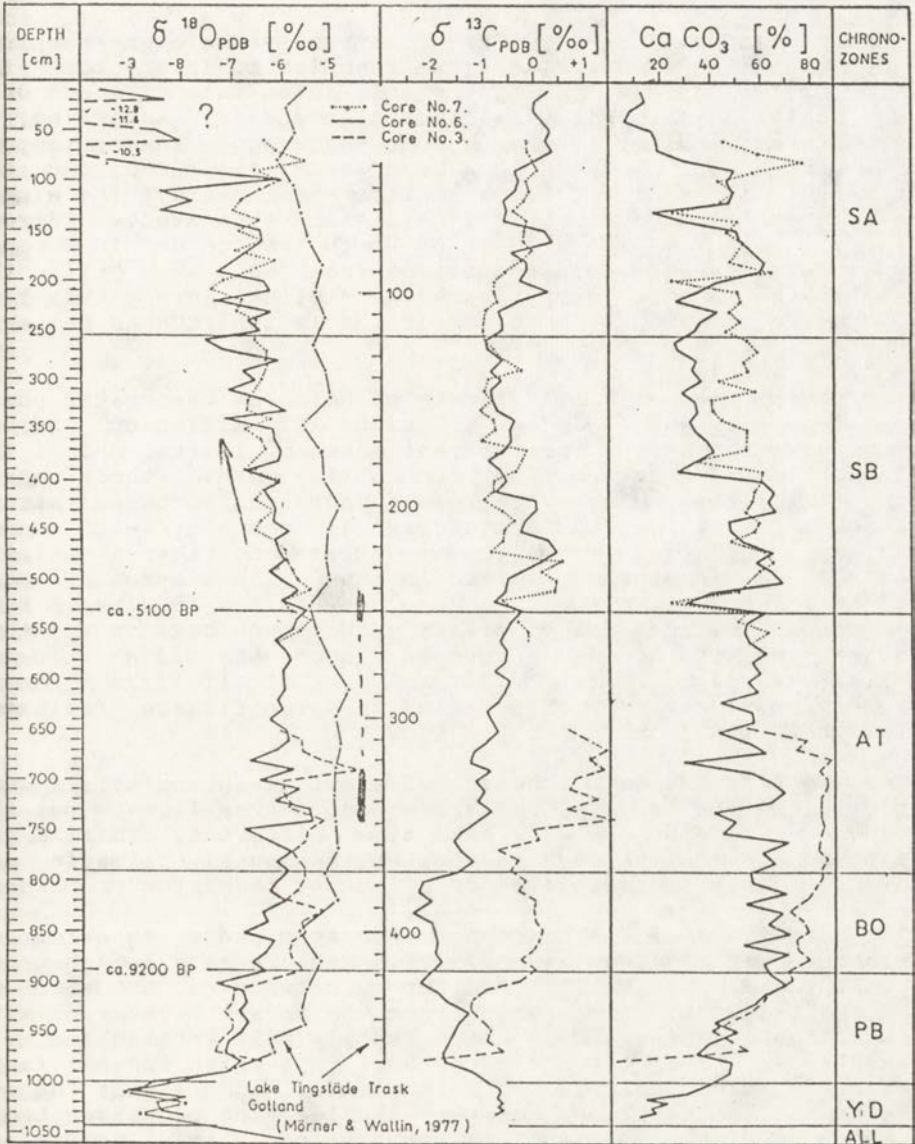


Fig.2 The  $\delta^{18}\text{O}$  curve from the carbonate sediments of Lake Strażym, central lake districts of Poland (after Różanski 1987)

What could be said about the climate of mesocratic phase? Our knowledge about past climates is still rather limited. Using as much of different independent evidence for changes of climate as possible is the only way to improve it. The data coming from a stable isotope, fluctuations, lake level changes, shifts of the forest limit in the mountains and in the far North are of a great help here.

The multidisciplinary COHMAP (Cooperative Holocene Mapping) Project operating in North America attempted to infer about the past climatic changes using the well-dated paleoevidence on a global scale and paleoclimatic simulation models. According to their reconstructions, around 6000 years ago, summer temperatures were higher by 2-4°C than at present time throughout the continental interiors of North America and Eurasia. The winter temperatures might have been 1-2°C higher than today. Strong westerlies blew in the Midwest of North America and in Europe. They gradually weakened in the period from 6000 yrs till the present; the summer temperature is declined during that time too, due to the reduction in summer insolation (COHMAP Members, 1988).

The warmer (and milder?) climate of Holocene mesocratic phase is documented by the finds of remnants of different thermophilous taxa far beyond their recent northern limits, and of the lowland taxa, (or even plant communities) above their recent altitudinal limits. There has been found, for instance, strong evidence for a typical lowland alderwood community with *Alnus glutinosa*, *Calla palustris*, *Carex elongata* and other associated species being widespread on mires in the Polish Bieszczady Mts. up to at least 700 m a.s.l. between ca. 800 and 4500 years B.C. The accompanying presence of plants growing nowadays on a rather moist lowland with deciduous forests, such as *Tilia cordata*, *Rhamnus cathartica*, *Hedera helix*, and most of all *Vitis vinifera* ssp. *sylvestris* is of a similar significance (Ralska-Jasiewiczowa 1980).

The mesocratic warm phases of previous interglacials were characterized by broadly similar deciduous tree flora, but the sequences of assemblages were each time different. This might have been caused by various reasons—environmental, climatic, and also those connected with factors affecting migration processes.

The actual end of the Holocene mesocratic phase, as evidenced by changes in pollen assemblages, appears as a metachronous process progressing in temperate Europe between ca. 5500-5000 BC and ca 2500-2000 BC. It started from the forest vegetation with the maximum denseness, built up on fertile well aerated and well drained soils, most often of brownsoil type, rich in soil fauna contributing vigorously to the soil mixing and litter decomposition. With the time, however, the leaching processes began and advanced; the upper soil layers, being slowly acidified, developed an iron pan; the soil fauna declined; all the typical podsolization processes—advancing more and more—contributed to gradual elimination of such trees as *Tilia*, *Ulmus*, *Fraxinus*. As



the first retrogressive stage, the more open forests with the dominance of *Quercus* and *Corylus* were formed. Later, *Carpinus*, *Fagus* and *Picea* expanded on habitats of mesocratic deciduous forests, and finally *Pinus* and/or *Betula* become the dominant trees.

The oligocratic retrogressive phase of the Eemian interglacial involves the decline of *Ulmus*, *Fraxinus*, *Tilia*, *Quercus* and *Coryllus*, and expansion of *Carpinus*, later *Picea* and *Abies*, and finally of *Pinus* and *Betula* forests (Mamakova 1989).

The complexity of the whole change is still not perfectly understood. The soil retrogression might have advanced independently from the climate deterioration, but the reduction in summer insolation, temperature decline and rise in humidity certainly contributed to, and accelerated the environmental changes.

However, the natural trends in vegetational succession of Holocene retrogressive phase become influenced by an additional factor growing more and more in its importance since ca 6000-5000 BC. This factor was the development of human settlements.

The first recognizable episodes of human interference into the natural environment, connected with the spreading of Neolithic cultures coincided with the beginning of retrogressive succession. These were clearings made in the dense deciduous forest cover, by ax and fire (slash and burn techniques), the deforested land to be used for a short-term cultivation and grazing. *Corylus* was probably coppiced to get nuts, and so were some trees like *Ulmus* and *Fraxinus*, the leaves of which were suitable for feeding cattle. These practices created areas of open forest and scrub forest and used harvesting and grazing. Burnt uncultivated places were soon overgrown by pioneer trees like *Betula*, *Salix*, *Populus tremula*. These activities resulted in the formation of habitats with a disturbed ecological equilibrium. At the early stages of human interference the disturbances were local and short-lived; the succeeding regeneration of deciduous forest, proceeding rather quickly, involved mostly trees typical of mesocratic phase, like *Tilia*, *Fraxinus*, *Quercus*. Most probably the long discussed definite decline of *Ulmus* participation in deciduous forests of Europe around 5000 BC might have been partly connected with human activities in combination, however, with some other factors (?), most probably. Dutch elm-disease, (Rackham 1980, Groenman-van Waateringe 1983).

The later development of more permanent land-use practices, like cultivation with the use of ploughing, breeding of large animal herds, which needed the extensive forest clearances, resulted in larger-scale and deeper changes in natural forests. The vast and long-lasting opening in forest cover changed the regeneration balance between particular tree species. The natural processes of soil degradation were accelerated by changes in vegetation-litter-humus type, the hydrological balance of

ground water was disturbed by changes in evapotranspiration. All those changes gave stronger chance of spreading to the new tree species, better adapted to the changed soil conditions. *Carpinus betulus*, *Picea abies* expansions were basically equivalent to the corresponding expansions during the interglacial (e.g. Eemian) oligocratic phases, though their development was distinctly connected with the cultural history of invaded areas (Ralska-Jasiewiczowa 1983). However, the migration of *Fagus sylvatica* across the lowland Europe was probably possible only due the creation of large openings on areas formerly occupied by mixed deciduous forests. This expansion does not find an equivalent in the interglacial successions. Other types of secondary forests unknown from interglacials developed as well.

With the time, however, those new forest types became also endangered by man too. A new, cultural landscape with the dominance of totally deforested areas has been created. The invasion of plant taxa typical for the oligocratic and even for protocratic phase progresses in response to the advancing soil degradation. However, man started attempts at influencing those processes using first natural, then artificial fertilizing, which created completely new, unbalanced conditions. The ecological equilibrium is thus more and more disturbed.

I am not going to discuss this situation in more detail, as it was not to be the subject of this paper. Now I would like to end by raising a question: by the comparison with the previous interglacial cycles we can clearly see from both the vegetation/soil development, and also from the advanced age of our holocene interglacial where we should now be within the interglacial cycle. We have advanced already by ca 5.000 yrs since the decline of the mesocratic phase. If we take, as shown by newest datings, the duration of the Eemian being ca 12.000 years, or at least much less than 20.000 years, we should be approaching now the decline of oligocratic phase. And due to all the global human activities, the greenhouse effect, and what not: where are we now within the interglacial cycle??

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## VEGETATION OF INDUSTRIAL CENTRES UNDER PROSPECTIVE CLIMATE CHANGE

Erich WEINERT\*

### INTRODUCTION

Safeguarding the planet we share, human beings have nowadays, in general, a greater awareness about the planetary problems, such as a conjectured global warming of the biosphere, the greenhouse effect, depletion of stratosphere ozone, acid rain, and deforestation. A prerequisite for a global warming may be constituted by an increase of 3.5 - 4.2°C by the middle of the next century (Kerr 1986). That would mean a general shifting of the temperature zones in direction to the poles on the continents; it is going to be reflected by a change of the global atmospheric circulation, the wind system, interactions between oceans and atmosphere and the precipitation patterns accordingly at a global level. Even when the climate change proceeds slowly, a successive change of distribution patterns of the vegetation, the plant and animal species, for instance, in the northern hemisphere seems to be inevitable. In case of changes of the environment plant behaviour provides a relative sensitive and responsive criterion for a global change. Although the mechanisms which connect climate and vegetation are poorly understood, so far, general observations prove that variations in climate can influence the constitution of vegetation and therefore control plant distribution.

### CLIMATE CHANGE AND PLANT RESPONSE

Amplitude and period of climate change, in particular, are critical for the change of vegetation affecting plant distribution. But not all changes in plant distribution were due to lethal threshold effects, some were also due to non-lethal threshold effects, whereas others may have been competitive as result of alterations in ecological amplitudes. We agree with Woodward (1987), who emphasized that in order to investigate the

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climatic control of taxa distribution it becomes necessary to divide the life of a plant into a number of stages, each of which constitutes a link in the chain of survival, and each of which can dominate the control of distribution.

If an increase of temperatures in the temperate zone of Central-Europe should take place by several degrees centigrade during winter and summer, it would be a reason for the migration of a bulk of thermophilous plant species from the Mediterranean and Oriental-Turanian regions to the north and for a considerable change in the constitution of vegetation types in Middle Europe. Potentially harmful impacts from climate change are also to be expected for the European boreal forests.

Industrial centres as areas with a variety of anthropogenic influences in Central-Europe are established within the framework of the native vegetation complexes. They are mainly surrounded by significantly changed vegetation types: these are secondary plant communities due to the prevailing industrial environmental conditions. Sites of Central-European industrial centres often are located close to main rivers, such as Rhine, Ruhr, Elbe, Saale, Oder/Odra, Wisla, Danube, and their tributaries, because of the necessity of the availability of sufficient water supply, where riverine ash-elm forests (*Fraxinus excelsior*, *Ulmus* spp.) and on the adjacent hills the zonal broad leaved oak and beech forests (*Quercus* spp., *Fagus sylvatica*, *Carpinus betulus*) represent the native or primary vegetation. These forest communities are often substituted by anthropogenic or secondary ruderal plant communities with many thermophilous weeds from southern Europe, Eurasia, and North America.

Although affected by industrial stress and pollution by industrial dust, smoke, steam, these riverine forest ecosystems appear to be relatively stable due to resilience of their trees, shrubs, and herbs here in existence. The local warming of industrial centres and towns in winter and summer has already resulted in a climatic gradient from the warmer centre to a less warmedge. In city centres of Central European towns we can recently find therefore a new establishment of thermophilous trees and shrubs, such as *Ailanthus altissima* populations stemming from the meridional zone of SE.Asia and *Buddleja davidii* a. o. (see Kowarik & Böcker 1984, Klotz in Schubert 1985, Weinert 1985, Henke & Sukopp 1986, Müller 1987). Actually, the vegetation of industrial centres in Central Europe, as well as elsewhere in forest zones, is dominated by nitrophilous trees, shrubs, perennials and, in particular, annuals which appear to be well adapted to the stress and nutrient conditions in the neighbourhood of industrial settlements where they build up different kind of ruderal communities.

Competitive shrubs in European industrial areas are nowadays the nitrophilous *Sambucus nigra* (Fig.1), *Robinia pseudoacacia* and *Lycium barbarum* which are accompanied by several nitrophilous perennials and annuals as weeds. *Sambucus nigra*, a shrub of the European mixed deciduous forests on nutrient-rich soils

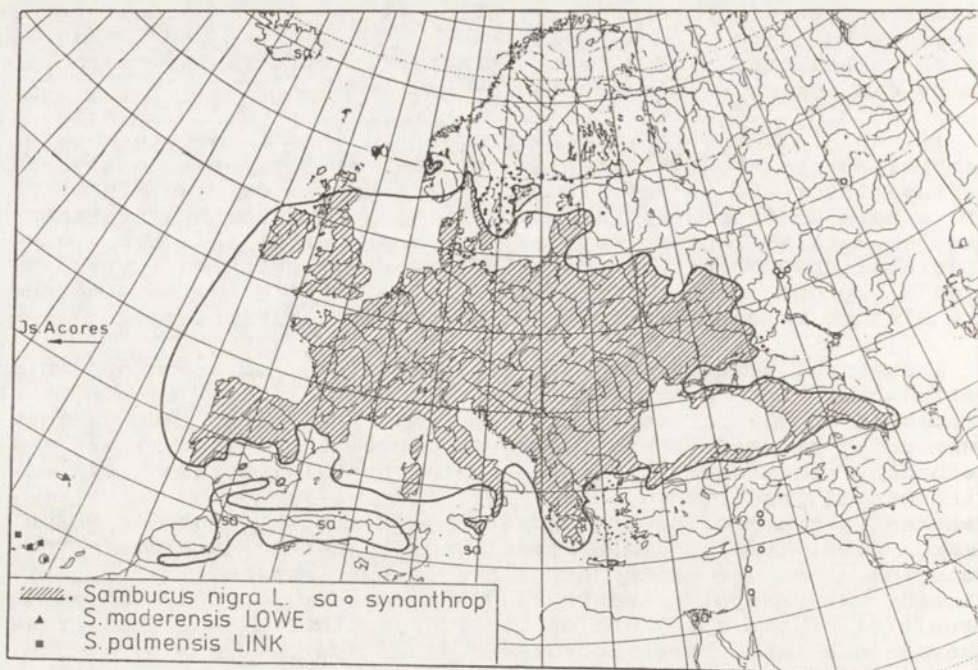


Fig.1 The total distribution of *Sambucus nigra* L. and related species. After Meusel, Jäger, Weinert ms. modified.

with an actual total distribution from the Mediterranean region to the Baltic Sea in the temperate zone, displays a wide range of distribution; it is dispersed easily everywhere in Europe by endozoochory of birds and it has a relatively large ecological range. A general prospective rising of the temperatures by several degrees will also further enable this shrub to grow predominantly on our Central-European industrial centres.

A similar behaviour can be assumed for the nitrophilous perennials, such as *Calamagrostis epigeios*, *Solidago canadensis*, *Lolium perenne*, *Urtica dioica*, *Ballota nigra*, *Artemisia vulgaris*, *Tanacetum vulgare*, which are prevailing species in ruderal plant communities on ± stabilized habitats along industrial buildings, walls, fences, trails of tubes, pipelines, and roads. *Calamagrostis epigeios* (Fig.2), for instance, grows from the meridional to the boreal zones in Eurasia, even far reaching into the steppe and desert area of the continent, and it occupies a wide ecological range from taiga forest communities to broad leaved deciduous forests up to garbage places near human settlements and industries. The growth form of this perennial rhizomatous grass provides this species with a high competitive (aggressive) capability to occupy vast extents of dust polluted industrial plains near buildings, roads and on rubbish deposits



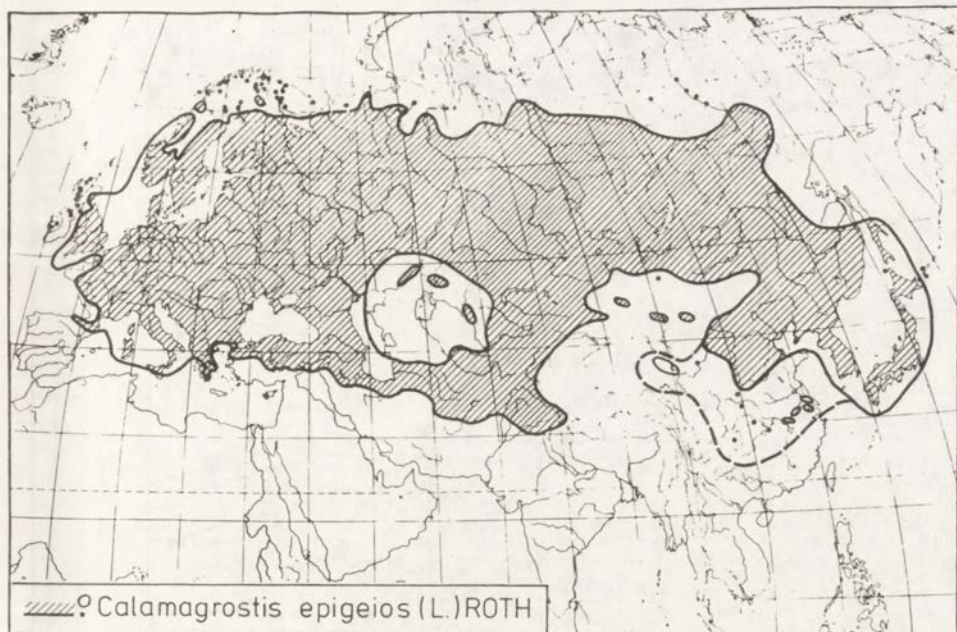


Fig. 2 The total distribution of *Calamagrostis epigeios* (L.) Roth. After Meusel, Jäger, Weinert 1965, Hultén & Fries 1986 a.o. modified.

("industrial steppe community"). Due to its wide ecological amplitude, even to the heat and drought stress resistance, it can be expected that *Calamagrostis epigeios* will not vanish when air temperatures will rise generally by a few degrees in industrial centres. Similar reactions might be expected for *Diplotaxis tenuifolia*, a common perennial herb with a deep reaching taproot on the open fields and along rail roads, streets and footpaths in dust polluted industrial areas (Fig. 3, Weinert 1981).

With the destruction of native vegetation, the flora changed and better adjusted, mainly annual neophytes get introduced and immigrate either with or without the assistance of man. Most of the present-day neophytic flora spreads best in cities and industrial areas, whereas many archaeophytes, which migrate as field weeds, have a better access to rural areas (Henke & Sukopp 1986).

Industrial centres in Central Europe are nowadays occupied by a set of ruderal plant communities particularly composed of annual neophytes, as *Atriplex* spp. (*A. nitens*, *A. tatarica*, *A. oblongifolia*, *A. patula*), *Salsola kali*, *Kochia scoparia* subsp. *densiflora*, *Oenothera* spp., *Cynodon dactylon*, and *Galinsoga* spp.

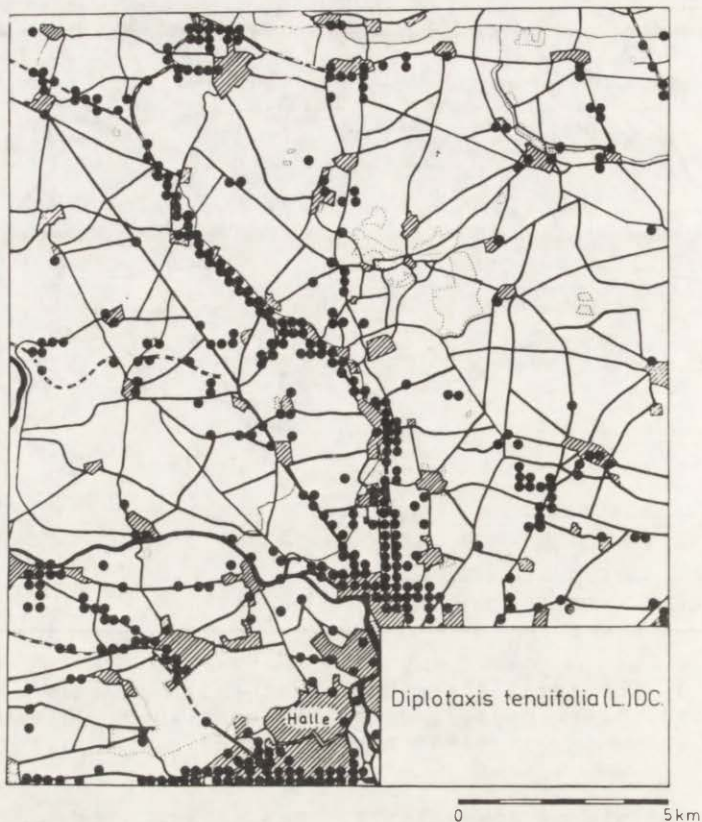


Fig. 3 The distribution of *Diplotaxis tenuifolia* (L.) dc., a neophyte since 1768, in the northern surroundings of the industrial city of Halle (Saale). Occurrences are concentrated along dust polluted traffic roads, railroads and around dusty industrial establishments. After Große in Weinert 1985.

*Atriplex nitens* (Fig. 4,5), an annual neophyte originated from SW. Asia with an aralocaspian-pontic-pannonian main distribution pattern, displays the tendency to migrate further to the west into the industrialized districts of Central and Western Europe. Its growth is confined to open, low competition habitats, such as freshly deposited garbage or rubble places close to human settlements and industrial establishments. The ample range of its distribution reveals its ecological ability to adapt to meridional and temperate climatic conditions. Warmer local climate favours the growth of this annual weed, even warmer industrial ruderal habitats with newly deposited rubbish and rubble will not affect the development of an *Atriplicetum* nitentias, when on the other hand enough water for



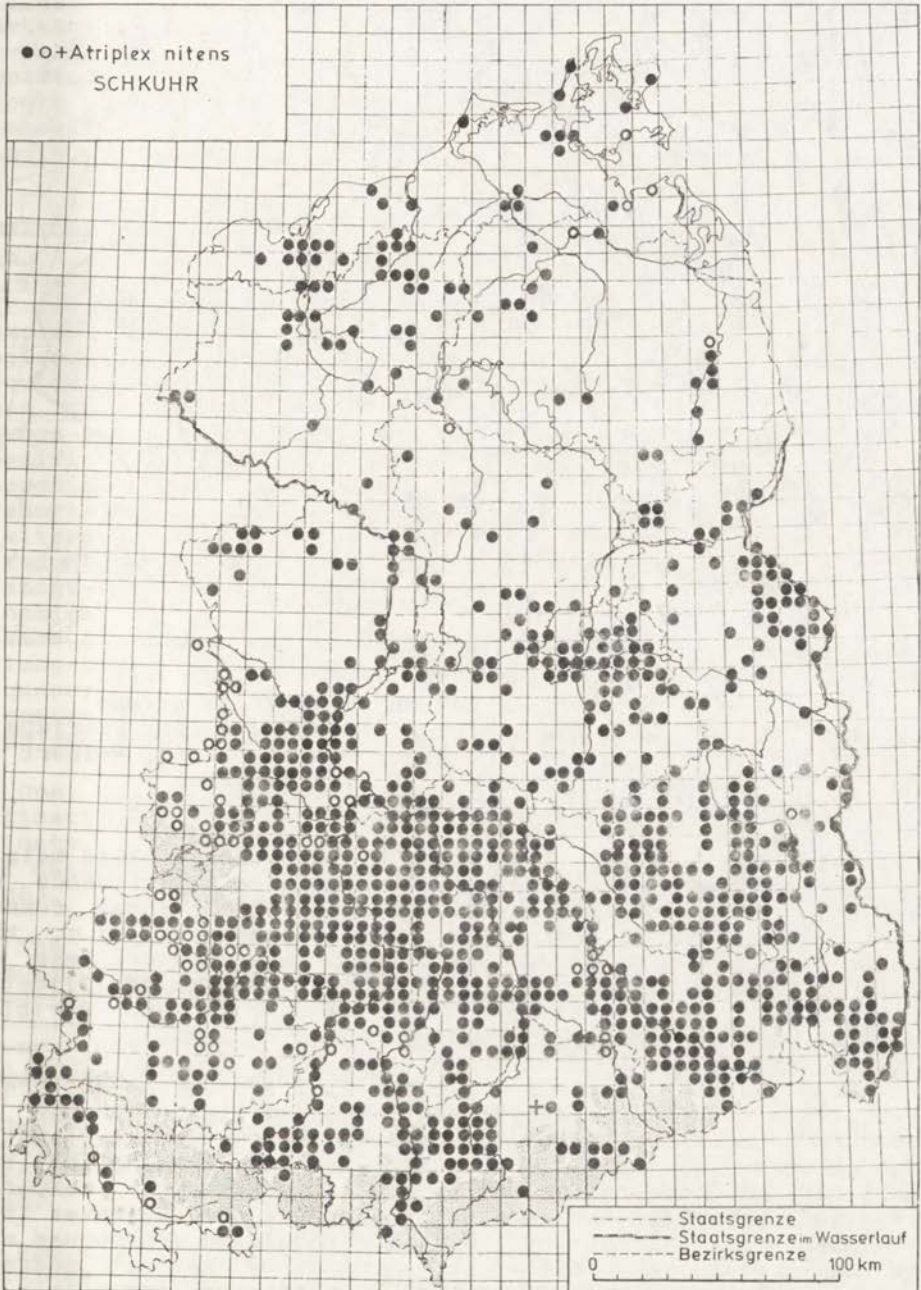
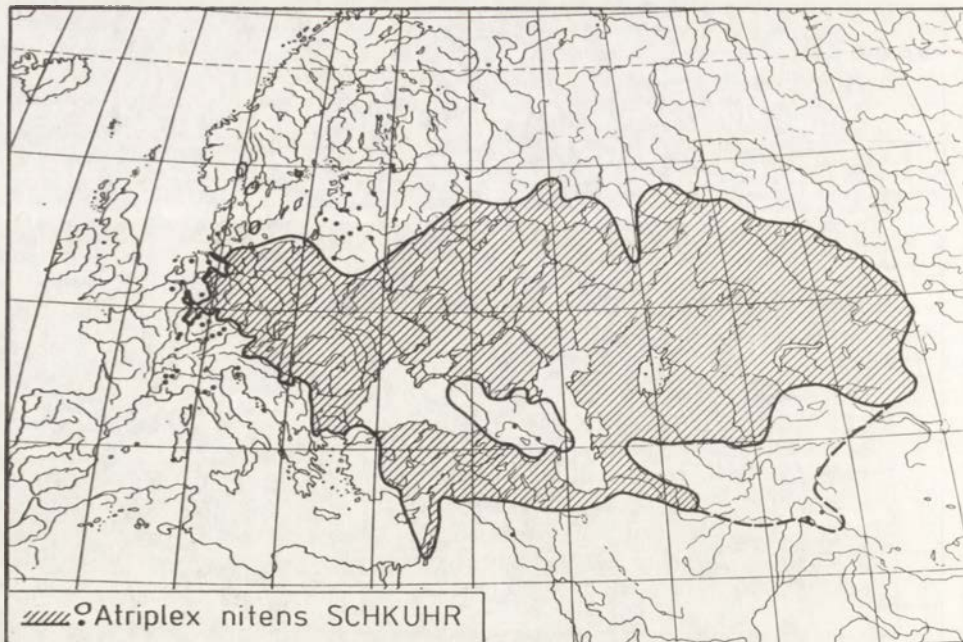


Fig.4 The distribution of *Atriplex nitens* Schkuhr on the territory of GDR with highest frequency of occurrences in the most industrialized parts of the country. After Weinert 1985.





**Fig.5** The total distribution of *Atriplex nitens* Schkuhr. In SW. Asia the distribution of *A. nitens* overlaps with that of *A. aucheri* Moq. After Meusel, Jäger, Weinert 1965, Hultén & Fries 1986 a.o. modified.

germination and growth is available. Climate change based mainly on a increase temperature may have a significant influence on vegetation and plant distribution. But forest and shrub communities in the riverine areas near industrial centres, e.g. the *Fraxino-Ulmetum* and *Aegopodio-Sambucetum*, are more or less of higher stability than weed communities, such as *Atriplicetum nitentis*, *Lolium perenne-Diplotaxis tenuifolia* and *Atriplex tatarica* - communities along roads.

A key question of today is, how will ecosystems and their vegetation - also in industrial centres and cities - change in response to possibly speeded up prospective changes of climate. Those changes might be induced by accelerated burning of the fossil fuel and biomass leading to higher atmospheric temperatures and injecting carbon dioxide at unprecedented rates into the atmosphere (cp. Huntley 1988). The resulting greenhouse effect that produces a predicted net warming by several degrees centigrade during the next century - an increase comparable to that experienced since the last Ice Age - together with variations in precipitation patterns is important for alterations of biotic stocks and productivity, composition of plant commu-

nities, and it will be reflected in a change of distribution patterns of plants and animals also in the industrial centres. We also have to take into account a change of the ecological amplitude for various species of plant communities due to warmer growth conditions which may lead to an alteration of the species composition and to a shifting of the range of distribution of single plant species.

#### MONITORING OF FLORAL AND VEGETATION CHANGE

The prediction of plant response during and after the change of climate seems to be very sophisticated because it is a complex phenomenon. The actual knowledge of growth strategies, life cycle and phytogeographic behaviour of plants provide us with tools for assessing the environmental change, when applied on a regional base (RRC). Prospective climatic change will be modified in industrial centres and cities due to specific thermostress and pollution effects but may be recognized by:

- short-term and long-term reactions by changes in growth and alteration of the distribution pattern of plants (extinction, reduction, migration, invasion, abundance, expansion),
- short-term and long-term alterations of the species combination in plant communities (reduction of diversity, appearance of new and/or invasive neophytes),
- long-term evolutionary response in morphology, gene frequency and autecology of plant populations resulting in more competitive and adaptive ecotypes (mutation and selection, polymorphism, polyploidy).

One of the numerous parameters to measure for the identification of Global Change ought to be the plant response on climate change, both in time and space, as a principle source for detecting the factorial change in the environment (Weinert 1986).

The Report of the Earth System Science Committee NASA Advisory Council (Anonymous) 1988 proposed for cases of sustained long-term measurements of variables important for the study of global change the use of greenness as an index of vegetation cover. A long-term, global scale time series of this vegetation index should be undertaken, apart from research efforts, in a variety of locations in order to establish correlations of this index with other significant variables at a regional level, as mentioned above, to be able to establish a basic understanding needed to design the measurement technique adequate for the task.

For the investigation of global change industrial centres as well as other human settlement areas deliver only local or regional signals modified by their own, inherent prevailing factors, however, a visible change in the floristic composition of the actual vegetation provides parameters for assessing the condition of the environment and for predictions at a regional

level. The calibration of these parameters will be achieved by a parallel analysis of adjacent representative biosphere reserves with their core zones or the strict nature reserves (s. MAB activities), and a comparison of the results of these test zones with those of industrial sites.

## CONCLUSIONS

The biomonitoring of geo-biospheric processes, in temporal and spatial range, by observation, registration and/or mapping in industrial centres, could be focused on:

- areal reduction and distribution change of sensitive plants,
- invasion of competitive (aggressive) neophytes and the response of native vegetation,
- fluctuation in the diversity of plant communities.

Check-lists of sensitive indicator plants for various stress factors in industrial centres, of the pool of potential invasive neophytes and of indicator plant communities for human-made habitats, could facilitate bio-indication of global change in regard to its part in urban and industrial environment.

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## THE UPPER SILESIA REGION AS AN AREA OF ECOLOGICAL CALAMITY

Andrzej T. JANKOWSKI\*

The Upper Silesia region lies in the southern part of Poland. This is the most industrialized and urbanized part of the country. It is situated in the Katowice province. In 1987 there were 3971 mln of inhabitants, that was 10.5% of the whole country population, in the province, which covers 6650 sq. km, that is 2.1% of the whole country area. Over 3,4 mln of people lived in towns (87.7%) in that province at that time when the average for the country was 60.9%. These data are a proof of an intensive urbanization.

Such a great number of people living in towns causes a very high coefficient of population density. That coefficient was 597 pers. km<sup>2</sup> in 1987, the average for the country was 121 pers. km<sup>2</sup> 20% of the country industrial production comes from the province and it is even higher in certain products. 100% of lead and zinc ore is processed in the province: 98.1% of coal, 53% of steel, 46% of rolled products, 34% of coke and 24% of energy comes from this area. There were 2798 industrial factories in this province in 1985, i.e. 7.7% of the total number of factories in the country. In 1987, 232 factories working in this area were extremely burdensome for the environment, mainly due to air pollution. The total number of such factories in Poland was 1364.

High concentration of industrial production, and in many cases old technologies, are the main reasons of immense emission of dust and gas pollution, large amount of industrial and municipal wastes and an increasing degradation of the area which needs recultivation and land development.

The degree of urbanization and industrialization is not the same in the whole province. A few regions of distinctive anthropopressure can be distinguished in the area (Jankowski, 1987 - Fig.1.

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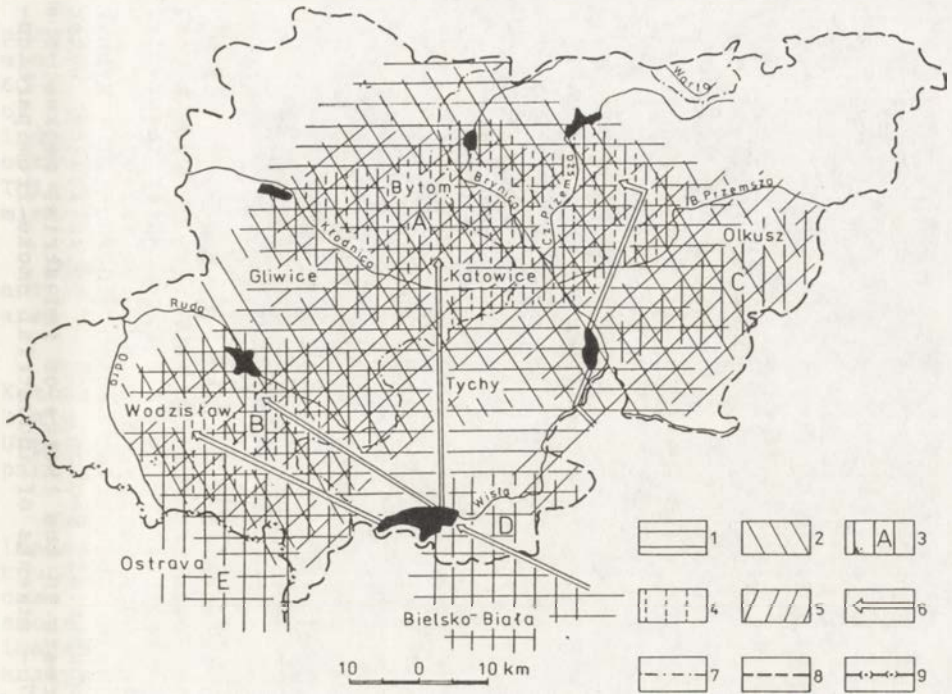


Fig.1 Upper Silesian area of anthropogenic changes of the environment

- 1 - area of intensive anthropogenic changes of the ground
- 2 - area of excessive air pollution
- 3 - industrial regions: A - Upper Silesia Industrial Region (GOP), B - Rybnik Coal Region (ROW), C - Olkusz-Chrzanów Industrial Region, D - Bielsko-Biała Industrial Region, E - Ostrava-Karvina Industrial Region,
- 4 - areas of compact settlement
- 5 - area of distinctive decrease in water resources caused by mining
- 6 - main directions of water outflow
- 7 - watershed dividing the Odra and the Vistula catchment areas
- 8 - border of province Katowice
- 9 - bordery of country

The Upper Silesia Industrial Region (GOP) covers the central part of the province. This is the place where the biggest agglomeration in Poland is situated, it is sometimes called Upper Silesian agglomeration or Upper Silesian conurbation. The agglomeration consists of 15 strictly connected towns. It covers approximately 1500 sq. km. Density of population is the highest in Poland (e.g. in Świętochłowice up to 4672 pers. km<sup>2</sup> and in Chorzów 4176 pers. km<sup>2</sup>). Anthropogenic factors have been influencing the environment here since XIII century.



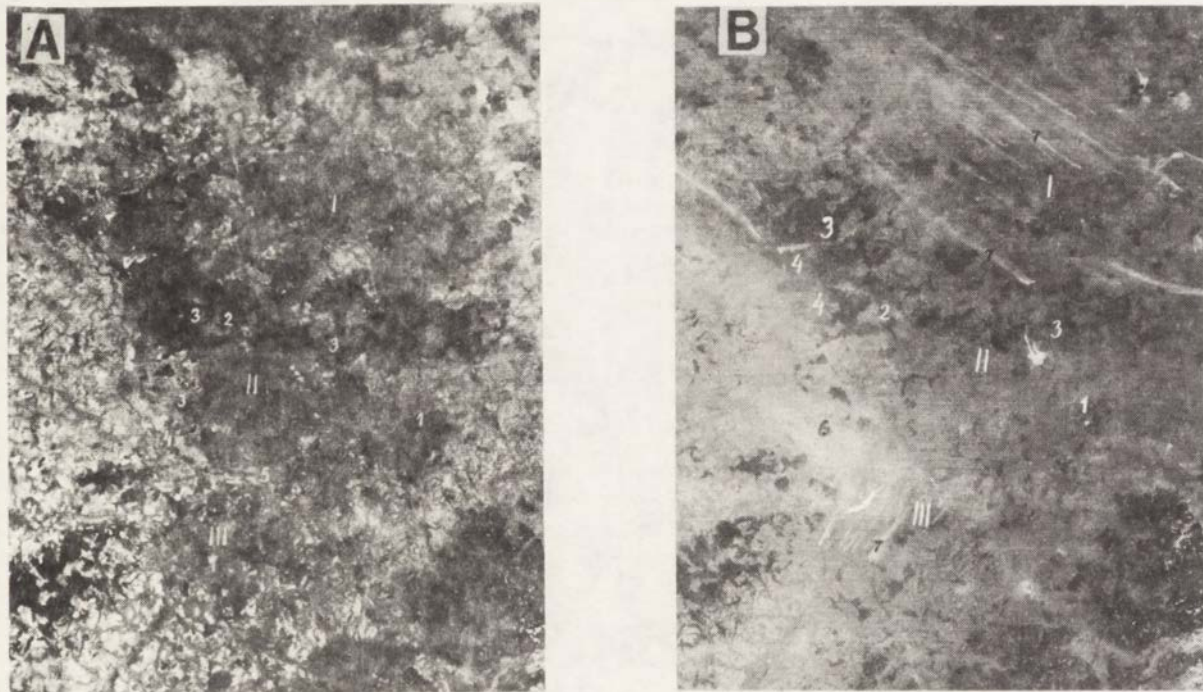


Fig.2 Highly industrialized areas in satellite images of Landsat:

A - 1 April 1978, channel 5: I - Upper Silesia Industrial Region (GOP), II - Rybnik Coal Region (ROW), III - Ostrava-Karvina Industrial Region, 1 - Goczałkowice water reservoir, 2 - Rybnik water reservoir, 3 - forests, 4 - the Odra valley, 5 - the Olza valley;  
 B - 2 November 1973, channel 4: I - Upper Silesia Industrial Region (GOP), II - Rybnik Coal Region (ROW), III - Ostrava-Karvina Industrial Region, 1 - Goczałkowice water reservoir, 2 - Rybnik water reservoir, 3 - forests in the limits of industrial smokes, 5 - large sand excavations, 6 - the Odra valley, 7 - streaks of industrial smoke from particular chimneys-emitters.

Rybnik Coal Region (ROW), situated in the western part of the province. Industrial activity there is dominated mainly by coal mining, which was commenced 150 years ago and intensified in the 60-ties of the century. The area covers 1000 sq. km, 600 sq. km of it show intensive signs of anthropopressure. Another industrial region is situated on the border of this region, outside the country, i.e. the Ostrava-Karvina Industrial Region. This is a Czechoslovakian region with heavy industry, mainly mining and metallurgy.

Olkusz-Chrzanów Region, the region of intensive influence of anthropogenic factors, which began in 15th century. This is an area of lead and zinc ore exploitation.

The last regions of intensive economy are the border areas of Katowice and Bielsko-Biala provinces. It is formed by Bielsko-Biala Industrial Region, which is in a direct contact with the Upper Silesia area, because of many economic concepts and as a part of Silesian water-economy system.

The above mentioned regions are very well visible in satellite images as distinguished dark spots when compared with the surrounding areas, despite microclimatic conditions (Fig. 2A). In case of continuous winds of constant direction, long lines of smoke from particular chimneys can be registered in satellite images (Fig. 2B). This distinguishable complex appears in all analysed images and canals. The phenomenon cannot be identified equivocally, however, anthropogenic factors it is probably influenced by. The darker complex corresponds with the described by Landsberg (1983) "municipal heat island" or by J.G. Lockwood (1984) "a climatic cupola" over the urbanized area. High concentration of air pollution is also important.

The complex of miscellaneous factors influencing geographical environment in the distinguished regions is connected with economic activity of man. It has caused immense changes of geographical environment, referred to as ecological calamity. Although the beginning of anthropopressure here dates back to the 13th century, it has become especially intensive during the last fifty years. All the elements of geographical environment have changed, but changes of sanitary conditions of atmospheric air, hydrological conditions and surface of earth are especially significant.

#### CONTAMINATION OF ATMOSPHERIC AIR

In 1987, the annual emission of contaminations from factories situated in Katowice province to the atmosphere amounted to 390 thousand tons year<sup>-1</sup> of dust pollutions and 1505 thousand tons of gas emissions year<sup>-1</sup>, including 795 thousand tons of sulphur dioxide (SO<sub>2</sub>) and 439 thousand tons of carbon monoxide a year.

Table 1 shows dynamics of emission of contaminations, as well as levels of reduction in years 1975-1987. The data presented

here indicate that there was a slight decrease of emission of dust and gas contaminations into air during that period.

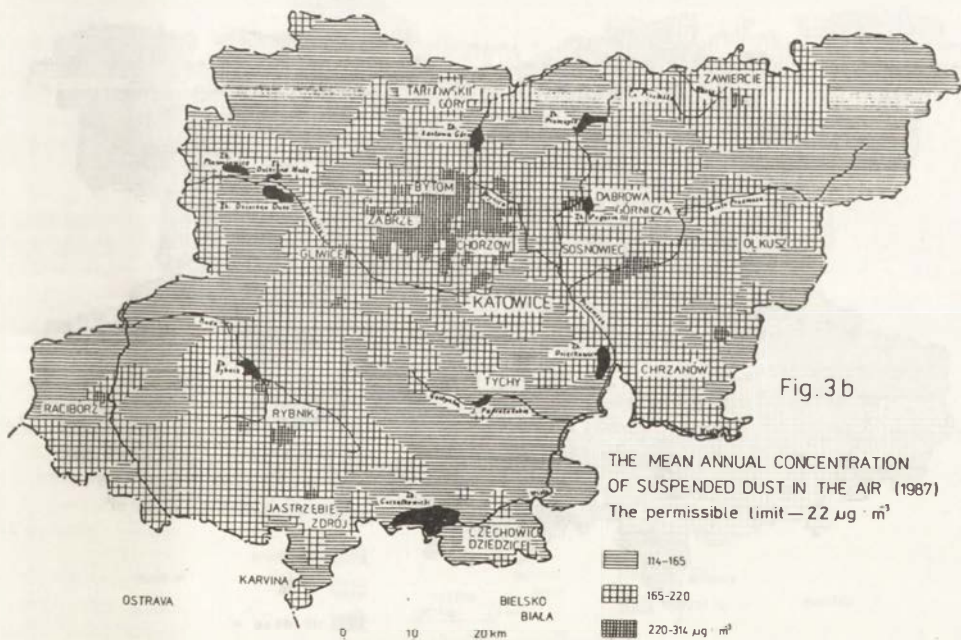
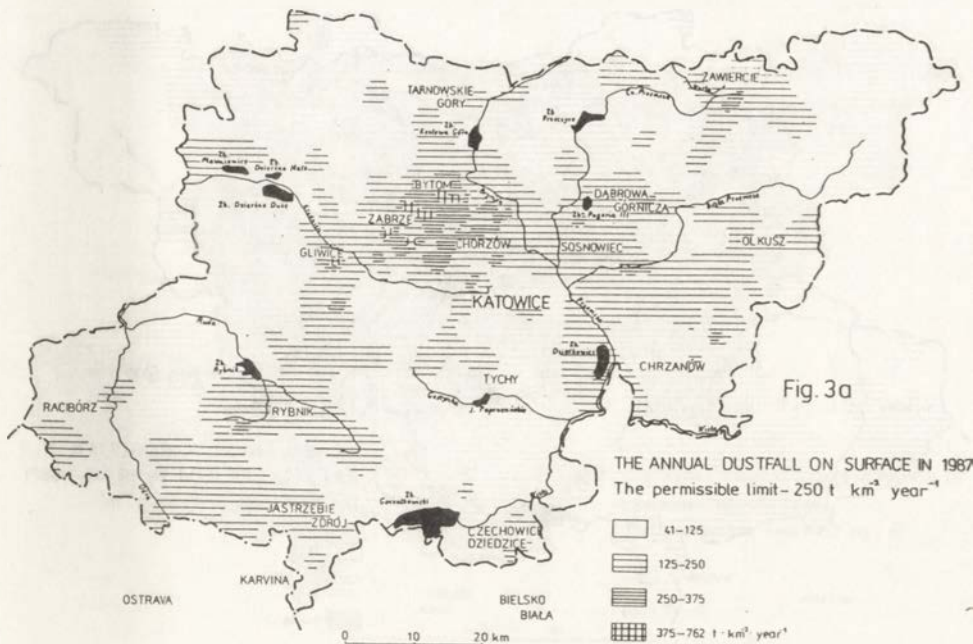
Table 1. Emission and reduction of industrial contaminations of atmospheric air in Katowice province (according to Rocznik Statystyczny (Statistical Yearbook..., 1988))

Specification	Katowice Province				Total in Poland 1987	Share of Katowice Province (in %)
	1975	1980	1985	1987		
Factories which are burdensome for air	193	192	227	232	1364	17,0
Emission of contaminations in thousands of tons:						
dust contaminations	611,7	637,5	453,9	390,1	1803,0	21,6
gas contaminations including: SO <sub>2</sub>	795,7	1776,2	1540,8	1505,2	5399,4	27,8
CO		953,3	778,1	795,8	2903,3	27,6
		745,4	462,1	439,6	1456,5	30,1
Contaminants deposited in instalations for reduction pollutions in thousands of tons:						
dust contaminations	4564,6	6961,9	6638,0	6555,4	29610,5	22,1
gas contaminations		66,6	106,0	113,2	764,7	14,8
Reduction level of produced contaminations in %						
dust contaminations	88,2	91,6	93,6	94,4	94,3	
gas contaminations		3,6	6,4	7,0	12,4	

The estimation of sanitary state of air in the Katowice province can be made on the basis of distribution of main indices of pollution of air. These indices, examined by the Sanitary-Epidemiological Station in Katowice are: dustfall, suspended dust, sulphur dioxide, carbon monoxide, nitric oxides, lead, benzo-apyren, formaldehyde, phenol (Fig. 3 a-h). Their contents are characterized by multiple exceeding of permissible norms. There are regions where summatic excess is almost by 100 times. The occurrence range of contents of main air pollution indices, in the sense of emission, in the area of Katowice province, is illustrated in Table 2. The reasons of such high contents of pollutions are great emissions of industrial contaminations, numerous home furnaces, as well as an inflow of contaminations from farther regions, also from abroad. It is confirmed by satellite images.

The consequence of air contamination by sulphur and nitric compounds are acid rains described in literature. Research on





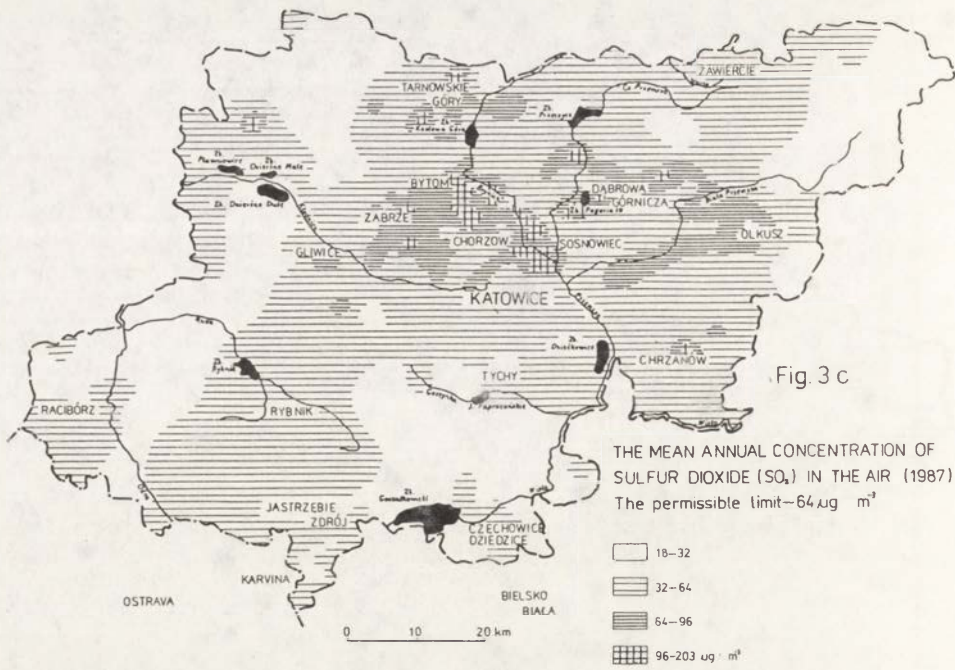


Fig. 3 c

THE MEAN ANNUAL CONCENTRATION OF SULFUR DIOXIDE ( $SO_2$ ) IN THE AIR (1987)  
The permissible limit— $64 \mu g \cdot m^{-3}$

- 18—32
- 32—64
- 64—96
- 96—203  $\mu g \cdot m^{-3}$



Fig. 3 d

THE MEAN ANNUAL CONCENTRATION OF NITROGEN OXIDE IN THE AIR (1987)  
The permissible limit— $22 \mu g \cdot m^{-3}$

- 58—88
- 88—110
- 110—169  $\mu g \cdot m^{-3}$

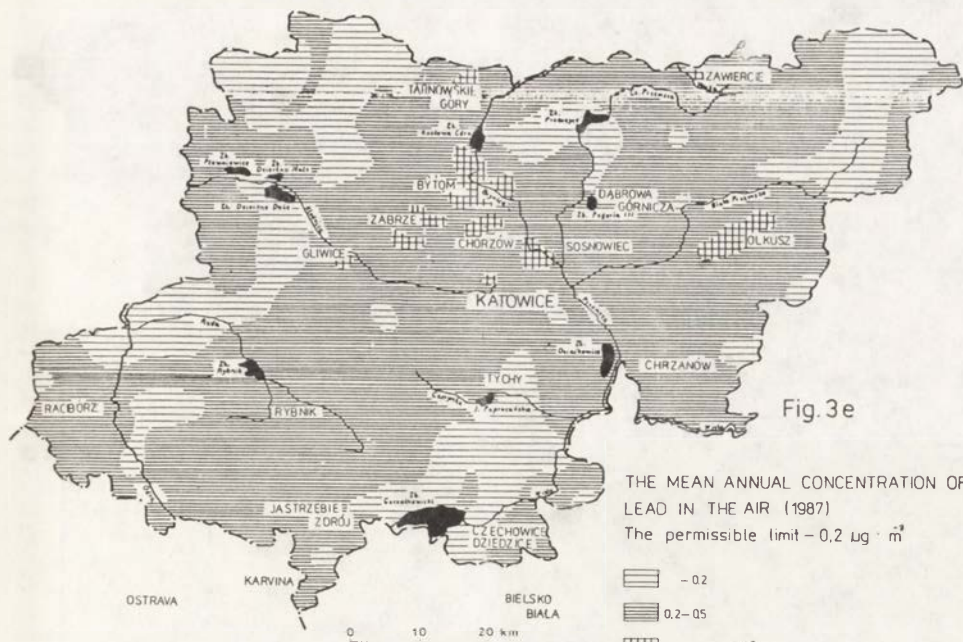


Fig. 3e

THE MEAN ANNUAL CONCENTRATION OF LEAD IN THE AIR (1987)

The permissible limit –  $0.2 \mu\text{g} \cdot \text{m}^{-3}$

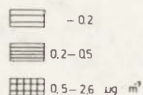


Fig. 3f

THE MEAN ANNUAL CONCENTRATION OF BENZO- $\alpha$ -PYRENE IN THE AIR (1987)

The permissible limit –  $10 \text{ ng} \cdot \text{m}^{-3}$

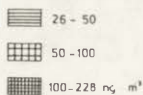






Fig. 3g

THE MEAN ANNUAL CONCENTRATION OF  
FORMALDEHYDE IN THE AIR (1987)  
The permissible limit –  $3,8 \mu\text{g} \cdot \text{m}^{-3}$

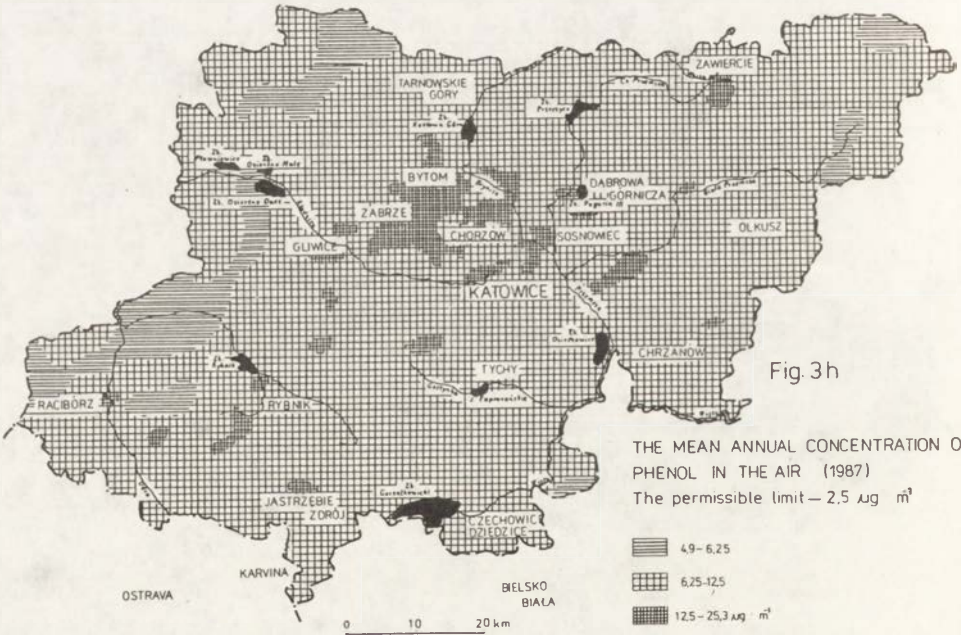
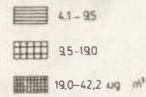


Fig. 3h

THE MEAN ANNUAL CONCENTRATION OF  
PHENOL IN THE AIR (1987)  
The permissible limit –  $2,5 \mu\text{g} \cdot \text{m}^{-3}$

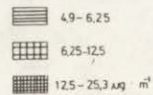


Table 2. Occurrence range of contents of main air pollutions in Katowice Province in 1987 (according to Contamination of Atmosphere ....., 1988)

Type of pollution	The highest permissible content in year	Occuring values of contents	Multiple of exceeding	Long-time trend
Dustfall	250 t.km <sup>-2</sup> y <sup>-1</sup>	41-762	0-3	remarkably decreasing
Suspended dust	22 µg.m <sup>-3</sup>	114-314	5-14	decreasing
Sulphur dioxide	64 µg.m <sup>-3</sup>	18-203	0-4	slight increase in recent years
Nitric oxides (N <sub>2</sub> O <sub>5</sub> )	22 µg.m <sup>-3</sup>	58-88	3-4	increasing
Lead	0,2 µg.m <sup>-3</sup>	0,2-2,6	1-13	decreasing
Benzo-a-pyren	10 ng.m <sup>-3</sup>	26-228	3-22	increasing
Formaldehyde (CH <sub>2</sub> O)	3,8 µg.m <sup>-3</sup>	4,1-42,2	1-11	constant
Phenol (C <sub>6</sub> H <sub>5</sub> OH)	2,5 µg.m <sup>-3</sup>	4,9-25,3	2-10	constant

this phenomenon is conducted by our Physical Geography Department. Although the amount of collected materials is too small to issue precise conclusions, it can be stated that the lowest average values of pH in rain water occur outside the central GOP area and amount to 4,8 - 5. However, there are infrequent instances when pH of rain water has acid reaction, namely 2,9.

#### SUBSTANTIAL FACTORS SHAPING WATER RELATIONS IN THE INDUSTRIAL PROVINCE OF KATOWICE.

Hydrological conditions of the Upper Silesia Region are characterized by the following specific features:

Silesian Highland constitutes a source field of majority of rivers discharging to Vistula and Odra. Those are short and narrow rivers, with small slopes, characterized by small water resources. The average runoff from the region of the province is 65 m<sup>3</sup>.s<sup>-1</sup>, that is 5,6 mln m<sup>3</sup>.d<sup>-1</sup>. This value calculated per 1 inhabitant corresponds to a daily outflow of 1,5 cu.m.; the average value in Poland is 6 m<sup>3</sup>.d<sup>-1</sup> per an inhabitant.

Intensive consumption of water for industrial and municipal needs on the area of the Upper Silesia agglomeration, lying in the watershed zone separating river basins of the Vistula and

the Odra, and therefore poor in disposable water resources, caused a very fast drawing out of available resources. Consequently, a permanent deficiency of water occurred. In that situation, the shortage of water has been and still is compensated by transfer of water from neighbouring draining areas, sometimes even distant ones, such as those of the Sola and the Skawa. In 1980 the amount of water transferred from the region of Bielsko was  $11,5 \text{ m}^3 \cdot \text{s}^{-1}$ . Up to the present moment this value has not diminished; on the contrary, it shows a growing tendency.

Industrial and municipal land development caused a significant restriction of infiltration of precipitation and extortion of outflow by municipal sewage system. Zmuda (1973) calculated that building caused almost a total lack of infiltration of rain water on an area of 30% of the Upper Silesia agglomeration. Because of that, losses in supply of underground waters are estimated at about 90 mln cu.m. a year.

Underground mining of coal as well zinc and lead ore resources and open mining of building raw materials, above all filling sand, causes drainage of deep and shallow subsoil (dewatering works). Deep depressive cones in exploited geologic formations (Rogoż, and al. 1986; Rogoż, and al. 1987) are the effects of these processes. Another effect is transferring considerable amounts of underground (mining) water to surface hydrological network. The total amount of pumped out underground water is about  $20 \text{ m}^3 \cdot \text{s}^{-1}$ . Half of this is used for economic purposes, the rest, that is about  $10 \text{ m}^3 \cdot \text{s}^{-1}$ , heavily contaminated, is carried away directly to rivers of the province.

Disposing of saline mining waters into surface hydrological network increases systematically. It is expressed by salt load (sum of chlorides and sulfates) carried into rivers (acc. to Węgrzynowska, 1986): 1975 - 2346 t·day<sup>-1</sup>, 1980 - 4153 t·day<sup>-1</sup>, 1985 - 6000 t·day<sup>-1</sup>, 1988 - 6823 t·d<sup>-1</sup>, predicted value for 1990 - 8500 t·d<sup>-1</sup>, for 1995 - 11500 t·d<sup>-1</sup>. In 1988 about 2,5 mln  $\text{m}^3 \cdot \text{d}^{-1}$  of industrial and municipal wastes containing 160 t·d<sup>-1</sup>  $\text{BTZ}_5$  and 220 t·d<sup>-1</sup> of suspended matter were carried into rivers of the province. Disposing of saline mining waters and wastes, properly purified only in 24%, causes an excessive pollution of the surface hydrographic network. As a consequence, 67-68% of its length shows excessive contamination, in the area of GOP as much as 90%. The average index of river overcontamination in Poland is 33%.

Mining subsidence occurring in mining fields, which is the result of underground exploitation, causes swamping of the area, and further on forming numerous small water basins, only few of which may be used for economic purposes. In central western part of GOP (an area of 1967 km<sup>2</sup>) there are as many as 1707 basins, with total area of 4310 ha and water volume of 201657 thousand cu.m. Those water reservoirs take up more than 2% of the examined area. Their characteristic feature is a great temporal variability (Jankowski, 1987). Only these basins which





Fig.4 Zones of ground subsidence in Katowice province: 1—from 0 to 5 m, 2—from 5 to 15 m, 3—more than 15 m, 4—watershed dividing the Odra and the Vistula drainage areas

were formed in bigger excavations, may be useful. Sometimes it is the best way to recultivate such industrial waste lands.

#### THE MAIN SYMPTOMS OF ANTHROPOGENIC ALTERATIONS OF THE AREA SURFACE

Long-term industrial activity and shaping of big human settlements caused deep alterations of relief in the Katowice province. The transformations are especially significant in regions connected with mining. Direct influences of that activity can be observed in the area of 1000 sq.km. According to the specialists' estimations, lowering of terrain in the zone of mining influence amounts almost to 20 cm a year (Kowalski, 1986). Specialists predict a lowering of the area by 35-40 cm up to the year 2010 in some regions (Fig. 4).

As a result of industrial activities and taking up necessary infrastructural works, new forms of relief are being created. Those are what is called anthropogenic forms (Phot. 1-3). They are both concave (excavations) and convex (dumps). In some specific cases "relief inversion" can be observed. Moreover, intensification of some physical-geographical processes, degradation and devastation of soil and its useful values, as well as the accumulation of burdensome wastes must be pointed out. The Institute of Environment Protection observed a high concentration of heavy metals in soil and plants of this area. The results are presented in Table 3.



Photo 1. Cone dumping ground in the back table dumping ground  
- Rybnik Coal Region.

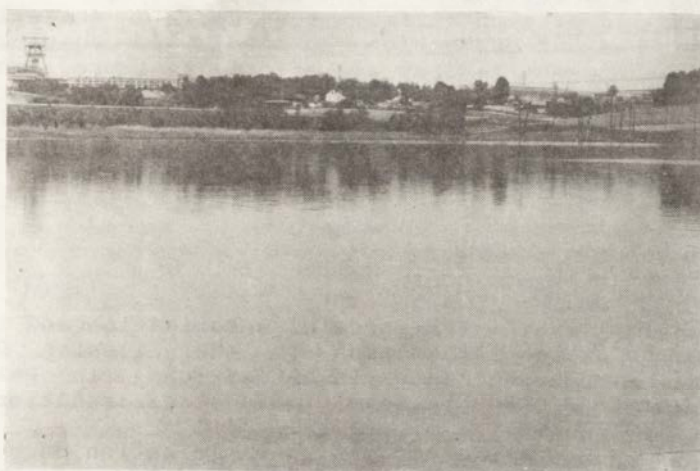
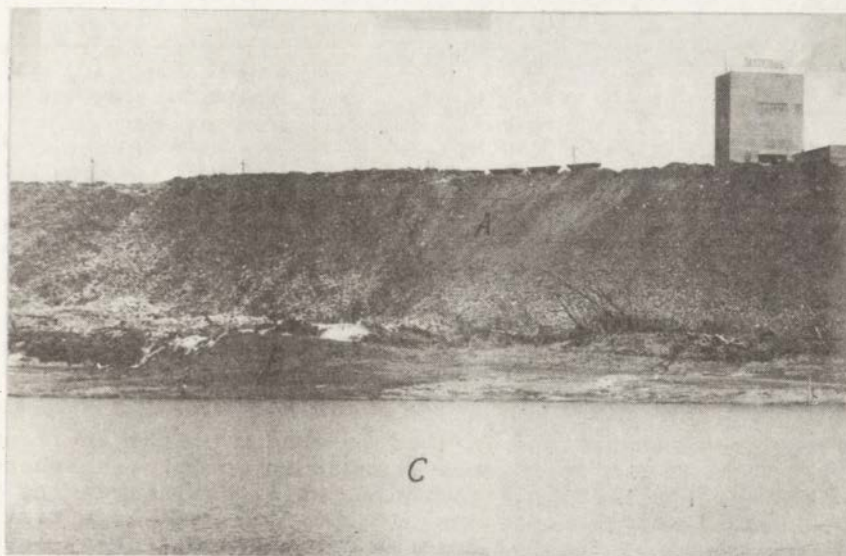


Photo 3. Water reservoir in a very distinctly formed subsiding trough 3.3 meters deep.

Summing up it can be assumed that, in the light of the above elaboration, treating Silesia as the black spot on environmental map of Europe seems to be fully justified. There have been



Table 3. Contents of selected heavy metals in soils and plants in unpolluted areas and in the Upper Silesia Industrial Region - GOP (acc. to Wieloletni . . . . ., 1983)

Selected heavy metals	Contents of heavy metals in soil (in mg·kg <sup>-1</sup> of soil)		Contents of heavy metals in plants (in mg·kg <sup>-1</sup> of dry vegetal mass)	
	unpolluted areas	GOP	unpolluted areas	GOP
Cadmium	0,01-1,0	3,0-103,0	<0,5	1,3-21,2
Lead	10,0-50,0	56,0-4958,0	1,0-10,0	16,0-102,0
Zinc	10,0-100,0	145,0-12595,0	0,0-10,0	50,0-391,0

presented only alterations in abiotic sphere of the environment, although there are also immense changes in the biotic sphere. It can be suggested that this region might be an interesting place for the Global Change Programme. It could be used as a test area of a geosphere-biosphere observatory where different investigations of anthropogenic changes of the whole geographic environment and its particular elements would be carried out. Central and local authorities, together with scientific world and institutions for protection, control and shaping of the natural environment take up all efforts to improve and restore natural values of this devastated region. Works on restructuring of the economy in the region have been commenced as well. There is a slight progress in improving the geographical environment of the area, but the changes are still much too slow.

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## THE CONCEPT OF GEOSPHERE-BIOSPHERE OBSERVATORIES (REGIONAL RESEARCH CENTRES) AND ITS APPLICATION TO THE STUDY OF CHANGES IN THE EURASIAN CONTINENT

V.M. KOTLYAKOV, A.V. DROZDOV, R.I. ZLOTIN, and A.A. TISHKOV\*

In recent decades the necessity to solve environmental problems and the advance of science triggered a number of international scientific programmes devoted to the analysis of the state and evolution of certain geosystem components and the spheres of the Earth. Such are primarily the International Biological Programme, the International Hydrological Programme, the International Programme on the Study of Climate, the Programme on the Study of Lithosphere, and Man and Biosphere Programme. For the realization of each of these Programmes special observation stations were created. The pattern of their networks was determined by the aims of the programmes and by the resources of countries-participants. We have not so far made a complete inventory of all the existing stations of environmental monitoring on the global and national levels, but their total number might be estimated to be dozens of thousands.

It is believed that for IGBP a network of special geosphere-biosphere observatories should also be organized. In 1989 they began to be called Regional Research Centres (RRC). They are to solve the main task of IGBP - collection and synthesis of information about changes in atmosphere, hydrosphere, lithosphere, pedosphere, biosphere and in the whole global system of the Earth under the influence of the changing interactions of geospheres and the biosphere with the human activity. The final aim of this work is to create a multicomponent model which would adequately describe the current state and development trends and predict the behaviour of the global system in the changing world. RRC will hopefully also play an integrative role in IGBP uniting different projects of it.

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This report has been prepared taking into account IGBP Special Committee recommendations, the results of meetings held by the Working Group on Geosphere-Biosphere Observatories (RRC) and of the Soviet experience in the matter of organizing a network of Biosphere Reserves, experimental geographical stations and nature reserves. In totality the great amount of information accumulated by this network represents a data bank on the past and present states of the global environment. But this abundance of facts represents one of the main problems and the primary task of IGBP - the need to revise all the diverse long-term field stations and environmental data accumulated by them with the aim to select those which are necessary for the solution of the general tasks of IGBP. Another means for resolving this problem might be the creation of a limited number of new research stations on the basis of existing ones, provided with all the necessary equipment, specialists and financing.

Many indices of the state of geospheres and the biosphere may be received by remote sensing methods. Here the task is to assess whether aerospace information is suitable for describing the global system. Of special significance is also the task of correlating aerospace and earthwatch data. Some scientists are under the delusion that remote sensing data are adequate for characterizing the state of the biosphere. Yet this tempting position must be checked and validated.

Hence the first problem to be solved is systematization of the existing networks of observation stations with a characteristic of the whole set of studies and synthesized parameters of the environment. Such an analysis is made on the national level, then a classification of continental and marine stations is made with the final aim of creating an atlas of all kinds of stations, both by oceans and by continents. Simultaneously an assessment of stations is carried out from the point of view of their correspondence to the RRC criteria.

A station may be included in the system of IGBP as a RRC, if it answers the following criteria: a) representativeness, i.e. the possibility to extrapolate the results of observations onto a certain area; b) the possibility to fulfill a complex of geosphere-biosphere observations, i.e. to receive simultaneously characteristics of the state of atmosphere, hydrosphere, lithosphere, soil and biota as well as of the interactions of spheres and components; c) the possibility to make comparative observations in areas transformed by human activity and under natural (control) conditions (the area of such compared pairs of plots should be not less than 100 sq.km). The a) through c) criteria are geographic categories. The other three criteria are of an organizational nature: d) the availability of sets of long-term observations over environmental parameters; e) the possibility to make a data bank and to include it into a universal geo-information system; f) the availability of appropriate specialists, equipment and instruments which can be used for fulfilling the aims of IGBP.

The second problem - creation of a geographical network of stations suitable for describing changes in the global system under the impact of changing factors at three spatial levels - global, regional and local. Each of the latter has its own set of processes and changing parameters. The global level is characterized by planetary geosphere processes determining the gas composition of atmosphere, thermal regime of air and natural waters, the structure of solar radiation and others; the regional one - by biotic and some abiotic processes and parameters (species diversity of organisms, productive-destructive balance, biogeochemical balance of a region, radiation, heat and water budgets, etc.), and the local - by indicator parameters reflecting changes in the location, structure and functioning of simple ecosystems.

It is important that the network of stations is allowed to receive answers to the following three questions: 1) what is the system for which the obtained data are representative in the coordinates of space and time; 2) what is the contribution of subsystems to the processes realized in the systems of a higher level; 3) in what way and to what degree can global changes manifest themselves in the changes of low-level systems.

The answer to the first question may be obtained if the structure of the global system is studied in the aspect of the enclosed homogeneous subsystems. This type of structure we call skeletal (or structural). In great measure it is characteristic for terrigenous (land) systems. Differentiation of the skeletal type is most often associated with the horizontal heterogeneity of the lithogenic base as well as with the areas of emergence, settlement and adaptation of biotic communities. Thus, the skeletal differentiation is most characteristic of lithosphere, biota and the sphere of their interaction - soil cover.

The answers to the other two questions lie in the understanding of the type of spatial differentiation of the global system, which we called dynamic (or functional). This principle of space organization is based on a dynamic relationship among subsystems. It is characteristic of such components of geosphere, as atmosphere and hydrosphere, while among complete systems it is most characteristic of the ocean (streams, upwellings, etc.). River basins of different orders are typical dynamic systems on land.

It should be borne in mind that differentiation of the global system into subsystems in accordance with their skeletal or dynamic properties does not coincide in the time-space coordinates at all levels, except the simplest one. In our opinion, it is here that the most important question for IGBP lies: how to locate stations in such a way as to receive adequate information on changes in the structure, functioning and limits of the present geosphere-biosphere systems?

The full-component subsystems of geosphere-biosphere are called ecosystems by ecologists and biologists, and geosystems - by geographers. Below we shall use the latter term, which we believe to be more general and closer to the concepts of "environment".

The ocean with seas, continents and islands are the largest geosystems of the Earth. A hierarchical differentiation of continental geosystems is presented in Table 1. Basing on the scales of a cartographic representation and the areas of detected geosystems of different levels, one can determine an approximate number of stations. For instance, changes in the state of geosystems of a local level may be recorded at 10,000 to 30,000 stations, with each station reflecting the situation within an area from 5,000 to 15,000 sq.km. For observations at the regional level, which is the basic level for IGBP, between 30 and 40 stations are needed which would be located in representative points of a region. They are chosen by similarity of relief and geological structure as well as by their location within certain climatic belts.

Table 1. Spatial levels of component systems and full land-surface geosystems (scheme by different authors)

Systems	Dynamic						
	Structural						
	Component systems			Full geosystems		Component systems	
	Troposphere	Biotic Cover	Soil Cover	River Basins	Landscapes	Geomorphological	Geological
Local (up to 10 <sup>3</sup> sq.km)	Local winds impact areas	Elementary ecosystem	Elementary region	1 order	Facies	Microforms	Areas of genetic types of deposits and facies
		Microchoras	Microstructures		2-3 order	Combinations of facies	
		Mesochoras	Mesostructures	Landscapes		Areas	
Regional (up to 10 <sup>7</sup> sq.km)	Regional winds impact areas	Subbiomes	Areas	4-5 order	Landscape areas	Regions	Structural-formation zones
		Biomes	Zones		Regions and provinces	Provinces	Fold areas, shields and platform plates
	Sectors of circulation zones			6-10 orders	Physical-geographic countries	Countries Zones	Geosynclinal belts platforms
Global (more than 10 <sup>7</sup> sq.km)	Circulation zones	Regional complex of biomes	Countries	10 order and more	Continental complex of landscapes	Continents	Lithospheric plates
							Continents



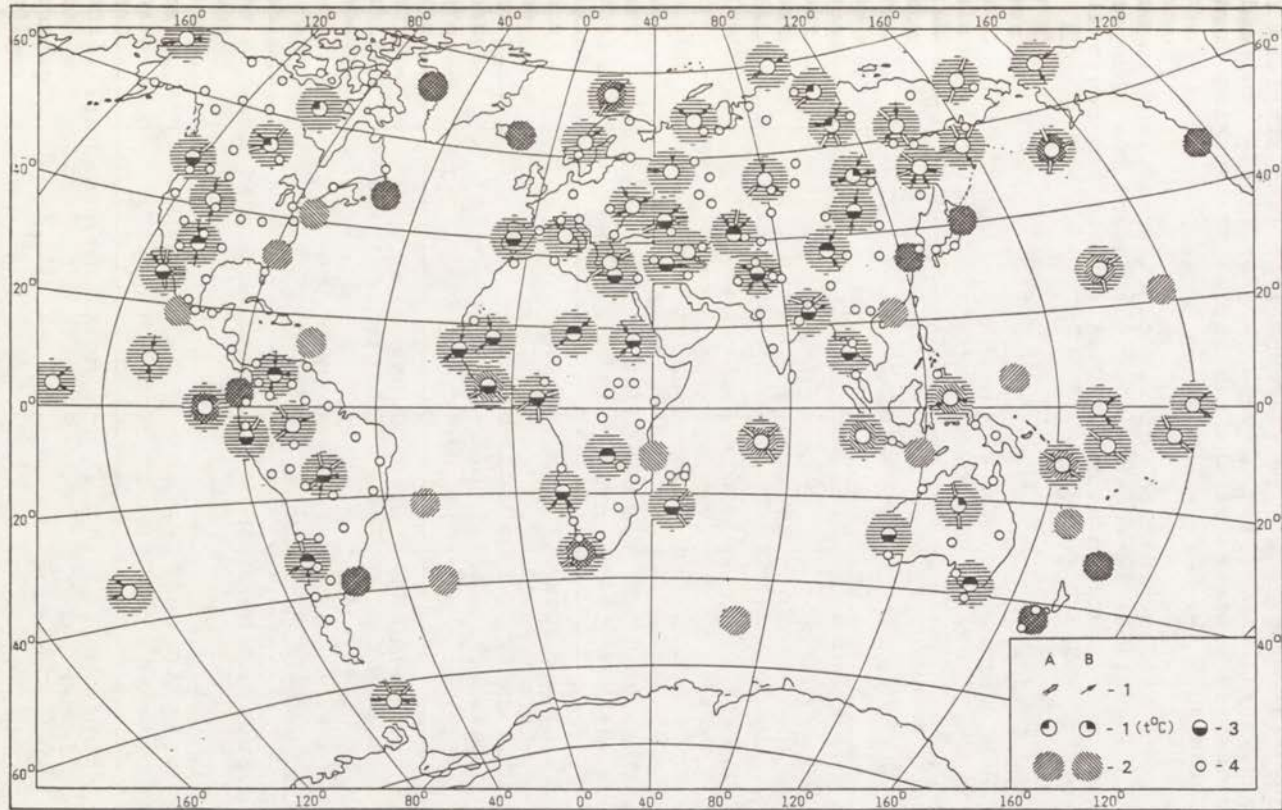
This network of regional stations of a skeletal type should be supplemented by approximately the same number of stations observing changes in regional systems of a dynamic type (for instance, in centres of air circulation zones, in the closing parts of watersheds, etc.).

Stations located within interface belts (ecotones) should in principle become an addition to regional stations on land. Ecotone geosystems are most sensitive to the change of outer conditions. They usually contain a maximal diversity of environmental conditions and natural components. It is in ecotones that the changes of geosphere-biosphere processes may be most prominent and rapid. According to the earlier estimations of Yu.G. Puzachenko, there are about 150 regions where biosphere reserves (Stations) should be located in the first hand (Sokolov et al., 1983; Sokolov, Puzachenko, 1986).

There must be about 10 to 15 stations of a global level representing areas of several dozens of millions of sq.km and located in the main radiation-thermal belts and sectors of atmospheric circulation.



Fig.1. Distribution of areas potentially suitable for the organization of biosphere stations (Sokolov et al., 1983), corresponding to the "structural" model. Physico-geographical boundaries: 1-belts, 2-countries, 3-areas with maximal diversity of natural conditions, potentially suitable for the organization of biosphere stations; 4- centres of formation of the basic agricultural crops.



The suggested estimations of the number of land stations for the local, regional and global levels approximately coincide with their numbers proposed at the meeting of the Working Group on GBO in Caracas in May 1988.

Examples of differentiation of the continental land in accordance with a skeletal (structural) principle and the project of the location of stations at two levels (global and regional) are given in Fig. 1 and 2 (maps).

Table 2. Climatic differentiation of the island land geosystems (after Ignatiev, 1979; with some changes)

Thermal belt	Climate seasons	Conditions of humidification			
		humid	temperate-humid	semiarid	arid
Polar	Cold winter and summer	-	glaciers, polar deserts	-	-
Subpolar	- warm winter cool summer	- -	tundra meadows waste lands	- -	- -
Temperate	cold winter warm summer	coniferous forests	bush thickets	-	-
	cool summer and winter	-	meadows waste lands	-	-
	warm winter cool summer	coniferous forests bogs	bush thickets	-	-
Subtropical	cool summer and winter	evergreen forests	bush thickets	-	-
	warm winter hot summer	evergreen bushes			
	humid winter hot summer	-	hardleaved evergreen bushes		
Tropical	humid summer and winter	evergreen forests	-	-	-
	humid summer dry winter	-	deciduous evergreen forests		
	humid summer very dry winter	-	-	savannas	-
	dry summer and winter	-	-	-	semideserts



A global differentiation of the island land along the above principles has not been made. Taking the elaboration of G.I. Ignatiev (1979), we made an attempt to compile a principle scheme of island land differentiation with the account of their location within the thermal belt, climate seasons, conditions of moistening during the warm period, the genesis of islands, and the type of biom (Table 2).

Similarly to the continental land, islands are characterized by a skeletal type of the organization of subregional and local levels. 15 stations may be tentatively suggested to be organized there. Their role in IGBP is double. Firstly, due to a relatively small size of the land and length of the contact line with the sea, island geosystems are vulnerable to changes of external environment. That is why they are characterized by dynamic geosystems processes. Moreover, young islands and their new surface are quite convenient for studying primary successions. Secondly, it is oceanic islands, removed from the continental land and the centres of environmental pollution, that can become objects of systematic observations over the state of the global environment under the conditions of a background pollution of the biosphere.

The coastal zone is another significant element of the spatial structure of geosphere and the biosphere. In its aquatic part, this global ecotone includes a shelf located between the continents and the seas, and in the terrestrial part - coastal plains or mountain slopes. Tentative estimates show that the total area of the coastal zone is not less than 10 percent of the Earth's surface. This zone concentrating the main part of the planet's population will obviously be subject to global changes in the greatest degree. That is why IGBP observations here should be carried out at stations of a specific dynamic type, which would assess changes in the processes of ocean-continent interactions. There must be 20 such stations for making observations in coastal waters and in terrestrial geosystems.

An ecosystem structure of the ocean was characterized by Koblents-Mishke (1983), who suggested to distinguish 6 levels of the organization (Table 3). For the needs of IGBP the ocean should be divided into 4 principal levels: 1) the whole ocean; 2) planetary and macrocycles; 3) synoptic whirlwinds; 4) meso-scale structures. The latter level includes local systems with characteristic dimensions of under 1 km. Such a hierarchy of the ocean in its photic zone takes into account climatic zonality, circulation of water and circumcontinental zonality. The enumerated factors determine temperature, salinity, and density of the water, the level of bioproductive processes and sedimentation.

Not so well advanced is the concept of structure and differentiation of intermediate and deep waters, although we know what great role is played by upwellings and downwellings as well as hydrotherms and other endogenic phenomena.

Table 3. Spatial differentiation of the palagic ecosystems of the ocean  
(after Roblents-Mishke, 1983, with changes)

Scale	Category of dimension	Names of the categories as suggested by different authors	Association with hydrophysical belts
10 <sup>4</sup> km	II	mega, planetary	planetary cycles
10 <sup>3</sup> km	IIa	macro	macroscale cycles
10 <sup>2</sup> km	III	meso, synoptic	synoptic whirlwinds, background planetary upwellings
10 km	IV	coarse, meso	local upwellings, including those in the regions of underground mountains and islands; inner waves
100 m	V	fine	a fine structure of water: cells of a convective nature
1 m 10 cm 1 cm	VI	micro	microscale turbulence

Taking into account the above and the impact of the ocean on atmosphere, continents and the planetary matter and energy exchange as a whole, one may indicate the following regions for locating oceanic stations of a regional level and the processes to which priority should be given: 1) regions of an open ocean and seas to study the processes of production-destruction cycles, gas exchange, heat exchange and evaporation, vertical sedimentation, eolian fans of terrigenous materials, decontamination, etc. Such stations should be placed in the centres of macrocycles and their number should be about 25; 2) regions of the periphery of macrocycles to study the processes associated with streams, horizontal transport of water, heat and pollutants as well as with biological productivity. The maximal number of stations should be 50; 3) regions with distinct processes in deep waters and on the oceanic and sea floor; processes of sedimentation and diagenesis, exchange through the "waterbottom" surface, hydrotherms and other endogenic phenomena. These processes may be studied in the centres of oceanic depressions as well as in troughs and rift zones. It is quite possible that observations over these processes can be fulfilled at the stations of the first and second groups positioned over corresponding bottom structures. Together with the above two groups of stations, the total number of the third group stations might be about 75; 4) regions of an interoceanic exchange and transfer of deep waters primarily associated with such straits as Bering, Magellan, Tartar, Gibraltar, Bosphorus and others.

There must be about 10 to 15 stations in such places, and the general number of oceanic and sea stations will be about 100 to 120.

Thus, the general network of subglobal and regional stations, including oceanic, sea, coastal, island, and overland, and providing for a synthesis of observations over the geosphere-biosphere processes will consist of between 300 and 350. The further breaking down of the network of stations for lower levels (subregional and local) is a special task.

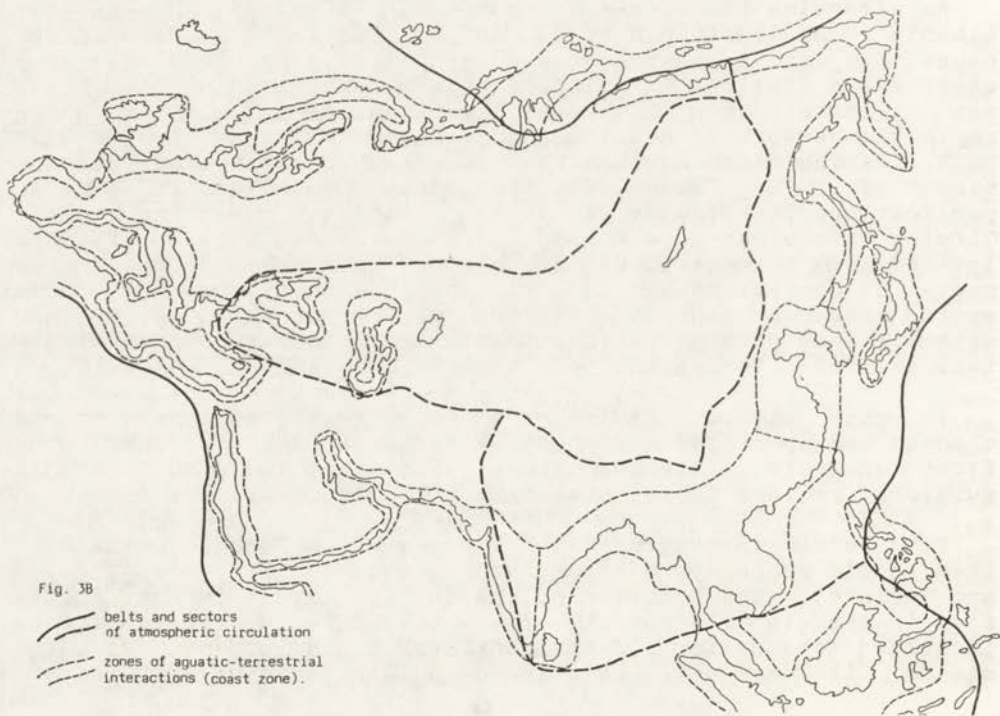
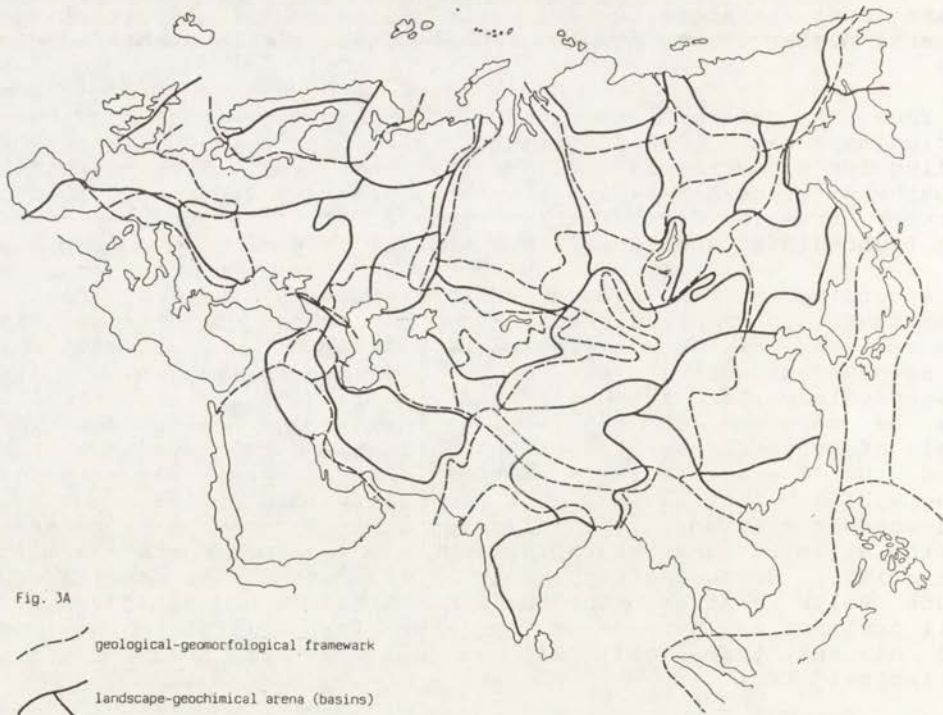
According to the latest recommendations of the IGBP Special Committee, 10 principal RRCs should be created with the aim to generalize the data collected by a wider network of stations. It seems to us that the task of a global generalization, in its essence, is of both scientific and organizational character. It may be resolved at the level of the Special Committee on the basis of proposals by the IGBP National Committees. On the land, the 10 suggested RRCs of the "first category" may serve as geographical centres for such generalizations. As for the sea and oceanic stations, the following centres could be foreseen: North Atlantic and South Atlantic, Indian, North Pacific (Hawaiian), South Pacific, West Pacific as well as North and South Polar centres. The total number of such oceanic centres will probably be the same as for land. - 10, while both on land and on sea there will all in all be not less than 25 "principal" RRCs.

An effective location and organization of global RRCs on continents is obviously easier to realize than in the oceans, because dry land is better studied and already provided with many observation stations on different environmental problems. We can illustrate how this task can be solved assuming as an example the network of stations suggested for Eurasia and the USSR, taking into account the geosystems structure of the continent (Fig. 3), as well as the ideas presented in earlier publications (Sokolov et al., 1983; Sokolov, Puzachenko, 1984). Circles on the map show a possible localization of 37 stations located on intersections of natural boundaries, 36 - in the nuclei of geosystems and 24 - in the coastal zone. In these spots research centres of IGBP may be created (or already exist). Some of the stations could make observations simultaneously over terrestrial and aquatic geosystems.

It goes without saying that the suggested system can be changed and specified, although it seems to us that already the first analysis presented above allows to single out the main subglobal regions for generalizing the data on RRC for IGBP.

Five such main centres may be suggested in Eurasia. Three of them should probably be subdivided into subcentres (see Fig. 3 and Table 4). The location of the centres may be further specified in the global context after the building of analogous idealized schemes for all the continents and oceans. For instance, it may well be that we shall have to make a Mediter-





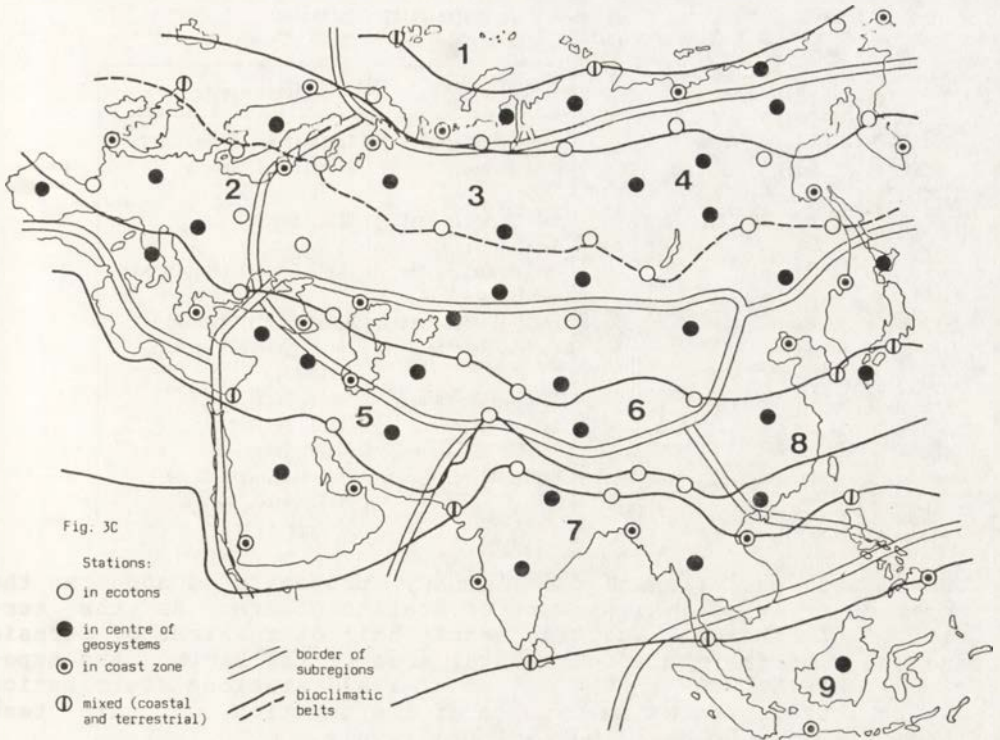


Fig. 3. Natural differentiation of Eurasia and proposals on deployment of IGBP stations.

3A: Geological-geomorphological structure and runoff basin, united in landscape-geochemical arenas (by Glazovskaya, Glazovsky, 1989); 3B: Belts and sectors of atmosphere circulation and zones of aquatorial-terrestrial interaction (coastal zone). 3C- Bioclimatic belts and subregions (1...9 - names are given in Table 4), distinguished for generalization of information on the network of IGBP stations; areas, proposed for the deployment of IGBP stations: a-at the crossing of natural land-surface boundaries, b-in nuclei of geosystems, c-in the coastal zone, d-combined for land-surface and coastal stations.

ranean centre uniting the countries of South Europe, Near East and North Africa. The equatorial centre of Eurasia suggested to be organized in the Philippines may at the same time serve as a West Pacific centre. It is quite possible that the Front Asiatic-Arabian subcentre together with the Central Asiatic one will unite with the Sahara centre into a general grass-savanna-desert centre of the Old World.

Let us consider now, in the context of IGBP concept, the state of the existing network of field experimental stations of the

Table 4. Subglobal regions of Eurasia for generalizing information by IGBP stations (tentative)

Biome characteristic	Name	Regional centre
1. Polar desert and tundra	Eurasian arctic	Spitsbergen, Barentsburg
2. Forests and steppe boreal-subtropic	West European	Switzerland, Geneva
3. The same	East European-West Siberian	USSR, Moscow
4. The same	East-Siberian, the Far Eastern	USSR, Irkutsk (Khabarovsk)
5. Desert-steppe	Front-Asiatic-Arabian	Saudi Arabia, El-Riad
6. The same	Central Asiatic	China (Urumchi) or USSR (Tashkent)
7. Forest and savanna monsoon	Indian-Indo-Chinese	India, Delhi
8. The same	East Asiatic	China, Beijing or Japan, Tokyo
9. Forest equatorial	Zond-Philippine	Indonesia, Jakarta or Philippines, Manila

USSR, and put forward preliminary proposals as concerns the location of an optimal network of stations there. As the territory of the USSR occupies nearly half of the area of Eurasia and 1/6th of the whole continental area of the Earth, the experience of the USSR in the matter of field stations distribution may be looked upon as an example of the solution of this task for areas of subglobal and regional levels.

We have made a sufficiently complete analysis of stations at which observations and monitoring of the state of the environment are being carried out in the USSR. 40 different categories of such stations have been defined (Table 5). These are, primarily, natural protected territories (about 3,000), stations of the Hydrometeorological Service (3,100), stations of an international system of monitoring (about 1,000, including those working according to international programmes), stations of monitoring the state of the agricultural environment (about 450), forestry enterprises (about 7,000), complex geographical and ecological stations (68). Besides all the above, in the USSR there is an extensive network of sanitation, geological, seismic, cryogenic and other kinds of services. A great number of stations (on board the ship and automatic) work in the framework of the oceanographic service. Another network of stations provide for the observation over the state of atmosphere in large cities (534) and on particularly important water economy objects (over 4,000).

Thus, in the USSR there are all in all about 20,000 stations that can be used for estimating changes in geosystems of a regional level for the purpose of IGBP. The most valuable among them, those which can be potential RRC, are biosphere reserves (18), nature reserves (162) as well as hydrological (228), lake (65), swamp (9), water-balance (38), and estuary (16) stations.



Table 5. A system of stations monitoring the state of individual components of geosphere and biosphere in the USSR (source: Sokolov and Puzachenko, 1984; with some additions)

Category of stations	Number of stations as for late 1980s	Functions of stations and types of observations
1	2	3
<u>Protected natural territories</u>		
1. Reserves	162	Conservation and study of geosystems and their individual components, "Chronicles of Nature"
2. Biosphere reserves	18	The same, including observations according to international programmes of monitoring
3. Conservation and hunting enterprises	7	Conservation, counting and reproduction of game
4. State, Republican and regional sanctuaries (complex, botanical, zoological, hydrological, etc.)	over 2,700	Conservation, assessment and partial use of individual components of ecosystems
5. National parks	13	Conservation of geosystems, counting of biota, recreation
<u>Stations of the Hydrometeorological Service</u>		
6. Hydrological control points	7,000	Periodic observations over water bodies
7. Hydrological stations	228	The same, including processing of information from control points
8. Lake stations	65	The state of physical, chemical and biological parameters of lakes
9. Swamp stations	9	Water regime and dynamics of the boggy vegetation
10. Water balance stations	38	Water balance of natural and anthropogenic landscapes
11. Stations in estuaries	16	Hydrological regime and dynamics of the large river estuaries
12. Marine hydrometeorological stations	240	Hydrometeorological regime of atmosphere and water surface of the sea

1	2	3
13. Meteorological stations	2,222	Hydrometeorological regime of the upper and lower atmosphere, actinometric observations
14. Hydrometeorological bureaux	95	The same, including an analysis and synthesis of materials received from stations
15. Hydrometeorological observatories	105	The same, including analysis and synthesis of the materials of stations and accumulation of data
16. Avalanche stations	38	Observations over the dynamics of the snow cover and avalanches in mountains
17. Mudflow stations	5	Observations of the formation of mudflows and over the behaviour of glaciers in mountains
<u>Stations of the international system of monitoring</u>		
18. Stations for monitoring the background pollution of the atmosphere	6	Control of the pollution of atmosphere by priority indices
19. Stations of a background geosystems monitoring	7	Control of chemical pollution of air, precipitations, soils and biota
20. Overland stations of observations over the trans-boundary transfer	9	Atmospheric transfer of pollutants
21. Stations for monitoring the snow cover pollution	933	Control of the snow cover for analyzing environmental pollution
<u>Stations of an agrarian profile</u>		
22. Stations controlling introduction of chemical substances, their branches and agrochemical laboratories	190	Control and rationing of the introduced fertilizers and toxic chemicals
23. Agricultural experimental stations (plant-growing, pedological, etc.)	116	Introduction of brands and cultures specially selected for definite regions, elaboration of new agro-techniques, etc.
24. Agrometeorological stations	99	Bioclimatic and phenological observations

1	2	3
25. Experimental ameliorative stations	31	Dynamics of landscape components after its melioration
<u>Forestry enterprises</u>		
26. Agro-forest ameliorative stations		Field protective forest belts and massives
27. Forest experimental stations selective forestry farms, nurseries and laboratories, mountain stations	88	Introduction of the means of reforestation, formation of highly productive plantations
28. Forestries	over 7,000	Regulation (usually once very 10 years) of earthwatch and aerovisual observations over the state of a regional forest fund with a detailed mapping
<u>Geographical and biogeocenological stations</u>		
29. Biogeocenological stations (zonal, mountain and others)	55	Structure, functioning and dynamics of ecosystems and their components, interaction of the abiotic environment and biota
30. Complex geographical experimental stations	13	Dynamics of geosystems and of their components

As sources of synthetic information, quite important are also hydrometeorological observatories (105), stations of monitoring of the background atmospheric pollution (6), agricultural and forest experimental stations (116 and 88), geographical (13) and biogeocenological stations. On the whole, in the USSR there are several thousands of stations suitable for fulfilling IGBP requirements, but they are distributed about the territory of the country very unevenly. In the densely populated European USSR their number is the greatest.

Fig. 4 presents in a generalized form proposals for the distribution of an optimal network of stations in the USSR on the basis of the above mentioned skeletal and dynamic concept, as well as approaches to selecting areas for biosphere reserves and monitoring stations (Sokolov et al., 1983; Isakov, Krinitsky, 1983; Drozdov, 1983; Sokolov, Puzachenko, 1986; Glazovskaya, Glazovsky, 1989 and others). In the proposed scheme, some of the stations are provided with information from the existing nearby stations. Others may be included into the IGBP network after broadening both their functions and the set of observed parameters of the environment.



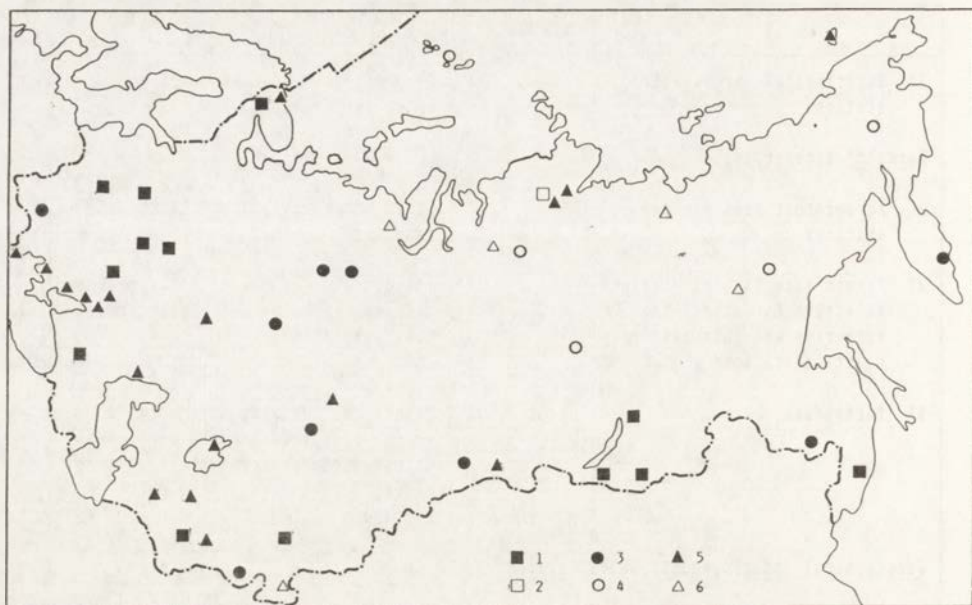


Fig. 4. A network of recommended stations in the territory of the Soviet Union for regional background monitoring (Glazovskaya, Glazovsky, 1989). Biosphere stations: 1-available, 2-proposed-to be set up first, 3-second, 4-additionally, 5-additionally on the basis of existing preserves, 6-additionally to existing preserves.

In our opinion, the Kursk Field Experimental Station of the Institute of Geography of the USSR Academy of Sciences, together with the Central Chernozem Biosphere Reserve, corresponds to the RRC of a higher rank. Another such station may probably be located in the Barents sea. It will be an oceanographic station.

The third problem facing the RRC campaign is the choice of environmental parameters observed at them. In principle, this problem must be resolved on the basis of proposals of all IGBP Coordination Panels. All the diversity of the parameters may probably be classified in three groups: a) areas (the change of areas, boundaries, configuration, and inner structure); b) structural (diversity of elements, matter and energy reserves in them, etc.); c) functional (productive and destructive processes, matter and energy flows). A principle scheme of the ratio of parameter number for the study of biota, atmosphere, hydrosphere, lithosphere and soils as well as the number of stations for different levels of differentiation of geosystems is given in Fig. 5.

An important task is to establish a recorded value of changes for each parameter of geospheres and the biosphere. For instance, to determine the dynamics of ecosystems by areas (the changes of the area), accumulated changes of not less than 4 percent of the area of the system are needed (Vinogradov, 1989).

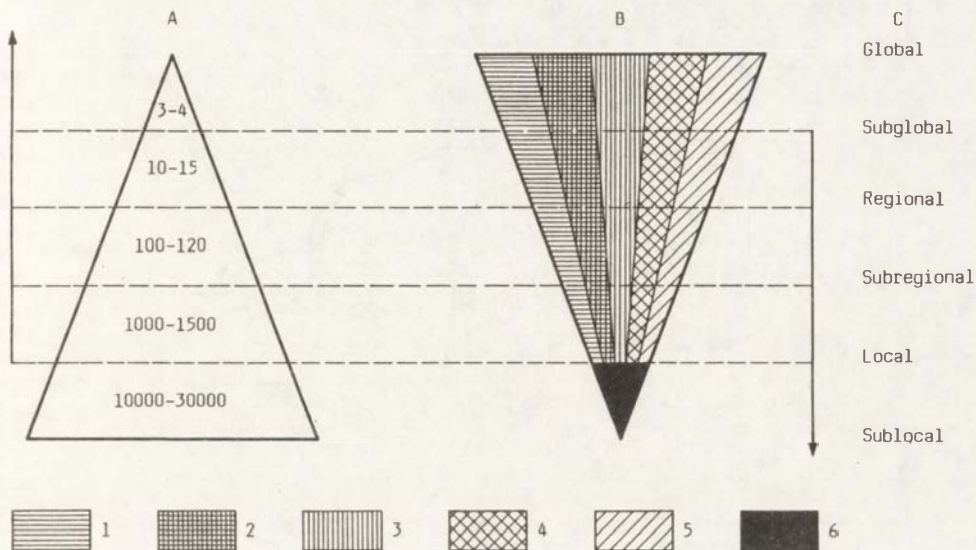


Fig. 5. Correlation of the number of stations (A) and parameters under study (B) for different levels (C) of geosystems differentiation. Groups of parameters: 1-atmospheric, 2-hydrospheric, 3-lithospheric, 4-soil, 5-biomatic, 6-specialization in one of the groups.

Table 6. Recurrence of the observation of objects for establishing dynamics of areas of different ecosystems (after Vinogradov, 1989)

Types of systems	Changes of the area during a year percent of the total	Recurrence of observations, years
Sustainable, weakly changed	0.5	8
Moderately changed	up to 1.0	4
Strongly changed	up to 2.0 and more	1-2

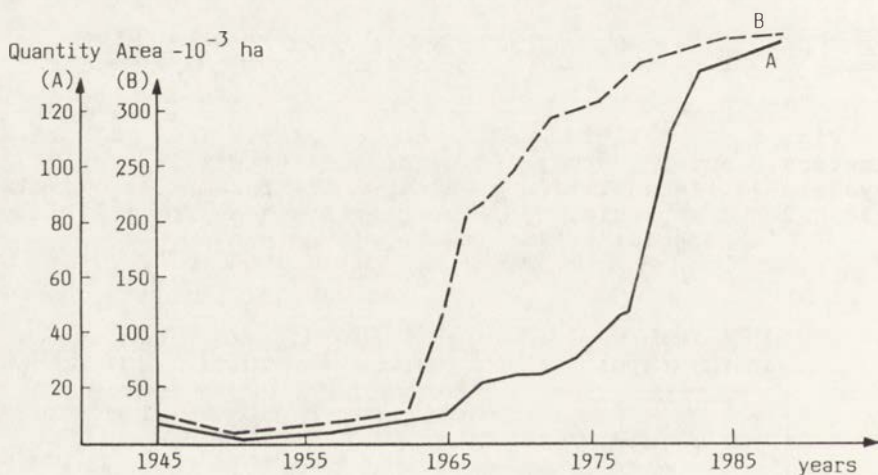
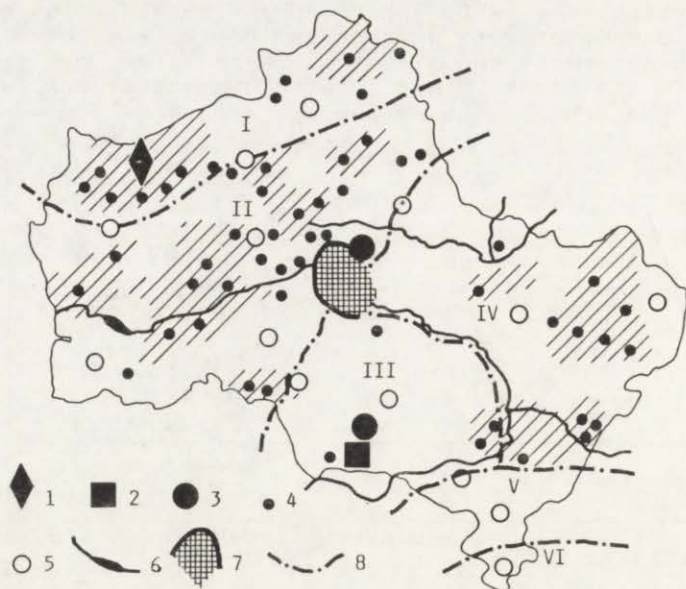


Fig. 6. The system of protected territories and its development in the Moscow Region. 1-preserve-hunting land, 2-preserve, 3-national parks, 4-game reserves, 5-proposed areas for IGBP local stations, 6-rivers, 7-Moscow boundaries, 8-boundaries of natural regions of the Moscow Region: I-Upper Volga lowland, southern taiga, spruce-forests; II-Smolensk-Moscow moraine upland, coniferous-broadleaved forests, III-Oka-Moscow eroded lowland, broadleaved forests, IV-Meschera lowland (out-wash), pine forests, bogs, V-Trans-Oka plateau, broadleaved forests, VI-forest-steppe plain (meadow steppes, groves)



The fourth problem - the working out of methods for collecting, storing and analyzing of information. Besides methods of proper data accumulation, very important is periodicity of observations. Using the materials of repeated remote sensing of different types of ecosystems, Vinogradov (1989) defined the following time intervals of observations (Table 6).

One of the leading functions of RRC is control and management of environmental dynamics. IGBP and its regional centres must formulate the ecological policy of countries by using the whole accumulated informational material in order to optimize landscape functioning and to preserve sustainability of the development of geospheres and the biosphere. The possibilities for elaborating a strategy of an optimal use of natural resources at subregional and local levels with the help of field stations data can be demonstrated by the Moscow Region (Fig. 6). The city of Moscow has the Hydrometeorological Centre of the USSR, the Central High-Altitude Hydrometeorological Observatory, the Aviation Meteorological Centre, and the Hydrometeorological Observatory. In the Moscow Region there is a network of meteorological stations, hydrological control points and stations, agricultural and experiment stations. The rational network of protected natural territories, a sufficient number of control points which monitor the quality of the environment and the observation of admissible anthropogenic loads - all this helps optimize the economy and provide for a sustainable development of this region.

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## THE "GLOBAL ELECTRIC CIRCUIT" PROJECT. GENERAL CONCEPT - INTERRELATIONS OF ATMOSPHERIC, LITHOSPHERIC AND COSMOPHYSICAL PROCESSES

S.V. ANISIMOV and V.A. MORGOUNOV\*

Data from studies of the solar-terrestrial physics, of the system "magnetosphere-ionosphere", of processes in the lower and middle atmosphere, the discovered correspondence between the structural features of the magnetosphere and lithosphere demonstrate that all the geospheric shells are but parts of a single multiparametric system, in which the feedbacks largely work via systems of electric currents. The Earth biosphere is an intrinsic part of this system and is fully affected by such multi-factor forcings. The advent of the anthropogenic epoch brings a transition from the environment of stable slowly evolving natural parameters to one of the anthropogenically modified ones.

The phenomena taking place in various geospheric shells cannot be understood out of the context of this unified multi-dimensional system. Since its interrelationships are, to a large extent, realized as electrodynamic processes, the task of describing such a system may be presented in terms of a single global electric system (circuit).

Such a global electric circuit (GEC) may be envisaged as a contour opened to external forcings, which contains parts susceptible to influence of the magnetospheric, ionospheric, lithospheric processes and processes in the lower and middle atmosphere.

The GEC Commission formulates problems in terms of the electrical properties of various media and factors in these geospheric shells, interacting with each other. The Commission aims at assessing the strength of interrelationships between various atmospheric, ionospheric, solar-magneto-sphere, and lithospheric processes with the GEC; the nature of the physical, chemical, and biologic mechanisms, through which such relationships are realized.

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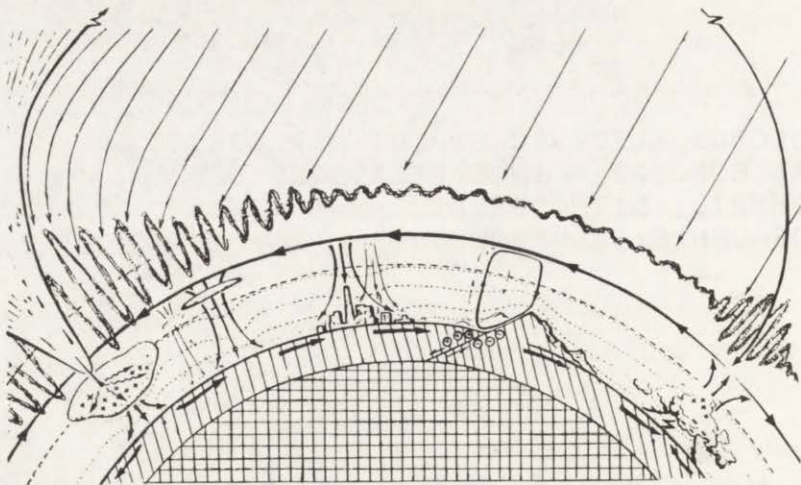


Fig.1

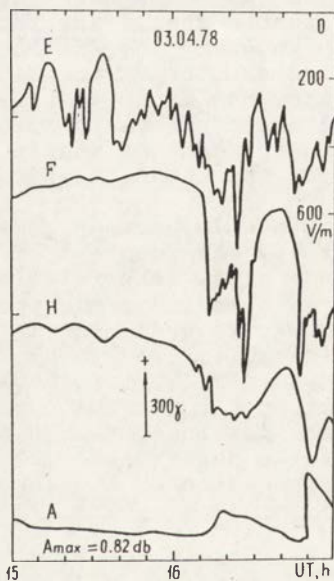


Fig.2

In contrast with the approaches followed by other acting Commissions it is expected to focus on perturbations of the electrical parameters of the media; these are heavily perturbed, orders of magnitude off their stable background values, as opposed to the respective magnetic parameters. Differentiations should be followed through between the inputs from the global and local generators, and between the quasi sta-

tionary and wave phenomena, and their spatial and temporal characteristics studied.

The Commission will pay particular attention to studying the electrical phenomena in middle atmosphere; it is looked upon as a medium mostly affected by the phenomena in the lower atmosphere and by the penetrating perturbations from the upper atmosphere. This region is also playing an active role in forming the information and energy components in the solar-terrestrial phenomena.

The present program based on deploying a network of surface stations for monitoring the atmospheric electrical parameters, and incorporating balloon and rocket remote sensing techniques and satellite data will make it possible to study the transitory electrical processes, i.e. phenomena relating the plasma shells of the Earth to its quasi neutral atmosphere.

Monitoring of electric fields will also help in assessing variations of the electric state of the atmosphere, the latter being an important but poorly understood ecological factor (in particular - in conjunction with heavy anthropogenic impacts). Thus a new approach opens for treating the problems of general ecology and of environmental pollution.

## SOME INFORMATION ON GLOBAL ELECTRIC MEASUREMENTS

Stanisław MICHNOWSKI\*

The Workshop organized by ICAE, Institute of Geophysics P.A.S. and Polish Geophysical Society was held in Poland on September 10-16, 1989 at Mađralin near Otwock with 42 participants from 11 countries.

### 1. OBJECTIVE

The Objective of the "Global Atmospheric Electricity Measurements" Program (GAEM) is to investigate in detail the local-global and the extra terrestrial global-local relationships among those elements that are relevant to the International Geosphere Biosphere Program (IGBP) and the Solar-Terrestrial Energy Program (STEP) of ICSU.

Among those are:

- a) Understanding and identification of solar-terrestrial influence on surface atmospheric electricity variables;
- b) Separation and identification of local and global effects in surface observations;
- c) Establishment of a global network of atmospheric electricity stations with digital recordings, possibility of high time-resolution, and communication for data exchange. Utilize existing stations as appropriate.

### 2. BACKGROUND

Atmospheric Electricity Measurements often include information on local, global and extraterrestrial processes in such a way that the dynamics of those are assessed in real time over a very wide temporal range. Separation of these groups of information is generally difficult and is a subject of research.

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\* International Commission on Atmospheric Electricity (ICAЕ) of Association JAMAP OF UGGI



These atmospheric electricity relations can be used as indicators for elements of other atmospheric and space parameters and processes, many of which are directly or indirectly of interest to IGBP and STEP.

### 3. APPROACH

The program will use a network of measurement stations including a dense network at high latitudes to collect coordinated data on atmospheric electricity variables. Analysis of the data will include other appropriate information such as meteorology, air pollution data, cosmic rays, solar events etc. using surface, aircraft, balloons and rocketborne sensors in order to establish and to verify theoretical concepts and models, and to create theoretical models necessary for distinguishing global and local effects.

### 4. MAIN RESEARCH TASKS

4.1. Perform Atmospheric Electricity Research in the time domain of one second to one solar rotation period.

Related data on magnetic fluctuations, solar events, and cosmic rays occur in this time domain. Measuring technique for separating global and local components also work well in this time domain.\*

Quantitative techniques of time series analysis will be applied extensively requiring the use of digital data recording techniques.

The study of statistical properties of atmospheric electricity noise (agitation) in the planetary boundary layer will be an object of further experimental and theoretical studies.

4.2. Extend the existing concepts of the global atmospheric electricity circuit by considering meteorological processes, ionospheric dynamo processes, magnetospheric sources, ionization and attachment processes.

4.3. Investigate the influence of natural and anthropogenic sources on the atmospheric electricity parameters which serve as indicators of interest to IGBP.

### 5. OPERATIONAL PLAN AND ORGANIZATION

A Coordination Board (CB) is established to guide coordination between participating stations and to assist the Alert

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\* Stations, especially those which are working continently, will also deliver longer period data.

and the Data Centers.

### 5.1. Members

See Proceedings of the Workshop to be published by Institute of Geophysics P.A.S.

### 5.2. An Alert Center will be established in the United States.

It will use alert criteria such as forecasted magnetic substorms, solar flares, coronal hole ejections, cosmic rays oscillations and special measurement campaigns including scheduled balloon and rocket launches. Further-more, alerts will be issued based on International Geophysical Calendar and on special periods determined by the Coordination Board. Communications will take place by telephone, telex, telefax or special messages through the World Solar Forecast Center. It is anticipated to have at least one measurement alert per month issued, but not more than one period per week.

### 5.3. Data Center

The data from network will consist mainly of two types:

- (a) hourly average of electric field, conductivity, current density, meteorological background and
- (b) measurements of one second intervals for limited time period of Maxwell current and electric field in connection with solar and magnetospheric events.

5.4. In the hourly average the World Data Center at Voeikov Main Geophysical Observatory, Leningrad USSR will be used. For high resolution data a new data center in the U.S. will be established.

### 5.5. Time plane

This program starts as soon as possible but not later than to be able to coincide with the schedule of STEP.

### 5.6. Network of Stations

At Madralin a preliminary list of stations to participate in the GAEM Program has been established. Some are already in operation, others being developed. Further participation is solicited.

- \* Antarctica: (1) Program of the USA: eight unmanned (automatic) and manned stations proposed; (2) Possible participation of other countries, eg. USSR and others.
- \* Bulgaria: Institute of Hydrology and Meteorology of Sofia, one station.
- \* India: (1) Department of Physics, Kashmir University Sinagar; (2) University of Roorkee with nine stations proposed.
- \* Mexico: Section de Electricidad Atmosferica, Centro de Ciencias de la Atmosphere, one station under development.

- \* The Netherlands: Bays-Bollot Laboratorium, Utrecht, 1.
- \* Poland: Insitute of Geophysics, Polish Academy of Sciences, two stations in Poland, one station in Arctica (Spitzbergen).
- \* Sri Lanca: University of Colombo, Department of Physics, one station.
- \* Sweden: Department of Meteorology, Uppsala University, one station.
- \* USA: (1) University of California, Los Angeles - one station; (2) Pacific Missile Test Center, Point Mugu CA - one station; (3) Rice University, Houston TX - one station and US stations in Antarctica; (4) Colarado Scientific Inc., Berthond, CO - one station; (5) Colotron Research Inc., -Boulder, CO - one station; (6) International Commission on Atmospheric Electricity - one station.
- \* USSR: (1) Geophysical Observatory of Institute of Earth Physics, USSR Academy of Sci., Borok, three stations; (2) Rostov Institute of Engineering, Rostov, 6 dormand stations; (3) University of Irkutsk - one station; (4) Voeikov Main Geoph. Observ. Leningrad, one station; (5) Tartu University, Tartu Estonia Atmosph. Electr. Laboratory - one station.
- \* Vietnam: Vietnamese Academy of Sci., Phu-Lien, one station.

#### 5.7. Contact with other Organisations

The Coordination Board will maintain contact with ICSU, WMO and SCAR.

It will establish coordination with STEP and IGBP from which it seeks endorsement. GAEM will also maintain contact and co-ordinative activities with appropriate national programs such as the "Global Circuit Commission" of the USSR and the "All-India Coordinate Program on the Global Circuit".



## THE GLOBAL CHANGE REGIONAL RESEARCH CENTRES (RRCs)

### REPORT FROM IGBP WORKING GROUP 2 IGBP/IIASA/UNESCO/PAS

#### SUMMARY

A network of Global Change Regional Research Centres will be designed to promote and instigate research on a regional basis in the IGBP. These centres will focus on interdisciplinary aspects of global change research. The number of RRCs is thought to be small (about 10) and to be located in different areas of the world in response to the scientific questions, biogeographic representation, the existence of institutions of appropriate nature, geopolitical considerations as to national commitment, stability, access etc. The selection of a specific site within a region should be based on four major criteria: 1) the existence of a scientific institution or "nucleus"; 2) interest of local scientists and of governments of the region; 3) availability of logistical support, and 4) access to the RRC for visiting scientists and technicians.

The RRCs should provide regional institutions with possibilities of expanding present interests towards global understanding and convenient access to global data sets. RRCs will be continental or subcontinental centres with strong links to other scientific institutions within the region and even to appropriate local stations. They would be especially involved in analysis, interpretation, synthesis and modelling of global change phenomena and use this information for assessments and predictions at the regional level. Training and exchange programmes will be established in the RRCs, especially in the use of new technologies and in data synthesis and modelling in interdisciplinary areas. Each RRC would develop differently according to site specificity, scientific questions and other considerations, but common to all will be a minimum structure that assures that they can meet the general objectives.

The relationships among the various RRCs as well as between the RRCs and the IGBP, and to other networks within and outside

the region are shown in Fig. 1. Depending on the selected scientific priorities of field research and monitoring at each RRC, they will by necessity have direct links to the coordinating offices for relevant IGBP core projects. However, special links will have to be developed with the IGBP Coordinating Panel on Global Analysis, Interpretation and Modelling (CP5), as they will be the regional focal points for this IGBP research activity. This should be taken into account by CP5 during its deliberations and preparing their report to the 2nd SAC-IGBP. The RRCs will also be the regional focal points for the activities planned by the IGBP Working Group on Data Information Systems (WG1). The RRCs will enhance existing endeavours, taking into account the goals and decision-making processes of existing institutions in the region as well as the governmental and non-governmental organizations responsible for networks and programmes.

## INTRODUCTION

In May 1988, the first meeting of the IGBP Working Group of Geosphere-Biosphere Observatories (WG2) was held in Caracas, partially sponsored by Unesco. On the basis of the report from that meeting, it was concluded in "A Plan for Action" (IGBP Report 4) that "the development of an interdisciplinary integrated observatory network is a key step toward the investigation of global change". For this reason it was recommended that a network of Geosphere-Biosphere Observatories (GBOs) should be designated to facilitate the achievement of the underlying themes of the IGBP through the following primary objectives:

- \* to identify and decipher global change phenomena, as distinct from local or regional signals;
- \* to promote coordination, cooperation, and communication among participating disciplines and among nations in an attempt to facilitate global change research;
- \* to serve as focal points for documenting Earth system parameters, process studies, development and validation of models, and ground-truth locations for remote sensing data.

This was thoroughly discussed by the representatives from the Scientific Unions, the National IGBP Committees and invited scientists during the IGBP Scientific Advisory Committee (SAC-IGBP) in Stockholm, October 1988. During the SAC-IGBP and the regional meeting for the Southern Hemisphere, which followed in Swaziland, December 1988, a number of concerns were raised regarding the proposed structure and possible development of the GBOs. The Special and Executive Committees for the IGBP have discussed these points and were convinced of the need for the

GLOBAL CHANGE  
Regional Research Centres

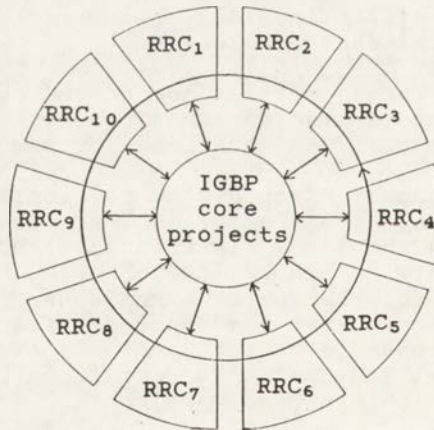
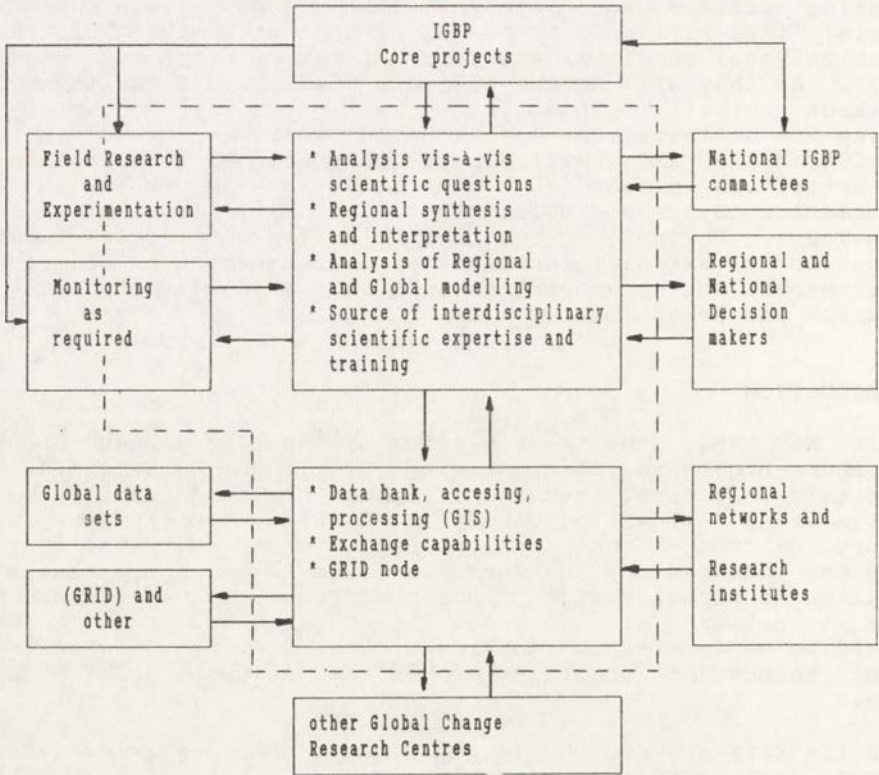


Fig.1



development of a network of regional IGBP centres, with special emphasis given to data compilation, analysis, synthesis and modelling of global change phenomena in a regional context.

In order to prepare further material for discussion, an ad hoc meeting of WG2 was convened in New York in May 1989. Apart from members of the Working Group, a few additional scientists were invited to take part in discussions. The SC-IGBP (meeting in Brussels, June 1989) evaluated the report from the New York meeting, approved the suggestion to change the name of the Working Group and hence the new name became "Global Change Regional Research Centres" and decided to circulate a revised version of the report to national IGBP Committees.

The Working Group on Global Change Regional Research Centres met in conjunction with a Scientific Seminar organized by the Polish Academy of Sciences in Warsaw, 25-28 September 1989, with support from IIASA, Unesco and IGBP. Twelve scientific papers were presented and discussed, in addition four papers synthesizing the philosophy and development of the RRCs were presented. This joint meeting offered an excellent opportunity to discuss the proposed concepts with a larger group of scientists in the fields of ecology, geography and long-term monitoring with experiences over a wide range of countries and/or international organizations. During the last two days a closed meeting of WG2 met in Jablonna to synthesize and discuss in detail the New York Report in the light of scientific input before and during the meeting. The group found the basic principles laid out in the New York document to be sound and proceeded to add some further perspectives which are incorporated in this report.

After closing the WG2 Meeting, Dr. Jane Robertson from the Division of Ecology, Unesco MAB, made a presentation on a proposal to carry out a feasibility study on the characterization of monitoring and research sites in the international network of Biosphere Reserves. Historically, an early joint proposal by Unesco, SCOPE and IUBS to create a network of Biosphere Observatories served as an initial basis for the discussions on Geosphere-Biosphere Observatories. Mention was made of the intention to convene a task force joint meeting to discuss further this avenue of cooperation at some time in early 1990.

## PURPOSES OF REGIONAL RESEARCH CENTRES

The main purpose of each RRC is to facilitate research on issues important to global change. They will also develop strong synthesis and modelling programmes of relevance to regional priorities and the overall IGBP objectives. The RRCs will stimulate the regional scientific community to establish links with a network of scientific stations for more specific or comparative studies relevant to the IGBP. The research will include a variety of approaches such as monitoring, experimental manipulation, integration and modelling. The RRCs will also help to

catalyze the integration of data from all regions into models at global scale.

Facilitation of regional research will involve at least five activities. The RRCs will:

1. Promote cooperation among scientists of the region in a network fashion for the purposes of: a) defining regional research questions that have global significance, and b) facilitate that research is carried out in a coordinated way.
2. Provide data management of regional and global data sets.
3. Encourage the sharing of research results among network scientists and establish mechanisms for sharing the results with scientists from other regions.
4. Develop synthesis and modelling activities.
5. Establish training and exchange programmes, especially in the use of new technologies and in the area of data synthesis and modelling.

Cooperation among scientists is at the heart of the IGBP. The RRCs will promote this cooperation from the beginning of the implementation phase of the IGBP. The initial cooperative task will be to make regional interpretations of the IGBP research plans. This will be done through a series of workshops within the region that are organized and run with the help of the region's RRC. A follow-on set of workshops will be held to promote cooperation as the research is carried out.

The RRCs will also promote cooperation between regional scientists and the IGBP organizational structure that includes Coordinating Panels, Working Groups and Scientific Steering Committees. This cooperation will ensure the appropriate siting and implementation of the core projects of the IGBP.

The management of regional data sets is a major responsibility of the RRCs. This responsibility has many dimensions including: 1) banking of critical subsets of data from regional research sites; 2) control over the quality of those data; 3) incorporation of appropriate data in regional geographic information systems that are in place at the RRCs; 4) providing scientists with access to global data sets they need to interpret regional research results or to conduct between-region research and synthesis. Help will also be available from the RRCs to various research groups within the region concerning their data management problems. Close links will be established with GRID (UNEP/GEMS).

The contents of the regional data bases must be available to all scientists and decision makers. The RRCs will encourage the sharing of research results by establishing easy-to-use communications networks within and among the regions. Electronic communication devices, newsletters, and scientific meetings will be among the tools used to achieve this goal of data exchange.

One of the major purposes of data exchange is to foster synthesis and modelling activities that will ultimately lead to predictions of the effects of global change on the capacity of the planet to support humankind. Each RRC will provide scientists with access to the computer hardware and software needed for synthesis. The RRCs will also promote training in modelling.

The training component of the RRCs will also include the use of new technologies and techniques. The training will most likely occur as short courses (weeks to a month), apprenticeship programmes (months to years), and exchange programmes between research sites in different regions. Initiatives such as the recent creation of the new International Centre for Earth and the Environment at Trieste, Italy could provide a focal point to involve scientists from the developing nations into General Circulation Modelling and data handling activities.

Finally, when the RRCs are fully developed they will communicate research results to regional resource managers and policy makers. This will be accomplished in a variety of ways according to the specific types of relationships between the scientific establishment, governments and non-governmental organizations within each region.

#### SITE SELECTION CRITERIA

The suite of sites that will make up the global network of RRCs will be selected through a two-tiered process. The first level of selection is the identification of appropriate regions of the globe (about 10) in which RRCs will be located. The second is the choice of specific regions and sites. The proposed criteria for each tier are given below.

#### SELECTION CRITERIA FOR THE IDENTIFICATION OF REGIONS

##### \* Scientific Consideration

Selection criteria of equal importance will be guided by the scientific questions that the IGBP will address, as expressed in the research plans for core projects that are now being formulated. The scientific questions, when taken together, may suggest some optimum way of dividing up the globe into regions. For example, it may be best to establish regions using the "biome" concept, although a "transect" concept has also been proposed. Other concepts than these should be considered. Once the scientific questions are set by the SC-IGBP, the selection of regions may go forward.

##### \* Biogeographic and Geopolitical Coverage

The goals of the IGBP demand the active participation of scientists and technicians from all regions of the globe, to



enlist the necessary corps of active workers, and to ensure that the research results of the programme are brought effectively to the attention of local and national governments. These factors argue for distributing the Research Centres in such a way that major biogeographic and geopolitical regions are appropriately represented. Particular attention must be paid to regions of the developing world, where the environmental concerns that drive the programme are often very acute and in most cases less studied.

The final selection of regions will be based on a judicious mixture of scientific, biogeographic and geopolitical considerations.

#### **CRITERIA FOR THE SELECTION OF SPECIFIC RRC SITES WITHIN EACH REGION**

It is proposed that the selection of a specific site within a region be judged according to four major criteria: 1) the existence of a scientific institution or "nucleus", 2) interest of local scientists and governments of the region, 3) availability of logistical support and 4) access to the RRC for visiting scientists and technicians.

It is proposed that the exact location of a RRC not solely be dictated by the specific scientific emphasis of the region but based upon the existence of a major scientific institution.

##### **1. An existing Nucleus**

Siting RRCs in existing institutions will accelerate the programme while saving set-up costs and minimizing the bureaucratic infrastructure that each will require. For these reasons, RRCs should be established, where possible, in active scientific institutions such as universities or research establishments which are multidisciplinary in nature or that have the potential of becoming multidisciplinary. These centres will serve as nuclei for further growth and networks of regional satellite stations.

##### **2. Interest and Involvement of Local Scientists and of National and Regional Governments**

The nomination of potential sites for an RRC should originate either nationally or through multinational agreements, on the basis of local scientific and governmental interest, to ensure the active participation of local scientists and technicians and to respect concerns of national governments. This is also needed to ensure stability and continuity in the host country.

### 3. Availability of Logistic Support

Certain logistic capabilities are another requirement for specific site selection. These include, for example, proximity to an international airport, the availability of reliable regional and international communications, housing for local and visiting staff, and a building and other structures to house the RRC. Additional resources to be desired include:

- \* A minimum number of research scientists, on at least part-time basis, to provide an initial "critical mass" of talent,
- \* A minimum number of support personnel, including research assistants, clerical and maintenance staff,
- \* A scientific library adequate for initial research activities,
- \* Computational facilities,
- \* Access to Geographical Information System (GIS), and
- \* The availability of a suitable conference facility in the area for the regional research conferences that will be an outreach activity of each RRC.

It is recognized that in a number of regions in which RRCs are to be established, many of these desired facilities might not be available, and they will need to be provided.

### 4. Access to RRCs by Visiting Scientists and Technicians

RRCs are by definition regional and of necessity international. Access to scientists and technicians from at least the region, who are not nationals of the host country, is an obvious need and a requirement of any ICSU activity.

### RELATIONSHIPS OF RRCs TO EXISTING NETWORKS AS WELL AS REGIONAL AND INTERNATIONAL ORGANIZATIONS AND PROGRAMMES

It is evident that the ways in which the RRCs will relate to existing networks and national and international organizations and programmes cannot be defined in detail until the scientific programme of the IGBP has itself been elaborated. However, there are some general principles on the approaches and the types of relationships which are envisaged.

In most regions, existing governmental and non-governmental networks will form the basis for the multidisciplinary work of the IGBP. The RRCs will enhance these existing endeavors, since they shall provide focal points for the integration of the wide range of data available to meet the needs of the IGBP scientific research programme, for the communication of this information across disciplinary boundaries, and thereby feedback to existing networks and programmes. Care should be taken in tailoring the RRCs to the specific socio-cultural conditions of each region, taking into account the goals and decision making processes of existing institutions as well as the governmental and non-

governmental organizations responsible for those networks and programmes.

There are in many parts of the world existing networks which have been established with disciplinary-oriented objectives. Such networks include observatories for the collection of data, monitoring of soils, water, vegetation, agricultural systems, physical and chemical state of the atmosphere, etc. Some of these observatories are part of national bodies, which in turn can be coordinated with regional or international networks. In addition there are sites dedicated to specific research programmes more or less independent of activities elsewhere (e.g. Long Term Ecological Research Sites in the USA, or the Unesco/MAB Biosphere Reserves). It is envisaged that the RRCs will play an important role in facilitating a wider use of data obtained from these sites for the multidisciplinary objectives of the IGBP. It should be clear, however, that the RRCs will not duplicate data management efforts.

An initial objective of the RRCs should be to provide inventory of activities within the specific region to enhance awareness of research activities. Special attention should be given to the development of appropriate links with programmes such as GEMS/GRID of UNEP. Indeed, in some cases, the RRCs might be linked to regional GRID nodes.

#### **FUNDING STRATEGY FOR GLOBAL CHANGE REGIONAL RESEARCH CENTRES**

Although it is difficult to establish a specific approach for funding the RRCs without knowing their exact number, location and funding requirements, it is possible to develop a general funding strategy focusing on the identification of the potential RRC funders and the conditions necessary to mobilize those funds. Based on the assumption that there will be approximately ten RRCs and half of these will be located in the developing world, a strategy for funding the RRCs must be developed that recognizes the fundamentally different conditions existing in both regions. The access to financial resources and strong institutions in the national setting of the developed world and the absence of these conditions, particularly the former, in the developing world, necessitate the creation of distinct funding strategies according to specific conditions.

Before elaborating on these strategies, it is important to highlight a number of general objectives for these funding approaches. These include that:

- 1) Funding be directed towards institutionalizing the functions of the RRCs within the regional setting;
- 2) Funding be as long-term and stable as possible;
- 3) Funding be programme directed rather than project driven and
- 4) Funding be for a whole programme of work including both administration and research; and that the RRCs programme of work



be directed as much as possible by scientific concerns as opposed to the interests of the funding bodies.

It is essential that funding for RRCs is directed towards an institutional framework within the regional settings. This institutional structure is necessary for a number of reasons, for example:

- 1) The RRCs will have multiple functions including scientific research, training, knowledge transfer and administration;
- 2) Because the RRCs will be multinational, institutional structures must be developed to be relatively politically neutral, and yet to have negotiating power with governments;
- 3) Well organized institutions tend to survive longer and be more stable than individuals, informal collaborations and tightly focused projects;
- 4) Strong institutions can better ensure that programmatic goals will be met rather than imply functioning as a collection of projects;
- 5) Institutions can better ensure continuity of strong and effective (as well as novel) leadership compared to other structures.

A critical responsibility of the RRCs leadership will be to insure that the scientific goals of the centre will be achieved even in the presence of changing funding body interests, demands of individual projects, or institutions and from other RRCs. Rigorous review procedures within funding cycles will be essential for both internal health of the RRC and external perception of the centre's activities. Mechanisms must be sought between the centre and funding agencies to fulfill these two needs but not be made so complex and frequent that they interfere with RRC activities.

The context in the Third World is such that the options of government and government-related funding for RRCs are almost absent. Most governments in the developing world have neither the resources nor the interest in funding global environmental related research. At the same time, per capita income and public awareness of the environment are generally low and therefore, one cannot expect to obtain public funding for the RRCs. Although some private foundations and corporations in the OECD countries may provide some funding for the RRCs in developing countries, they are not nearly as important as potential sources of funding as the multilateral and bilateral donor agencies. These agencies include the World Bank, US AID, the Nordic Countries (SIDA; NORAD, FINNIDA, DANIDA), JICA, CIDA, GTZ, ODA, French Government, etc.). They are responsible for most of the overseas development assistance to the Third World. As most of the agencies reflect to varying degrees their national priorities, it is not surprising that all these agencies have in recent years begun to focus their attention on the environment. Other funding sources for RRCs in the Third World in order of importance include: the private foundations and corporations mentioned above, the UN system and regional institutions/develop-

opment banks and environment programmes where they exist. Clearly the institutions to which the RRCs would be affiliated in the Third World cannot be expected to divert programme funds to the RRCs given the scarce and declining nature of these financial resources. Yet, these institutions should be required to make a minimal contribution in terms of providing to some extent staff time, accommodation, access to the scientific equipment and the library.

Unlike the case in the developed countries, the absence of the site selection for the RRCs should not prevent the preparation of a funding strategy for the RRCs in the Third World given that the funding sources are international in nature. This strategy should be aimed at developing a consortium of international funding bodies which, as in the case of the CGIAR, would allocate funds as a group based on agreed long-term RRC programmes of work and budget.

### IGBP REGIONAL RESEARCH CENTRES - A PLAN FOR ACTION

To ensure the future development of the IGBP as a whole and the RRCs in particular, the IGBP should consider creating a RRC Advisory Committee to develop an implementation plan for the establishment of the centres, including appropriate fund raising activities. Such a committee will require as much attention as the IGBP Coordinating Panels, and its overall success or failure will determine the success of the IGBP in the future. A first meeting should, if possible, be arranged in 1990.

Given the precise definition of the mission of these centres, and the need for global participation in the IGBP, it is essential the regional centres are in place as rapidly as possible. Given that the IGBP has profound implications for sustainable management, these centres will play a major role in providing the necessary knowledge base for planning purposes in all major regions of the world.

## REGIONAL RESEARCH CENTRES OF THE IGBP AND BIOSPHERE RESERVE NETWORK OF UNESCO MAB (Man and the Biosphere)

In 1971, Unesco launched the Man and the Biosphere (MAB) Programme to provide the scientific knowledge and the trained personnel required to improve the relationships between people and their environments throughout the world. Biosphere reserves are designated by participating countries as sites identified under the MAB Programme to undertake a combination of activities integrating nature protection, sustainable use of natural resources to meet human needs, and basic and applied research and monitoring.

As at end 1989, some 276 biosphere reserves exist in 71 countries, covering more than two-thirds of the major ecosystems of the earth. Since the launching of the IGBP, the MAB Programme has been identified as one of its intergovernmental partners. Indeed many of the scientists constituting MAB National Committees are contributing substantially to the formulation of the IGBP activities. MAB and IGBP links have been in particular forged around the use of the international biosphere reserve network established under MAB. In January 1987, MAB and SCOPE jointly convened a small workshop at ICSU headquarters in Paris to discuss the possible characteristics and siting of the then proposed geosphere-biosphere observatories (Dyer et al., 1988). The IGBP Working Group at its meeting in Caracas (Venezuela) on 2-4 May and subsequently the IGBP Scientific Advisory Council (Stockholm, 24-28 October 1988) largely followed the conclusions of the report prepared as a consequence to this Workshop and recommended that a hierarchical network of sites be established. At that time, it was envisaged that a number of carefully selected biosphere reserves could serve form part of this network.

The IGBP ad hoc meeting held at New York (May 1989) and the working Group 2 meeting in Warsaw (Poland) in September 1989 however recommended the setting up of a limited number of Regional Research Centres for which the exact purpose and siting would be determined once the scientific programmes of the IGBP had been elaborated. The role of MAB and biosphere reserves in developing this aspect of IGBP was again acknowledged and the IGBP Secretariat invited MAB to re-state the interest of biosphere reserves when further defining IGBP activities.



## WHAT ADVANTAGES CAN BIOSPHERE RESERVES OFFER?

These are of several types:

- a) the international biosphere reserve network offers the advantage that it exists already. As biosphere reserves are nominated by participating countries for designation under the international MAB label: by this, countries are proposing these sites for international exchanges of information and personnel under a mutually accepted understanding of purpose and standards;
- b) many biosphere reserves are located in areas which are vital to studies on global change, for example at interfaces between desert and semi-desert, between tundra and boreal forest, at coastal areas and high mountains with well defined vertical zonation which will serve to detect "shifts" in the distribution of vegetation types with climatic change;
- c) biosphere reserves are generally grafted on to protected areas such as nature reserves or national parks within the legislation of the country concerned. They can be used as background sites for comparative purposes with areas under greater human impact and for research to better understand short-term fluctuations against longer-term trends;
- d) number of biosphere reserves are located in areas that have been the focus of long term ecological research and observations and/or have excellent research and monitoring facilities. These facilities and data sets have been recently inventoried through a recent survey of biosphere reserves (Wargo and Gregg, 1989). For example, the tropical forests of Luquillo Biosphere Reserve in Puerto Rico have been investigated in detail for already 100 years; and arid ecosystems in the Repetek Biosphere Reserve in the USSR for almost 80 years. Many of existing biosphere reserves, such as the Konza Praire Biosphere Reserve in the USA serve already as pilot areas to find out how to link space observations with in situ measurements in an optimal way.

The convergence of IGBP work with MAB biosphere reserves also offers advantages as follows:

- a) although the MAB Programme has numerous themes and orientations (see Unesco, 1987), there is a need to generally improve the scientific programme of the overall biosphere reserve network. It has been suggested that this improvement could best be tackled on a regional basis where countries have a common ground for cooperative scientific efforts along binding themes (eg. temperate forest degradation in Northern Europe; soil erosion and land use change in South and South-East Asia);
- b) the MAB Information System keeps a file of a standard format descriptions for all biosphere reserves with the help of the services of the World Conservation Monitoring Centre at Cambridge (UK). Most of the descriptions are static, for example size, status of legal protection, altitude, mean annual

precipitation and temperature, physical features, flora and fauna. In only a few cases has there been an attempt to measure features which would provide for a comparison of data between biosphere reserves: one example comes from the USA and the USSR where comparative methods are being undertaken in "twinning" biosphere reserves possessing analogous characteristics. Such work needs to be expanded to other sites so that a minimum set of parameters are continually monitored in order to respond to present and future research hypothesis;

- c) MAB has adopted an interdisciplinary approach, i.e. it promotes the interaction between disciplines of both basic and applied sciences which are required for a given land use problem. For example MAB will bring together specialists in the natural sciences (plant ecology, soil sciences, ecotoxicology) and the social sciences (human geographers, urban planners) to study and propose solutions to a given problem. The study of global change adds a dynamic dimension to all MAB work so that focus is given on adapting to change. Here, MAB can benefit from the work of the IGBP to better understand the rate and scope of change (for example warming of tundra ecosystems; changes in seasonal rainfall patterns in the tropics; sea level rise) in preparing its work for the future;
- d) The international biosphere reserve network has been built up from the conceptual stage since 1974 and is continually improving in terms of number and quality of sites. It is probable that the work of the IGBP can help to further this process by focusing attention on certain critical ecosystems which are currently under-represented in the network (for example moist tropical humid forests, coastal areas) and in developing research of local and global significance.

In conclusion, there are many ways in which MAB and IGBP can mutually strengthen each other. In the period end 1989-early 1990, MAB will be organising a certain number of planning meetings for developing the international biosphere reserve network and the MAB Programme in general for the period 1990-95. The subject of goal change will be a major concern in the design of the strategies to follow and hence MAB will be in a position to offer a substantive basis to the launching of RRCs and the related IGBP research programmes in the coming years.

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- Unesco, 1987. *A Practical Guide to MAB*. Unesco, Paris.
- Wargo, J. and W. P. Gregg Jr., 1989. *Analysis of the biosphere reserve survey*. University of Yale, Connecticut. (in press).

## PROGRAMME OF SESSION

September 25

- 08:00-09:00      **Registration**  
(Hotel "Solec", Warsaw, Zagórna 1 Str., tel. 25-92-41)
- 09:00-10:00      **Opening adresses**  
\* PAS Authorities  
\* IGBP Special Committee and Working Group  
\* IIASA  
\* Organizing Committee
- 10:00              **Scientific session 1: Geo-Biosphere processes in continental scale**  
Chairman: Prof. L. Starkel
- 10:00-10:30      *Climate and vegetation of Central Europe in warmer periods in the past* - Doc. dr M. Ralska-Jasiewicz, Institute of Botany PAS, Cracow, Poland
- 10:30-10:45      Discussion
- 11:15-11:45      *Trends and variability of climatic changes in the region of King George Island (South Shetland Islands, Antartica)* - Dr V. Martianow, Prof. S. Rakusa-Suszczewski, Institute of Ecology PAS, Dziekanów Leśny, Poland
- 11:45-12:00      Discussion
- 12:00-12:15      *The "Global electric circuit" Project. General concept and interrelations of atmospheric, lithospheric and cosmophysical processes* - Dr S. V. Anisimow, Earth Physics Institute, USSR Academy of Sciences, Moscow, USSR (short communication)
- 12:15-12:45      *Long-term fluctuations of hydroclimate in North-Eastern Europe* - Doc.dr M. Gutry-Korycka, Dr J. Boryczka, Department of Geography, Warsaw University, Poland
- 12:45-13:00      Discussion
- 14:00-14:30      *Organic matter decay in a climatic transect in North-Western Europe; relation to soil climate* - Doc. dr B. Berg, Swedish Agricultural University Uppsala, Sweden



- 14:30-14:45 Discussion
- 15:00 **Scientific session 2: Silesia - black spot on environmental map of Europa**  
Chairman: Prof. A. Ciołkosz
- 15:00-15:30 *Mining induced seismicity* - Prof. A. Kijko,  
Doc. dr J. Niewiadomski, Institute of Geophysics PAS, Warsaw, Poland
- 15:30-15:45 Discussion
- 15:45-16:15 *Vegetation of industrial centres under prospective climate change* - Doc. dr E. Weinert,  
Martin-Luther University, Halle, GDR
- 16:15-16:30 Discussion
- 17:00-17:30 *The Upper Silesian industrial region as an area of ecological calamity*  
Dr A. Jankowski, Department of Physical Geography, Silesian University, Poland
- 17:30-17:45 Discussion
- 17:45-18:45 Moving to Jabłonna
- 19:00-22:00 Reception in the PAS Palace of Congresses in Jabłonna

**September 26**

- 09:00 **Scientific session 3: Debates on monitoring and observatory systems**  
Chairman: Prof. T. Rosswall
- 09:00-09:30 *Monitoring contemporary geomorphological processes* - Prof. D.E. Walling, Department of Geography, University of Exeter, Great Britain
- 09:30-09:45 Discussion
- 09:45-10:15 *Consideration on distribution of geosphere-biosphere observatories* - Dr C. Margules, CSIRO Division of Wildlife and Ecology, Lyneham, Australia
- 10:15-10:30 Discussion
- 11:00-11:30 *Concept of geobiosphere observatories and its application to study the changes at the Eurasiatic continent* - Prof. R. Zlotin and Prof. A. Tiszkov, Institute of Geography, USSR Academy of Sciences, Moscow, USSR

- 11:30-11:45 Discussion  
 11:45 **Scientific session 4: Global Change Regional Research Centres**  
 Chairman: Prof. R. Herrera
- 11:45-12:05 *The concept of global change Regional Research Centres* - Prof. R. Herrera, Centre for Ecology and Environmental Sciences (IVIC), Caracas, Venezuela
- 12:05-12:20 Discussion
- 12:20-12:40 *Considerations of site selection criteria* - Prof. T. Rosswall, IGBP-Executive Director, Stockholm, Sweden
- 12:40-13:00 Discussion
- 14:00-14:20 *The role and needs of developing countries in the network of Centres* - Prof. W. B. Banage, University of Zambia, Lusaka, Zambia
- 14:20-14:35 Discussion
- 14:35-14:55 *Funding and maintaining long-term research sites* - Dr R. Woodmansee, National Research Ecol. Lab., Fort Collins, USA
- 14:55-15:10 Discussion
- 15:40-18:30 **Working group sessions**  
 \* Structure and expected scope of the Centres  
 \* Site selections criteria  
 \* Relationship to other networks as well as regional and international organizations  
 \* Funding strategies
- September 27**
- 09:00-09:45 Moving to Jablonna
- 10:00-13:00 **Concluding plenary discussion in the PAS Palace of Congresses in Jablonna**
- 14:00-18:00 Sight-seeing of Warsaw
- September 28**
- 09:00-18:00 **Closed meeting of the IGBP Working Group 2 on Regional Research Centres in Jablonna**
- September 29**
- 09:00-18:00 **Continued closed session for the IGBP Working Group 2**

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