System ecological concepts for environmental planning

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ABSTRACT - Environmental management and planning requires specific approaches and methods derived from landscape ecology and ecosystem theory. The concepts of ecosystem and ecotope have proved very practical if carefully defined. Whereas the ecosystem has its place in the hierarchy of organizational levels — where it represents the first level which fully integrates non-living and living factors — the ecotope is the smallest homogeneous spatial component of a landscape. Problems in applying both concepts are discussed, and a special system approach symbolized by a pyramid is developed. It combines both reductionistic and integrative methods and appears appropriate in dealing with the complexity of environmental systems.

Introduction

The environment of the many different organisms on earth, including humans, is notoriously complex and difficult to explore. Its subdivision and classification, however, is a necessity for all measures required to utilize, manage, protect, develop or change the environment, all of which involves planning. A generally agreed classification suited to as many purposes as possible would be most welcome, but is difficult to achieve — because complex phenomena allow many different approaches to classification. In addition, classifiers tend to stick to their own preference, some even considering classification a goal in itself.

F. Klijn (ed.), Ecosystem Classification for Environmental Management, 49–67.

The need for environmental planning is a special challenge for environmental classification. It must be based on ecological concepts, which should be scientifically sound and operational, and should contribute to ecological theory, or have at least a heuristic value. During 25 years of work at the Landscape Ecology Department in Weihenstephan, a number of ecological concepts were developed, adopted from others, examined, modified, or abolished (Haber, 1992; Duhme et al., 1992). From this experience, the concepts of ecosystem and ecotope have proved most useful and practical. However, they need to be carefully defined.

The ecosystem concept

The ecosystem as level of organization or integration

When Tansley (1935) introduced the ecosystem concept, he stated that organisms cannot be separated from their specific environment with which they form one physical system. These systems, he continued, are the basic units of nature on the earth's surface for an ecologist and can be called ecosystems; they occur in many different forms and sizes and represent one distinct category among the physical systems of the universe, which extend from the universe as a whole down to the atom.

With this last remark, Tansley pointed to levels of organization, later developed as a distinct hierarchy by Egler (1970), who called them 'levels of integration', and adopted by Miller (1975) and many others. We modified and expanded the — still simplistic — hierarchy as shown in Figure 3.1. Each level can be regarded and investigated as a system of its own. To each level corresponds a certain spatial and temporal dimension or 'scale'. Each level is also defined by its 'emergent properties' which distinguish it from the lower levels — the properties of which, of course, it comprises. The notion of emergent properties has been rejected by Harper (1982) and Fenchel (1987), but has been proven correct for even the subatomic level by physicists. The realm of ecology and of much of environmental science is derived from this hierarchy encompassing several — in our case seven — organizational levels, with the ecosystem as the central one. Many other scientific disciplines are devoted to only one single level, e.g. cytology, or molecular biology, and even within ecology there is a clear tendency to restrict research to only one level, for instance, population ecology. But the integrative goal of ecology is

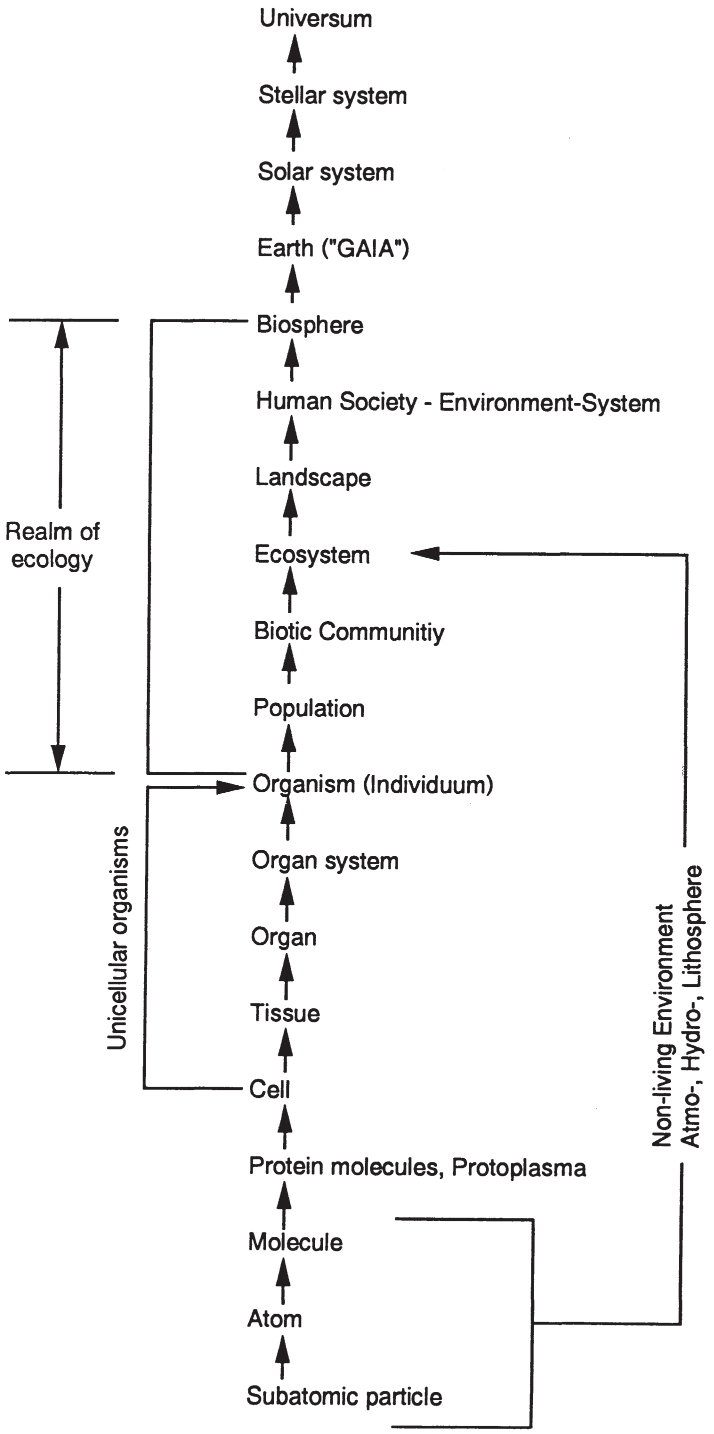

Figure 3.1 Hierarchy of levels of organization of non-living and living matter (from Haber 1993)

then disregarded. It is the very essence of ecology to relate different levels by 'downscaling' and 'upscaling', and to find out what, e.g. a certain environmental impact will mean for different levels — for which the results may be quite different.

Dimensions of the ecosystem

The place of the ecosystem in the hierarchy of organizational levels denotes that an ecosystem is a part or subdivision of a landscape as the next higher level, so its spatial dimension is restricted to a certain physical size or surface. By contrast, an understanding exists of ecosystems being of any size from the whole biosphere down to a small hedgerow between two fields. This is certainly not a workable concept. However, Ellenberg (1973, see also Ellenberg and Mueller-Dombois, 1974, p. 17), referring to this apparent lack of a given spatial dimension of ecosystems, introduced an elaborate classification of ecosystems into five categories, namely mega-, macro-, meso-, micro- and nano-ecosystems, that was as logical as it was comprehensive, but which did not find any wide application.

The ecosystem within the environmental spheres

There is another, much simpler hierarchical subdivision of the general environment, i.e. into 'environmental spheres', which was recommended and used by Van Leeuwen (1980). He distinguished the cosmosphere, atmosphere, hydrosphere, and lithosphere as the non-living environmental spheres, followed by the biosphere and pedosphere as living spheres (Figure 3.2). This hierarchical classification is important for the ranking of the effects of abiotic environmental or ecological factors, and should always be observed in environmental research and planning. We placed H. Walter's 'Standortsfaktoren' (Walter, 1986) into this hierarchy, which proved very valuable. Therefore, the environmental sphere approach was incorporated into the level-of-organization hierarchy (Figure 3.1). As the biotic organization levels from the molecular up to the community level represent a predominantly biological sequence, the non-living ecological factors are formally introduced into the hierarchy of organizational levels at the ecosystem level, thus making this level a particular and ecologically critical one. Ecosystems are the smallest components of the biosphere that can be regarded as systems themselves.

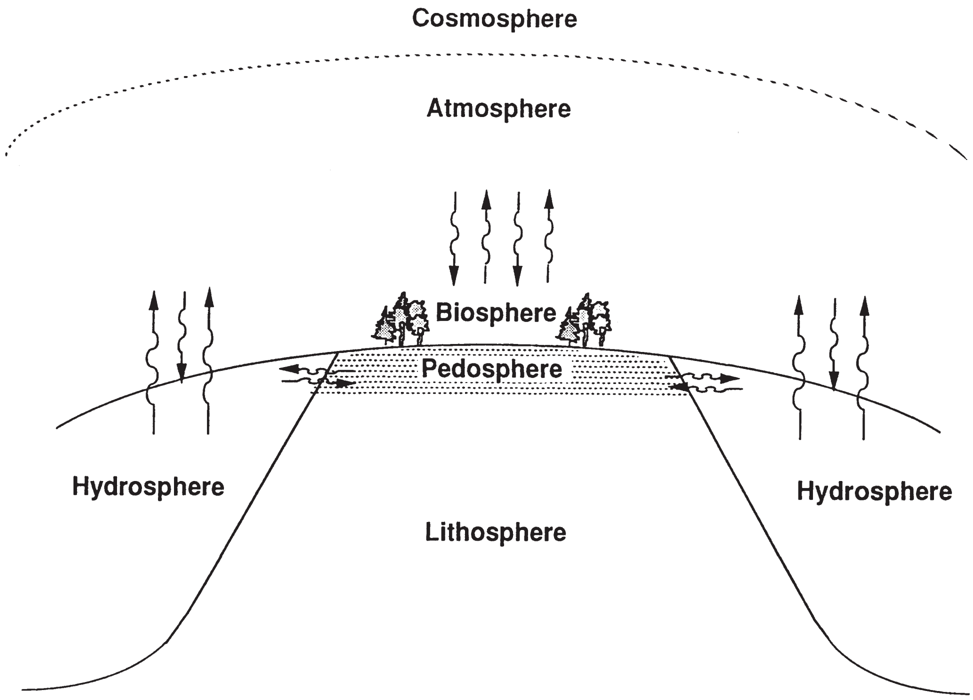

Figure 3.2 The environmental spheres and their hierarchy (Haber, 1993, after Van Leeuwen, 1980)

For understanding and explaining ecosystems from a functional point of view, we use the well-known functional scheme of a natural ecosystem modified from Ellenberg (1986); there is a terrestrial and an aquatic version (Figure 3.3). It does not need any further explanation here.

Problems in applying the ecosystem concept

The ecosystem concept is derived, as mentioned before, from an interaction of non-living and living components. The living components may be detached from the non-living ones and investigated as a biotic community with their own interactions. But it does not make sense — at least for an ecologist — to detach the non-living components from the ecosystem concept. They only typify the site of the ecosystem and point to the concept of ecotope, to be discussed below.

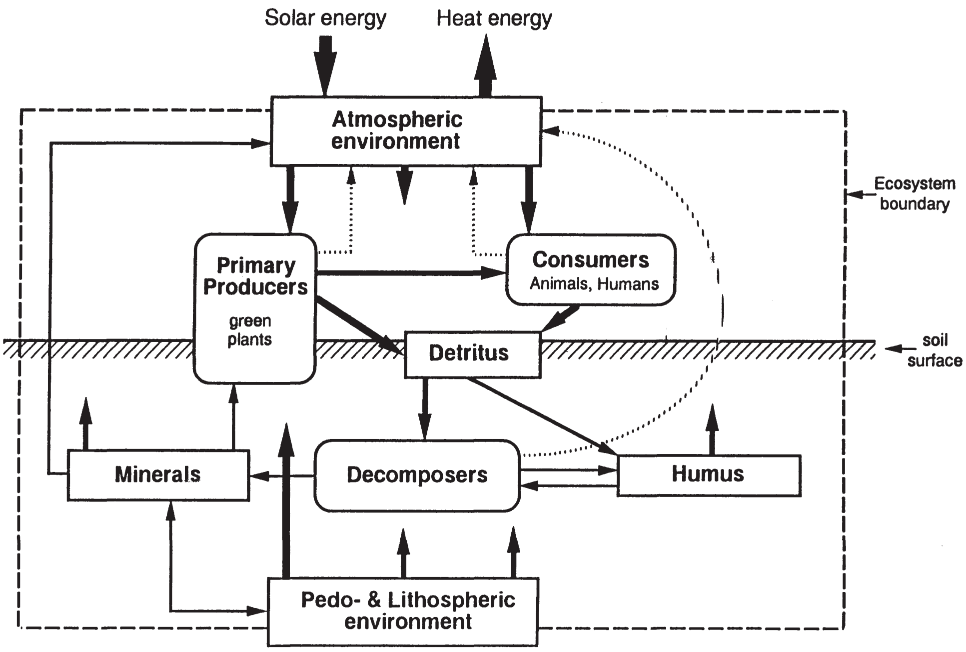

Figure 3.3 Simple functional model of a natural terrestrial ecosystem (adapted from Ellenberg 1986)

There is a problem with the ecosystem concept because it represents both an abstract unit (ecosystem type) and a concrete entity. For example, Kaule (1974) mapped and described a number of raised bogs in the pre-alpine region of southern Bavaria, each representing a distinct individual ecosystem, but all of them belonging to the same ecosystem-type of 'raised bogs'. In environmental planning, one is mostly dealing with concrete ecosystems, but sometimes, e.g. in conservation planning, with ecosystem types, too. To make a distinction and to avoid confusion, it has been proposed to call the concrete ecosystem 'ecotope' (cf. Naveh, 1984) (see below).

Another problem with the ecosystem concept is related to the fact that terrestrial ecosystems are defined (and also named) by vegetation characteristics. Animal ecologists have some difficulties in fitting animal communities and their biotopes, or animal habitats, into the ecosystem pattern, especially when working with larger vertebrates. The delineation of ecosystems clearly cannot be based on mobile organisms like freely moving animals, but only on immobile, firmly rooted and easily visible plants forming vegetation complexes. Yet, least part of the life cycle of every animal species can be assigned to a certain definable location — often with a specific vegetation structure — and, consequently, to a place in an ecosystem.

The ecotope concept

Origin and definition

As mentioned above, in environmental planning it is concrete sites that are to be dealt with or decided upon. Thus, many planners prefer a site approach. This desire can be met by the ecotope concept. Its origin is the discipline of landscape ecology. The first landscape ecologist was Alexander von Humboldt (1769-1859) who gave the first (and still valid) definition of 'landscape', but who did not mention landscape ecology, because 'ecology' was coined only six years after his death by Haeckel. The term 'landscape ecology' was introduced by Carl Troll in 1939. Both Humboldt and Troll were biology-minded and biologically trained geographers or landscape ecologists, respectively, which cannot be said of some younger landscape ecologists. It was Troll who coined the term 'ecotope' in 1950. His aim was to recognize the smallest component parts of the complex entity of a landscape. For these 'landscape cells' or 'tiles' ('Fliesen'[1]), as they were also called, he required spatial homogeneity which was basically defined by abiotic criteria, in particular physical and chemical properties of the substrate (bedrock) such as porosity, texture, pH, calcium content, silica content, etc. These properties constitute a small geographical land unit called physiotope or geotope. It may be colonized by organisms which are adapted to, and gradually transform, the physiotope by interacting with the physico-chemical properties. This interaction of living and non-living components constitutes an ecosystem and changes the physiotope into an ecotope. This change is manifested by phenomena such as humus and soil formation, the establishment of a special microclimate, of long-living plant structures and the creation of new ecological niches, to mention only a few.

Therefore, an ecotope is a concrete ecosystem at a given and defined site (cf. Haber, 1990a; 1993). There is some confusion caused by confounding 'eco-

[1] Schmithüsen (1948) introduced the term 'Fliesen' into his German explanation of the landscape mosaic which he liked to compare with a tiled floor or wall of a house or room ('Fliesengefüge'). Troll (1968) rejected 'Fliese', which he considered unsuitable for international discussions because it is difficult to translate and even to pronounce.

tope' with 'biotope'. Biotope means, by definition, the location (topos = place) of a biotic community, that is the living part of an ecosystem. So far, ecotopes and biotopes would coincide, but the approaches are different: one comes from landscape ecology, the other from community ecology. The ecotope approach yields the ecosystem more operational for planning purposes and results in a better fit in the hierarchy of organizational levels (see Figure 3.1). We tried to transform the functional ecosystem scheme (Figure 3.3) into a corresponding ecotope scheme (Figure 3.4), in which the key ecological processes are indicated by various arrows.

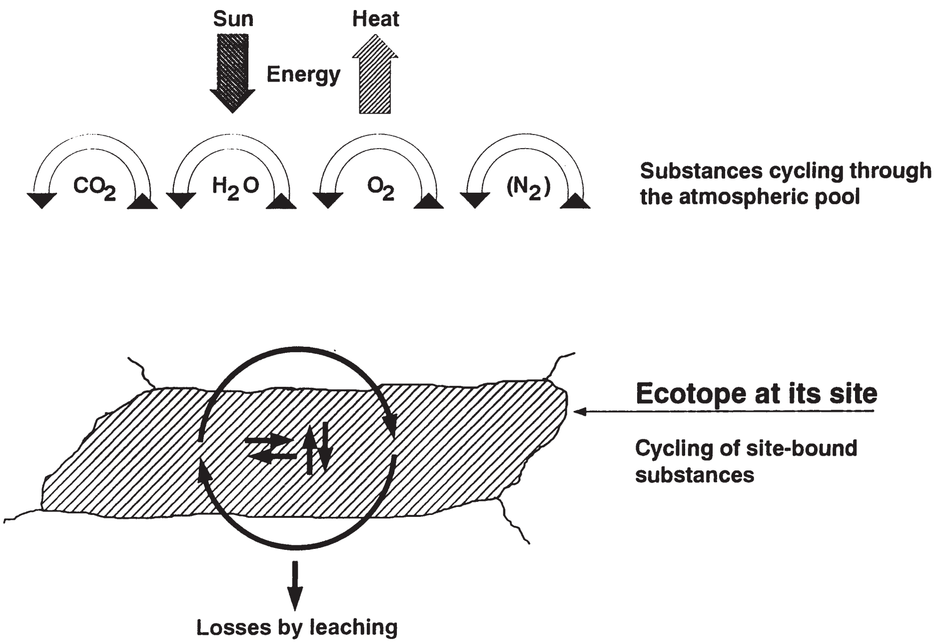

Figure 3.4 Model of a single ecotope at a given site as the basic component of a landscape. Note two types of matter cycling or flux: one through the atmosphere, the other bound to the site (circular pair of arrows). Vertical pair of arrows: relationships between organisms and site. Horizontal pair of arrows: relationships between organisms (from Haber, 1990b)

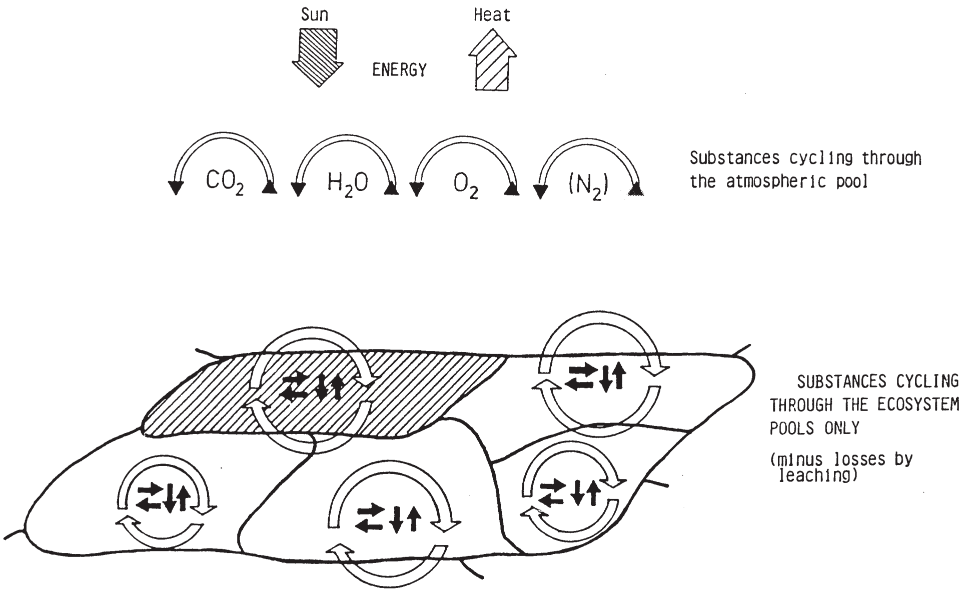

Figure 3.5 Ecotope pattern on level terrain. (From Haber, 1990b.) For explanations see Figure 3.4

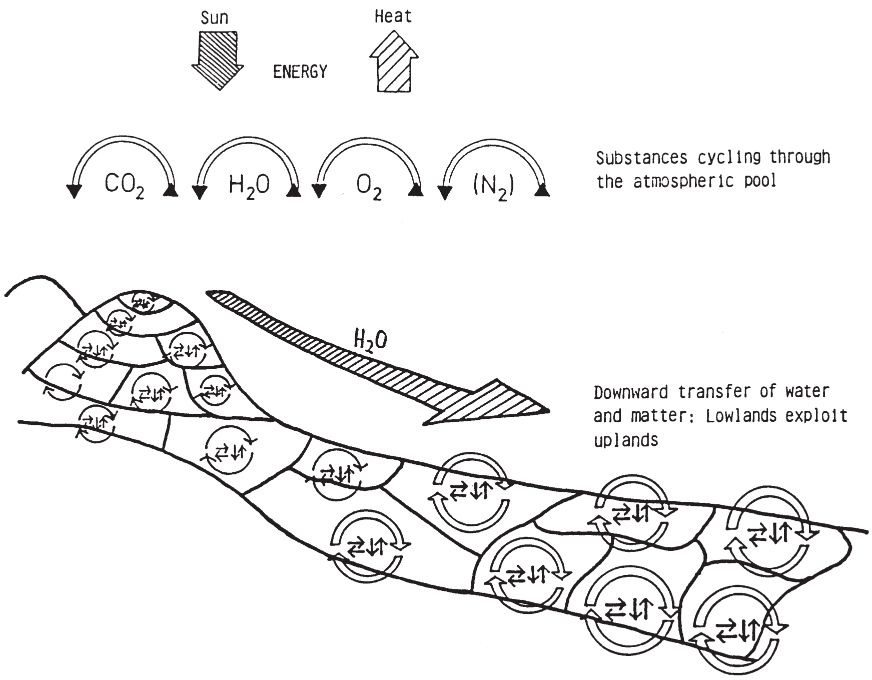

Figure 3.6 Ecotope pattern along a slope. For explanations see Figure 3.4. (From Haber, 1990b)

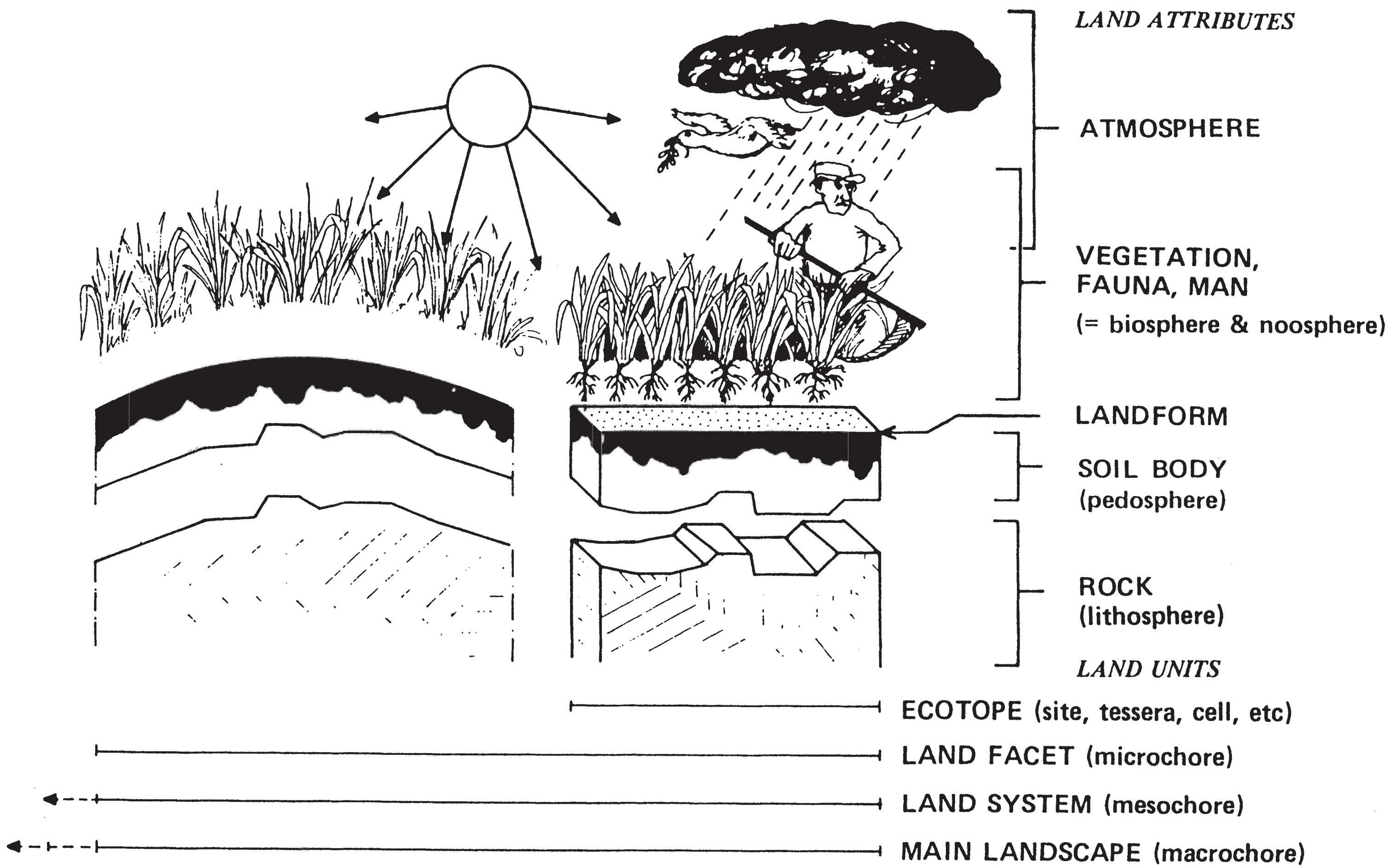

Figure 3.7 Spatial dimensions of landscape ecological units, based on the ecotope (from Zonneveld, 1990)

The ecotope pattern in the landscape

A landscape — also called ecosystem-complex or ecotope-complex, or, in geographical terms, a 'chore' — is considered as a pattern or 'mosaic' of ecotopes. Controlled by the general climatic, geological and relief conditions this is always a typical 'set' of ecotopes. The ecotope pattern of a natural landscape is largely determined by the physico-chemical properties of the bedrock which, however, may be altered or blurred by soil formation. Basically, there are two general ecotope pattern types:

1. on level terrain, where the lateral near-surface connections between ecotopes are few (Figure 3.5),
2. on inclined terrain, where the downward movement of water and substrate results in strong lateral connections and colluvial accumulations at foothills and in floodplains (Figure 3.6).

With pattern type no. 1, vertical interactions between ecosystem components dominate over horizontal interactions between ecotopes, whereas with type no. 2, horizontal relations between ecotopes are much more important. These are generally directed 'top-down', i.e. from the most elevated ecotopes to those downhill.

Of course, human land-use will profoundly influence or alter this spatial pattern. A homogeneous ecotope may be cleared of its vegetation cover (thus virtually 'reduced' to a physiotope), then subdivided into two or more parcels differently utilized: fields, meadows, planted forests or housing areas. This would result in the disruption of the original homogeneity and in a set of 'new', anthropogenic ecotopes and/or ecosystems, respectively.

The best graphical representation of an ecotope in a landscape with all attributes was given by Zonneveld (1990) and is reproduced in Figure 3.7.

Problems in applying the ecotope concept

This combined ecosystem/ecotope concept (Figure 3.8) has proved practical for environmental planning and management, at best in fine-grained landscapes. A disadvantage is that it does not easily lend itself to a comprehensive classification, nor does it fit into existing classifications. We devised, following a suggestion of Westhoff (1968), a simple classification of 'Main Ecosystem Types' according to decreasing naturalness (Table 3.1). This does not

Table 3.1 Main ecosystem or land-use types arranged according to decreasing naturalness or increasing artificiality

A.	Bio-Ecosystems	Dominance of natural components and biological processes.
A.1	Natural Ecosystems	Without direct human influence. Capable of self-regulation.
A.2	Near-natural Ecosystems	Influenced by humans but similar to A.1. Little changed after human abandonment. Capable of self-regulation.
A.3	Semi-natural Ecosystems	Resulting from human use of A.1 and A.2, but not (intentionally) created. Change significantly after human abandonment. Limited capability of self-regulation. Management required.
A.4	Anthropogenic (biotic) Ecosystems	Intentionally created by humans. Fully dependent on human control and management.
B.	Techno-Ecosystems Examples: Settlements (villages, cities) Traffic systems Industrial complexes	Anthropogenic (technical) systems: Dominance of technical structures (artefacts) and processes. Intentionally created by humans for industrial, economic or cultural activities. Dependent on human control and on the surrounding and interspersed bio-ecosystems.

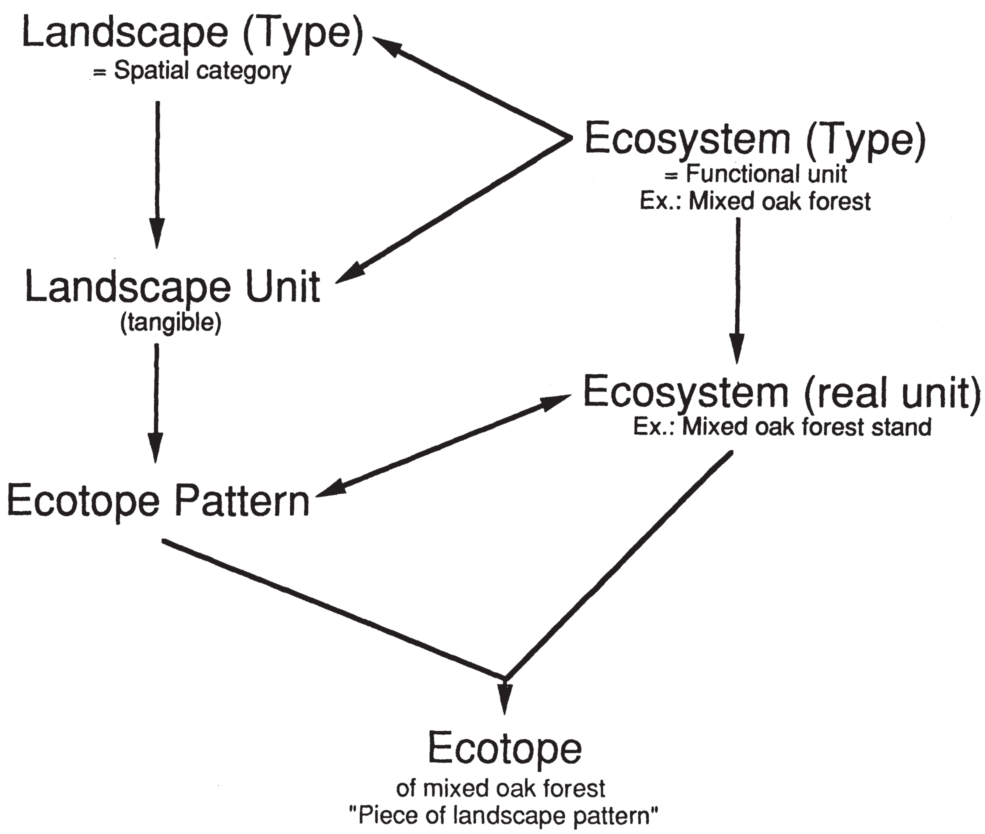

Figure 3.8 Landscape and ecosystem approach in landscape ecology

preclude the use of other classification systems, such as Ellenberg's (1973) mentioned before. And, also, it should be recalled that the available syntaxonomic vegetation classifications, in particular the continental Braun-Blanquetian system, offer excellent possibilities for ecosystem/ecotope classification. They are sometimes discredited for a too rigorous syntaxonomic emphasis, neglecting ecological connections or viewpoints; however, if used with less narrow-mindedness, the phytosociological approach is one of the most valuable tools for environmental management and planning.

The continental school of phytosociology has provided landscape ecology and environmental planning with an unrivalled, reliable basis of comprehensive ecological information (cf. Ellenberg, 1980; Westhoff, 1979), because of its thorough and detailed investigation, ecological interpretation, and floristic classification of Central European vegetation. This is especially the case after

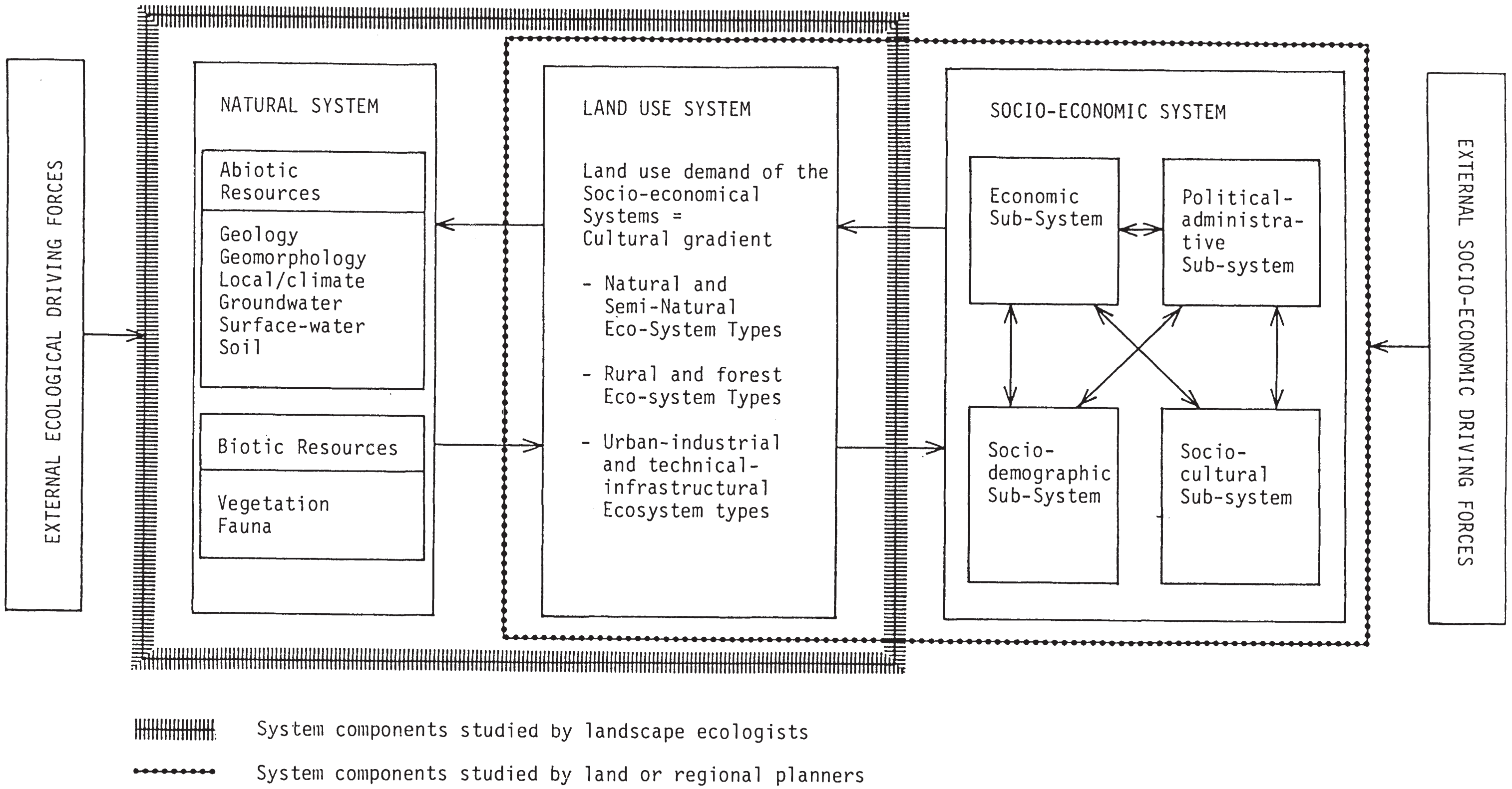

Figure 3.9 Simple model of a regional ecological-economic system. Explanation in the text. (Adapted from Messerli and Messerli, 1979)

a gradual shift away from 'pure' descriptive phytosociology and toward vegetation ecology (Pfadenhauer, 1992).

A system approach for environmental planning

Environmental management and planning needs additional system concepts to comply with new requirements and prescriptions. Looking at the hierarchy of organizational levels shown in Figure 3.1, much activity shifted from the ecosystem levels upward to the level of landscape and the society-environment-system. We can only briefly mention the concepts developed for these levels, but not treat them in any detail (see Haber, 1990a; 1990b; Haber et al., 1991; Tobias, 1991; Lenz and Schall, 1991; Kerner et al., 1991).

A very useful concept, originally developed by Messerli and Messerli (1979) for the Swiss Man and the Biosphere Programme (MAB 6), is the regional ecologic-economic system (Figure 3.9). It is a threefold system with the natural (eco-)system on its left side and the socio-economic system on its right side, representing the organization of nature and human society, respectively. The influence and imprint of the latter upon the former has produced the land use system, shown in the middle of the figure, which is nothing but our cultural landscape. Its gradient from natural to urban-industrial ecosystem-types corresponds to the classification shown in Table 3.1. Of course there are also external inputs and outputs, for example, air pollutants or government subsidies entering the regional system, and wastewaters or export goods leaving it.
To transform such a regional ecologic-economic system into an environmental planning or management model requires additional concepts allowing predictions and simulations. For such applications, a key problem is data availability and processing, characterised by the 'point-area dilemma'. One can get exact data from measurements only at a limited number of points that are expected to be representative for a given area. But for information about the whole area, one has to extrapolate from these points and, therefore, loses reliability. To avoid this and to be more exact, the number of measurement points may be increased, but this often requires a disproportionate expenditure of work and time, and one runs into another dilemma: the space-time dilemma. One can get reliable quantified data either in a spatial context or in a temporal sequence, but not in both dimensions.

To overcome these dilemmas, we have worked out a 'pyramid model' shown in Figure 3.10 (Haber, 1990a; Kerner et al., 1991). The bottom of the pyramid represents the cultural landscape or the regional system as shown in Figure 3.9. Here the 'ecological reality' with all its structures and processes is assessed and recorded, quantified wherever possible by measuring, counting, or weighing. However, this can only be done with high precision at a few carefully selected points (black dots in Figure 3.10).

To get an overall assessment of the whole region, the results of the point measurements have to be extrapolated and aggregated. This happens on the next higher level of the pyramid, called the 'spatial level'. The data are stored and processed in a geographical information system producing all kinds of maps and pictures of the region, input-output-comparisons and even plans — but only for specific points in time.

The dynamics of the region or of its components caused by human and other biotic activities, changes in inputs and outputs, etc., have to be assessed by introducing feedback processes. These require still more data aggregation and a higher degree of abstraction, and lead to a third working level called the 'temporal level'. Here, also, 'time charts' can be produced, showing where and when what changes will occur in the region under given impacts.
The last and uppermost level is the 'strategic level' where principal trends or changes in the regional system are estimated, using scenario or simulation techniques. Even erratic or catastrophic events can be simulated, of course in a more speculative way, but always supported by data from the lower levels.

The tapering of the pyramid symbolizes the unavoidable decrease in precision and reliability of both data and evidence. On each level, different methods of data processing are required, and different results are produced. But all data are derived from the same data set gained on the bottom level. Continuous validation of all results, especially of those having a predictive character, is necessary. It is achieved by iterative comparisons between levels and, in particular, with the lower levels. We call this procedure 'up- and down-scaling' or 'coupling of levels'. It prevents overemphasizing results of single-level approaches and methods. Thus, the pyramid concept combines reductionistic and integrative methods, which is very important for dealing with complex systems.

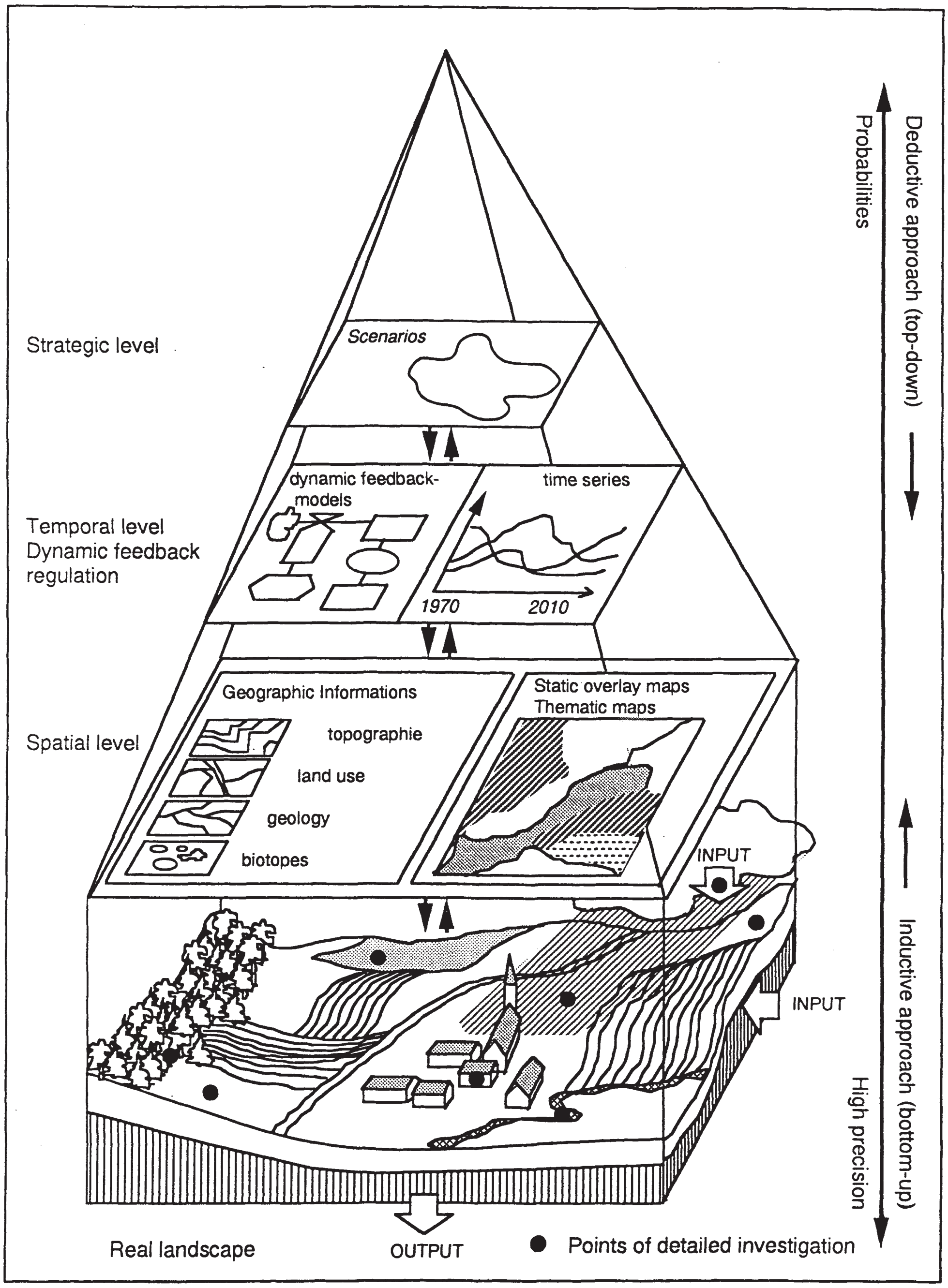

Figure 3.10 Different scale-adapted approaches to environmental management and planning of a given landscape or regional system. Explanations in the text. (From Kerner et al., 1991)

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