# Design of Ecological Networks for Monitoring Global Change

World-wide monitoring of agricultural and other natural-resource ecosystems is needed in assessing the effects of possible climate changes and/or air pollution on our global resource-base. Generally there are two choices for monitoring particular geographic areas, of which the first to consider is a detailed examination of all ecosystems in the area that could throw any light on those effects. This, however, is rarely possible except in small areas, and so we are left with the alternative, for most areas, of a sampling strategy that would select sites for examination. Monitoring of all sites is neither possible nor desirable for large areas, and so a means of choice has to be devised and implemented. The question then becomes: where should the necessary monitoring sites be located?

Monitoring sites that are truly representative of the kinds of sites which are found in an area, will provide more useful information than those selected otherwise. It is to be expected that monitoring data obtained from such a representative site would be useful for generalizing and extending from the available data, thereby *lowering the cost and time involved in monitoring*.

In recent years there have been numerous publications about ecosystems. In spite of this, only rarely (e.g. Breymeyer, 1981; Robertson & Wilson, 1985) have they used existing information about the geographical variability of ecosystems to design monitoring networks. None, so far as I am aware, has addressed the topic of *monitoring of ecosystems* in global environmental monitoring programmes. Moreover, manuals and handbooks do not specify how this should be done.

The foregoing paragraphs were adapted in part from a paper that I presented a year ago in Venice, Italy (Bailey, 1990). In that paper I discussed an approach for locating sites for monitoring predicted or at least possible effects of land management, and I now wish to examine this approach in terms of monitoring global change. This is timely because several national and international organizations and agencies — most notably NASA's 'earth systems' programme, the International Geographical Union's Commission on Geographical Monitoring and Forecasting, and the International Geosphere-Biosphere Programme, the Environmental Monitoring and Assessment Program (EMAP) of the US Environmental Protection Agency, the Global Environment Monitoring System (GEMS) of the United Nations Environment Programme, and the US Global Change Research Program — have expressed interest in this subject.

## *A Regional Approach*

To extend information from one site to another, it is necessary for the sites to be within ecologically similar types of lands. This requires the subdivision of the land into units displaying similarity among a number of geographical elements, such as ecosystems or ecological site units (ecocomplexes, *see* below).

Such an approach is based on the hypothesis that all replications of a particular ecosystem or allied type will show fairly similar behaviour and physiognomic response. This hypothesis has been questioned by a number of workers (for example, *see* Gersmehl *et al.*, 1982) on the grounds that correlations between ecosystem types and behaviour are apt to be low.

The reason for this is that the criteria used to classify the types were applied uniformly over an area, without due consideration of, or adjustment for, compensating factors. These factors may produce seemingly the same ecosystem type, but for different reasons. For example, the effects of climate may be modified by soil factors. It is well known that moisture-demanding species often extend into less humid regions on areas of sandy soils because these last tend to contain a greater volume of available moisture than do heavier soils. In humid climates, the same soil types support vegetation that is less demanding of moisture than it would be in dry climates. It is unlikely that the behaviour of a given type would be similar in diverse climates.

One way to establish reliable ecosystem-behaviour relationships is to divide the landscape into 'relatively homogeneous' geographic regions where similar ecosystems have developed on sites having similar properties. For example, similar sites (*i.e.* those having the same landform, slope, parent material, and drainage, characteristics) may be found in several climatic regions. Within a region, these sites will tend to support similar vegetation communities, but in other regions vegetation on similar sites will usually be different. Thus, beach ridges in the tundra climatic region support low-growing shrubs and forbs, whereas beaches in the subarctic region usually have a denser and taller growth of Black Spruce (*Picea mariana*) or Jack Pine (*Pinus banksiana*). Soils display similar trends, as the kind and development of soil properties vary from region to region on similar sites. These climatically defined regions suggest over what areas one can expect to find the same (physiognomically if not taxonomically) kinds of vegetation and soil associations on similar sites — *see* Hills (1960) and Burger (1976) for a discussion of regional differences in ecosystem and site relationships.

Furthermore, because of the interdependence of geographical elements, aquatic systems are linked or integrated with surrounding terrestrial systems through the processes of runoff and migration of chemical elements. By delineation of areas with similar watershed conditions in terms of terrestrial site characteristics, the freshwater aquatic systems which are embedded in them are thereby delineated. The aquatic systems delineated in this indirect way have many characteristics in common.

The theory behind such an approach is that climatic regions influence ecogeographical relationships, thereby militating for regional unity. Such regions delimit large areas within which local ecosystems (involving both terrestrial and freshwater aquatic sites) recur throughout the region in a predictable fashion. By observing the behaviour of the different systems within a region, it is possible at least to foresee the behaviour of an unvisited one. Hence a map of such regions can often be used to extend, spatially, expectable data obtained from limited sample sites. The results at representative sample sites from each region would be potentially useful in detecting and monitoring global change effects.

Application of this approach requires an understanding of the geographic patterns in ecosystems at varying scales of differentiation. These patterns are outlined below, followed by suggestions for locating sites for monitoring purposes. More details are presented elsewhere (Bailey, 1987).

*Geographic Patterns in Ecosystems*

As indicated above, climate is the most important factor influencing the relationships between vegetation, soil, and site properties. The basic idea here is that climate, as a source of energy and moisture, acts as the primary control for the ecosystem. As this component changes, the other components change in response. The primary controls over the climatic effects change with scale.

At the global scale, the ecosystem patterns are controlled by latitude (irregular solar energy), distance from the sea (continentality or oceanic influences), or elevation. Large ecosystem–climate units are arranged on the Earth's land areas in a regular, repeated pattern that corresponds with macroclimatic units, *i.e.* the climate that lies just beyond the local modifying irregularities of landform and vegetation, generally at the level of the broad climatic regions shown on the maps of W. Köppen (as modified by Trewartha, 1968). Maps such as these outline eco-climatic *zones* (much simplified without edaphic or anthropogenic influences being shown), each of which engenders characteristic ecosystems.

Each eco-climatic zone is clearly defined by a particular type of climatic regime and, with few exceptions, the zones largely correspond to zonal soil types and climatic climax vegetation. These zones seem to me to conform to the concept of 'ecocomplex' proposed by Polunin & Worthington (1990), to the extent that they are composed of spatially-related ecosystems. Called ecosystem regions, or ecoregions, they have been mapped and described for the United States (Bailey, 1980), and recently expanded to include also the rest of the continents (Bailey, 1989) based on a refinement of these zones. The new global map is on a scale of 1:30,000,000 (1 cm = 300 km) and was developed following a proposal by Bailey & Hogg (1986) to supplement the Udvardy (1975) system of biogeographical provinces with a treatment of higher resolution. On the 1989 world map (Bailey, 1989), 30 types of such zones are recognized. The global representation of one of these zones is shown in Fig. 1.

FIG. 1. *Generalized global pattern of the Warm Continental eco-climatic zone, herein referred to as an ecosystem region, or ecoregion. The map is simplified and drawn on a reduced scale from the Author's map (Bailey, 1989). In the Köppen system this area lies in the* Dca, *described as having very cold winters but warm summers. It is defined as having, for 4 to 8 months of the year, an average temperature of over 10°C, the average of the warmest month below 22°C, and no dry season.*

At the local scale, the pattern is controlled by microclimate and ground conditions — especially moisture availability. Within a landform there exist slight differences in slope and aspect, which modify the macroclimate to constitute a topoclimate, namely the climate of a very small space (Thornthwaite, 1954). As outlined by Hills (1952), there are three classes of topoclimate: normal, 'hotter than normal', and 'colder than normal'. In differentiating local sites within topoclimates, soil moisture regimes provide the most significant segregation of the plant communities. A common division of the soil moisture gradient is: drier, moist (normal), and wetter. A toposequence (Major, 1951), or a catena of soil moisture regimes ranging from drier to wetter as one proceeds from the top to the bottom of a slope, is an example of this.

Fig. 2 shows diagrammatically how topography, even in areas of uniform macroclimate, leads to differences in local climates and soil conditions. The climatic climax theoretically would occur over the entire region but for topography leading to different local climates, which

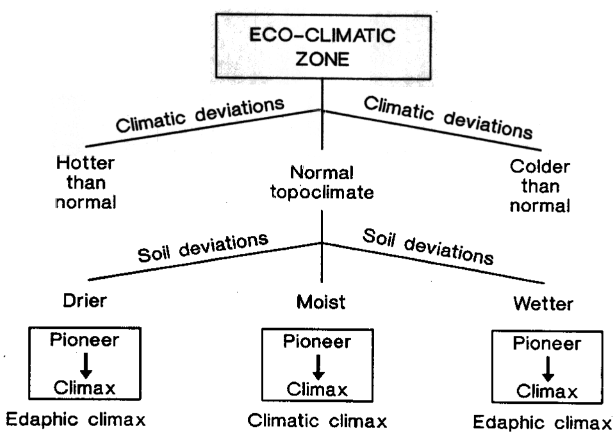


FIG. 2. *Deviations from normal topoclimate and normal soil moisture occur in various combinations within a zone (region).*

partially determine edaphic or soil conditions. On these areas different edaphic climaxes occur, whereas climatic climaxes occur only on mesic soils.

*Procedure for Locating Monitoring Sites*

Each ecosystem region is generally similar to its counterparts in the way in which the geographical elements associate themselves together on the land to form ecosystems. Within each region, there are the climatic and edaphic ecosystems that make up pertinent features of the region (Fig. 3).

These areas can be identified by careful study of local literature and on-the-spot inspection to determine the distribution of climax biotic communities and dominants in relation to landform position within a region. Then sites for monitoring can be located where similar relationships exist.

The areas at this scale correspond to areas with similar soil-particles' size and mineralogical classes, and similar soil moisture and temperature regimes. These are gene-

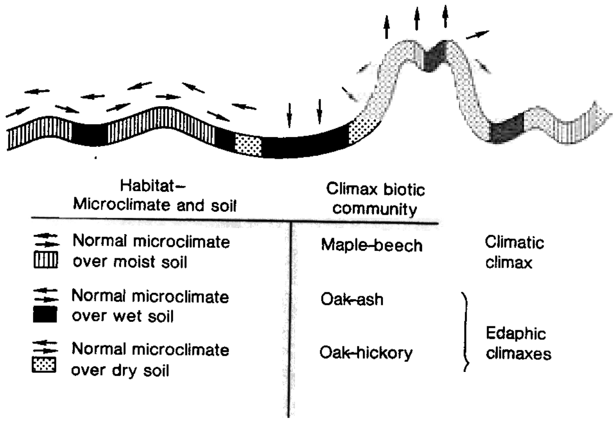


FIG. 3. *Different forest climaxes occurring in the Warm Continental zone of southern Ontario, Canada (simplified from Hills, 1952).*

rally the same differentiating criteria as were used to define families of soils in the System of Soil Taxonomy of the National Cooperative Soil Survey in the United States (USDA Soil Conservation Service, 1975). The potential, or climax, vegetation of these areas is the plant community with the rank of association, which is the basic unit of the school of phytocoenology involved.

This procedure for locating representative sites for sampling in such a way that data can be transferred to other sites, is based on an understanding of the relationships between climate and ecosystem distribution. Such understanding provides a basis for designing a monitoring network.

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## Joint Communiqué of Three Concerned Leaders*

Nineteen years ago, on this day of the calendar, delegates from all over the world gathered here in Stockholm for the United Nations Conference on the Human Environment. A few years before, the people of this planet had seen the first pictures taken from space of our one and single common home, 'small and blue and beautiful'. No wonder that the Conference theme became 'Only One Earth'.

The results of the 1972 Conference were of historic importance. The Stockholm Declaration laid down principles for the responsibilities of States which have never been challenged. The environment was firmly placed on the international agenda and its relationship to development acknowledged. The United Nations Environment Programme was created. Important conventions were signed in the follow-up to the Conference. A new awareness of the fragility of the world's ecological system began to influence minds and policies.

*World Changes During the Latest Twenty Years*

The world today is very different from that of 1972. Tremendous political and economic changes have taken place. But the impact of the Stockholm Conference has been felt throughout the period; environmental damage at the local and regional levels has been checked in many parts of the world, where progress, wealth, and advanced technologies, allowed countries to take effective action. Nevertheless, in other parts of the same world, most countries continued to face enormous economic and social problems — thus being unable to give the environment, in spite of increasing public awareness, the priority it might have otherwise deserved.

All these and many other efforts cannot conceal the fact that the planet's future is still at risk. Over the last decade, new and global threats have been perceived and others have become more acute — such as ozone-layer depletion, climate change, pollution of the oceans on a global scale, reduction of biological diversity, and degradation of land resources. The realization of those problems, whose consequences go far beyond national boundaries, leads to the realization of a sense of common responsibility towards the conservation of the planet's environment. The international community has to act as one — to tackle those problems in all their interrelated aspects — if we are to keep alive the hope of a better environment for the generations to come.

*Development Coupled to Environment*

Furthermore, we have begun to understand better that global environmental action requires global development action. Poverty is in itself both a cause and a consequence of environmental deterioration. The gravity of the detrimental effects of this vicious circle is particularly evident in the fast-growing cities of the 'developing' world, in which living conditions have been continuously deteriorating, sometimes to levels well below the minimum requirements of human dignity and surely of health. Individual responsibility for the environment, which is the basis for effective action, cannot be expected from people who see no hope of a better life. Solidarity at the international and national levels is a prerequisite for sustainable development.

Following the 1987 report of the World Commission on Environment and Development, all these strands came together in the resolution by the UN General Assembly to convene the United Nations Conference on Environment and Development that Brazil will host in Rio de Janeiro in June 1992. If the Stockholm Conference consolidated the inclusion of the environment in the international agenda, the Rio de Janeiro Conference is to be seen as a bridge between global environmental concerns, the many different initiatives already under way to face them, and a joint and concerted action by the whole international community — aimed at the promotion of new and environmentally sound models of economic development.

The unique amplitude and comprehensiveness of the agenda set forth for the 1992 Conference stand as a signal of the high hopes of the whole international community.

*Passing the Torch*

As the torch is now being passed — from Stockholm to Rio de Janeiro, from the Baltic to the Atlantic, and from North to South — Sweden and Brazil are united in a joint commitment to the cause of environment and development. The President of Brazil and the Prime Minister of Sweden, together with the Secretary-General of the Conference, solemnly pledge to spare no effort to make the Conference a success, and to cooperate closely in order to achieve decisions on concrete and effective action in Rio de Janeiro.

The Rio Conference is firmly placed in the perspective of the 21st Century. On this World Environment Day 1991 we look towards next year's great Conference as the dawn of a new era of international cooperation — a true global partnership for environment and development. *The Future of Our Only One Earth is In Our Human Hands.*

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* Issued in Stockholm, Sweden, on the occasion of the celebration there of World Environment Day, 5 June 1991 — *see also* the substance of the speech of the President of Brazil, entitled 'Passing of the Torch', to be published in our next issue. — Ed.



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