Landscape Ecology vol. 9 no. 2 pp 89-104 (1994)
SPB Academic Publishing **bv,** The Hague

A hierarchical approach to ecosystems and its implications for ecological land classification

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Keywords: ecosystem, (ecological land) classification, hierarchy (theory), spatial scales

Abstract

A hierarchical paradigm may help to better understand patterns of ecosystems. In this article we present and argue a framework for hierarchical ecosystem classification and mapping. It is based on a hierarchical model of an ecosystem fully incorporating abiotic components. We propose a nomenclature for hierarchical ecosystem classification based on common practice in ecological land classification and considerations on comprehensiveness which is inspired on and closely follows the Canadian terminology, but incorporating some frequently used European concepts. The relation between classification characteristics and the spatial and temporal hierarchy of ecosystem components is discussed. We exemplify that the approach is particularly valuable as a comprehensive tool for scientific analyses on behalf of environmental policy.

1. Introduction

For a better understanding of patterns in landscape ecology, Urban *et al.* (1987) advocated a hierarchical paradigm. Bailey (1985) earlier argued for the recognition of especially a spatial hierarchy of ecosystems also for reasons of a more adequate management. These pleas were held in a period during which a hierarchical approach was rapidly gaining ground in ecology and applications of (landscape) ecology in environmental sciences (O'Neill *et al.* 1986; Klijn 1988; O'Neill 1988). **A** special issue of Landscape Ecology was dedicated to Predicting Across Scales in a hierarchical context (see Dale *et al.* 1989).

In the Netherlands, a hierarchical approach can be traced back to at least 1976, when 'Towards a General Ecological Model (GEM) for Physical Planning in the Netherlands' (Van der Maarel and Dauvellier 1976) was published. In this document a spheric concept of our planet was suggested, in which it was regarded as an ecosystem with individual ecosystem components hierarchically ranked in spheres. The usefulness of this concept was relatively unnoticed for a long time, until Bakker *et al* (1981) specified it for the coastal dunes of the Netherlands and used it as a framework for a better understanding of processes in relation to management questions.

Recently, a generalized version of this hierarchical model of an ecosystem has received renewed attention, since it appears a comprehensive concept not only for understanding processes in ecosystems but also for relating these to spatial scales (Klijn 1988; 1991). In the latter function, it enables the formulation of a framework for classifying and mapping ecosystems at different spatial scales in behalf of environmental policy. This framework was established because it was noticed that many different elaborations of the ecosystem concept were used in landscape ecology and environmental science, each biased by a specific viewpoint and resulting in an overwhelming variety of different classifications. Secondly, it was noticed that the link between classification and temporal and spatial scales was not taken into account adequately in many instances. However, in some Canadian (Wiken and Ironside 1977; Bailey *et al.* 1985) and United States' (Bailey 1976; 1985; 1987; Hughes and Larsen 1988) examples of ecological land classification, a more systematic hierarchical approach is followed. Elaborating on these examples and relating them to the hierarchical model of ecosystem components, we formulated a framework for Hierarchical Ecosystem Classification (Klijn and Udo de Haes 1990).

In this article we present and argue this framework on hierarchical ecosystem classification. Firstly, we will briefly go into the ecosystem as central concept and the features of the hierarchical model of ecosystem components. Then, we will outline some general aspects of hierarchical ecosystem classification and examine current practice of ecological land classification in different parts of the world. Based on this overview and a number of general considerations on comprehensiveness, we propose a nomenclature for hierarchical ecosystem classification as now used in the Netherlands. The relation between classification characteristics and the hierarchical model of ecosystem components will be discussed next, and a brief description of the various classification levels will be given. Then, we shall discuss the problem of fitting in spatial or chorological relations. Finally, it will be exemplified that the approach is particularly valuable as a comprehensive tool for scientific analyses in behalf of environmental policy.

2. Ecosystem as central concept

In environmental science, we distinguish between a societal system and its physical environment, mainly for practical reasons. The environment is regarded as an ecosystem in order to incorporate all relevant interactions in the physical environment. Consequently, the environment as ecosystem becomes the central concept of our concern.

Some authors distinguish biological organizational levels above the level of the ecosystem, *e.g.* landscapes (Haber 1982*a.o.*), biomes or biosphere (O'Neill *et al.* 1986). However, Rowe (1961) and in his footsteps Schultz (1967) argue that the only organizational 'reality' which deserves looking at, is the ecosystem which can be understood as a tangible whole of interrelated biotic and abiotic components. The term ecosystem thus becomes scale independent, implying that there are small ecosystems as well as large ones, made up of smaller geographically related systems, presuming that the scientific viewpoint is not changed (see also Bailey, 1985). Despite the fact that landscape ecology has landscapes as research object, we will follow the opinion of Rowe and Schultz in this article. Landscapes, in this view, are merely very complex ecosystems. They should not be considered as higher organizational levels, but as larger scale levels.

Ecosystems are defined as communities in relation to their environment. In most ecosystem research, only the relations between biota and the *directly ecologically relevant* habitat characteristics are considered. Consequently, relations and processes in the abiotic environment which do not directly affect organisms are neglected then. They are considered as *external factors* and sometimes addressed as geo-factors (Zonneveld 1985). However, at larger spatial scales these abiotic processes are included in ecosystem approaches to the earth as a whole. At this spatial scale, atmospheric processes, geochemical processes, weathering, erosion, and soil forming processes are considered crucial for the stability of the ecosystem 'earth' (*e.g.* Arnold *et al.* 1990), even if their ecological effects are *indirect.* Especially in the context of research on global change, the abiotic environment is incorporated fully in an ecological approach of man's environment, since it is felt that such processes are relevant for our understanding of environmental problems (RIVM 1989; Klijn 1991). Also in landscape ecology, which generally focuses on larger spatial scales than the majority of ecosystem research, abiotic processes are often taken into account fully (*e.g.* Bakker *et al.* 1981; Vos *et al.* 1982). This goes especially for the ecological relevance of

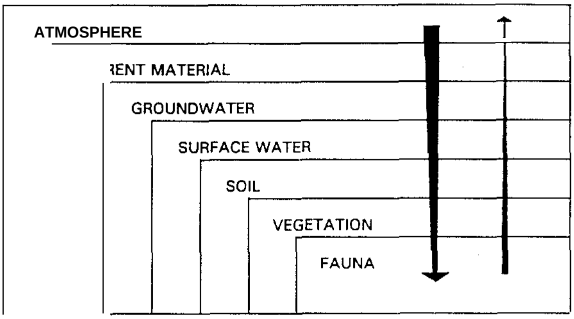

Fig. 1. Hierarchical model of an ecosystem (after Van der Maarel & Dauvellier 1978; Bakker ***et** al.* 1979; Piket ***et** al.* 1987).

ground-water flow and surface water flow (Pedroli, 1990).

Now, both the desire to have a central concept of ecosystems which is irrespective of spatial scale, and the experiences in landscape ecological research which demonstrated the fruitfulness of taking abiotic processes into account, can be considered arguments for a full incorporation of abiotic ecosystem components and processes within the ecosystem concept.

2.1. A hierarchical model of an ecosystem

When attempting to draw the outlines of a conceptual model of an ecosystem in which all abiotic and biotic ecosystem compartments are incorporated, we may end up with a much too intricate and complex picture for general purposes, which, moreover, differs for each ecosystem under consideration (*cf.* Odum 1983). Therefore, we must simplify our conceptual model, generalizing it by aggregating groups of compartments in ‘overall components’ which relate to each other in a way representing a rule rather than a case. Such a simple model, in which all abiotic components of direct and indirect ecological relevance are part, is shown in Fig. 1.

This model has a hierarchical character, meaning that the lower components are relatively dependent on those above (downwardly directed arrows). However, also the reverse influence of the lower ones on the upper ones cannot be neglected (upwardly directed arrows). **A** number of observations support this hierarchical model (free after Bakker *et al.* 1981), which can be ordered in two categories, namely a hierarchy of structure and a hierarchy of processes:

Hierarchy of structure:

- reservoirs diminish in size (parent material > soil > vegetation > fauna);
- patterns of the upper components are reflected in the lower ones (climate > soil; climate > vegetation; parent material > vegetation).

Hierarchy of processes:

- energy transport is commonly directed downwards;
- matter transport is generally directed downwards;
- genesis is determined (*e.g.* wind > dunes > sandy soils);
- the existence of lower components depends on the upper components (*e.g.* parent material > porosity > groundwater);
- changes in the relatively independent components have unavoidable effects on dependent components (*e.g.* climatic change > surface water discharge > soil erosion > vegetation).

2.2. Spatial and temporal scales

These two hierarchies also relate to spatial and temporal scales. This has been noticed by many authors (Leser 1976; Walter 1979; Odum 1983, *a.o.*) and is still an object of empirical research (Turner *et al.* 1989). We shall briefly elaborate on these scale aspects, because they support the hierarchical model. In this context we may also refer to Schultz (1967) who formulated a principle of temporal and spatial inclusion to be regarded as a prerequisite for the distinction of hierarchies of this kind.

As to spatial scales, we may observe that there is a difference in the spatial scale at which ecosystem components cause patterns in dependent components, predominantly the distribution of biota (Leser 1976; Van der Maarel 1976; Van der Maarel and Dauvellier 1978; Walter 1979; Bailey *et **al.*** 1985). Climate zones, for example, are a global phenomenon mainly determined by latitude and continental position. Geology determines moun-

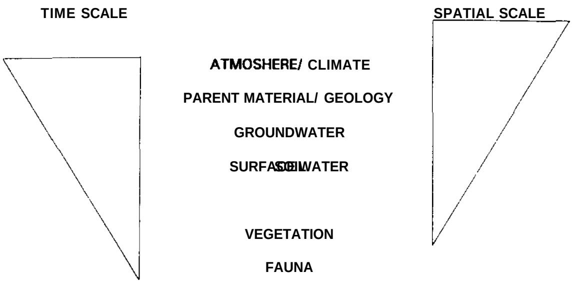

Fig. 2. The relation between ecosystem components and the spatial scale at which they are ecologically relevant and the time scale of relevant changes.

tain ranges and valleys at large scales, influencing relief, hydrology and soil formation. Soils show more fine-grained patterns, while vegetation superimposes an even finer pattern of various succession stages. In fact, the patterns we observe are a reflection of the hierarchy of structure mentioned above. In the hierarchical model this spatial hierarchy is reflected in the ranking of the components (Fig. **2**).

As to temporal scales, we may observe that the various components of the ecosystem are ecologically relevant at different time scales, as can be understood by looking at the natural rate of change in the character of the various components. Natural climate change generally takes tens of thousends of years. Geological processes such as mountain building, weathering, or meandering of rivers need as much time, but some processes may occur in decades, and disasters even within a day. Soil characteristics may change in thousands of years to centuries, although erosion may cause very rapid soil degradation even within a few hours. Vegetation may react within a year, although natural succession generally takes decades or even centuries, while fauna, of course, is the most rapidly responding component in ecosystems. These differences in the temporal scale of natural processes reflects the hierarchy of processes. It also accounts for the time lag which is so often encountered in the ecological effects of processes which imply abiotic changes first, such as acidification or climate change. The hierarchical model reflects these temporal scales in the sense that the most rapidly responding components are put relatively low in the hierarchy (Fig. 2).

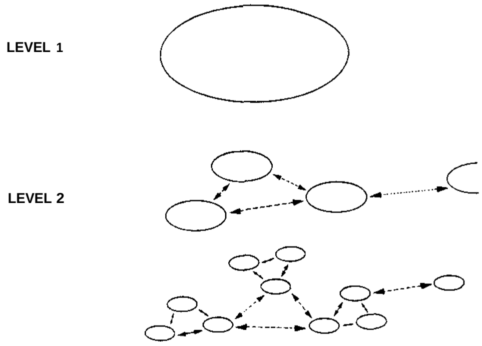

Fig. 3. **A** generalized hierarchical systems approach. Thick arrows indicate strong interactions, broken arrows indicate weak interactions (from: Urban *et **al.*** **1987).**

3. Hierarchical ecosystem classification

For distinguishing and delimiting ecosystems, it is often stated that we should use the criterion of the density of interrelations among biota on the one hand and between the biota and directly ecologically relevant habitat characteristics on the other. This would imply, that the density of relations is to be used as differentiating principle (Fig. **3).** In practice, this principle does not allow for the recognition of coral reefs or mangrove-ecosystems which, when we do recognize these, are fully dependent on external factors. The interrelations between the surroundings (sea) and the ecosystem we have recognized in this case are so vital and so dense, that we would not be allowed to delimit it when strictly applying this density principle. So, it does not match common practice. Common practice is much more straightforward.

In most instances, ecosystems are distinguished because they appear relatively homogeneous when compared with their surroundings. They may be considered as homogeneous constellations of abiotic and biotic ecosystem characteristics. This homogeneity is not absolute, but depends on the distance of the observer and the tools he uses for his observations. Consequently, different levels of homogeneity can be distinguished. This implies that ecosystems can be distinguished at different spatial scales: from entire oceans or climate zones to small ponds, hedgerows or even smaller. In general, pat-

Table 1. Comparison of the nomenclature of some ecological classification systems of hierarchical character, after Bailey (1981). Comparable concepts have been placed on the same level.

AUSTRALIA	BRITTAIN	CANADA	USSR	USA
			ZONE	
				DOMAIN
	LAND ZONE			DIVISION
	LAND REGION	ECOREGION	PROVINCE	PROVINCE
	LAND DISTRICT	ECODISTRICT		SECTION
			LANDSCAPE	
LAND SYSTEM	LAND SYSTEM	ECOSECTION		DISTRICT
	LAND TYPE	ECOSITE	UROCHISHCHA	LANDTYPE ASSOCIATION
LAND UNIT				
LAND TYPE	LAND PHASE			LANDTYPE
SITE		ECOELEMENT		LANDTYPE PHASE
			FACIA	SITE

terns or mosaics can be subdivided in finer patterns and mosaics again and again.

As a consequence, ecosystems can be mapped at different spatial scales, from very detailed to global. The maps can be regarded as hierarchical also, with the more detailed maps showing the internal variability of the units defined at the scale level above. This hierarchy can be understood as a hierarchy of nested ecosystems, as also conceived by Bailey (1985; 1987), and comparable to the nested systems as distinguished in geohydrology (Toth 1963; Engelen *et al.* 1988).

For the classification and mapping of such nested ecosystems the following principles are relevant:

- when zooming in, the detail is steadily increasing. Classes become more narrow and the number of limits increases;
- limits that have been defined at a certain level will, in principle, remain intact at more detailed classification levels. The differentiating characteristics of higher classification levels overrule those at lower levels;
- the limits between already existing mapping units may, however, be defined more accurately at more detailed mapping scales.

3.1. Ecological land classification in practice

When reviewing a number of ecological classification schemes from different parts of the world, it appears that many have indeed a hierarchical character. This goes, among others, for the Australian (Christian and Stewart 1968), British (Brink *et al.* 1965), Canadian (Wiken and Ironside 1977; Wiken 1979; Bailey *et al.* 1985), Russian (Isachenko 1973) and United States' (Bailey 1976; Bailey *et al.* 1985) classification systems, but also for the 'biomes' classification by Walter (1979) and a number of classification schemes from Central Europe (Leser 1991; Haase 1989). For an interesting and extensive treatment of approaches to ecological regionalisation in historical perspective we refer to Bailey *et al.* (1985). Upon closer examination of hierarchical classification systems, we see that some are characterized **by** nicely coherent ranges of classification levels for different spatial scales such **as** the United States', the British, and the Canadian systems, while others are rather complex in this respect.

When looking at the nomenclature, we notice a striking diversity. Almost all countries, and even individual scientists appear to be using there own nomenclatures. Some of these have been compared by Bailey (1981) (Table 1). A number of nomenclatures commonly used in the Netherlands, have been put in Table 2 in a comparable way. The nomenclature used by Walter (1976) is shown in Fig. 4. Still other nomenclatures can be found in Leser (1991) who compares a number of nomenclatures used in Germany, or in Haase (1989).

It is obvious that this review is by far complete.

***Table* 2.** Comparison of four series of nomenclature frequently used for ecological land classifications in the Netherlands (from Klijn 1988).

1	2	3	4
	SUPERREGION		
MAIN LANDSCAPE		DISTRICT	
	SUBREGION		
		GEOTOPE	LANDSCAPE
(SUB)LANDSCAPE			
		ECOCHORE	
LAND UNIT			PHYSIOTOPE
		ECOTOPE	ECOTOPE

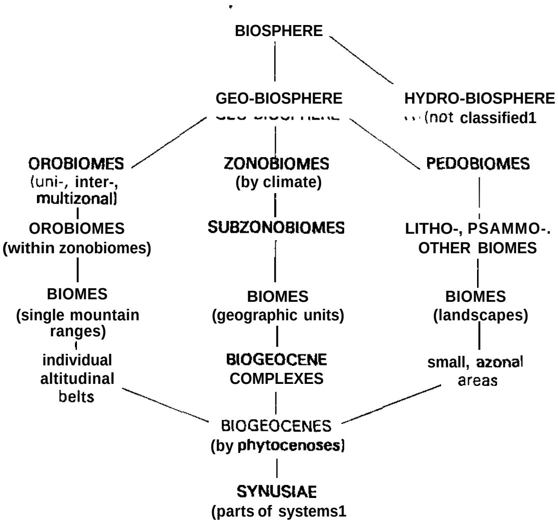

Fig. 4. Hierarchical levels of ecosystem classification on vegetation characteristics at different spatial scales according to Walter (1979). The nomenclature reflects the determining abiotic factors in a main climatic series (centre), an orographic subseries (physiography; left) and an edaphic subseries (soil; right).

No French or other Roman nomenclatures have been taken really into account (*cf.* Blandin and Lamotte 1988; Theurillat 1992), the eastern European countries have not been checked, nor have Asian classification systems been looked at. Part of the differences can be explained by different approaches, €or example a more chorological approach to landscape by those who study fauna relations against a topological approach by vegetation ecologists. Secondly, there are schools of landscape ecology sprouting from, for example, various countries or universities. Thirdly, different languages may explain part of the differences. Despite these largely valid arguments for a diversity in nomenclature, we state that it is a handicap in discussions among scientists and policy makers.

Also, with respect to the classifications themselves, many ambiguities can be detected. The majority of these can be traced back to insufficient attention for the spatial scale aspects of ecosystem components. This results in the selection of differentiating characteristics which are not suited for mapping at the desired mapping scale. Of course, a correlative relation exists between the ecosystem components which determine the pattern at that scale and the pattern of biotic ecosystem components resulting from the (causal) topological relations between components. This does not imply, however, that the biotic components are most suited as mapping characteristics. In this context, we would like to refer to the so-called Vegetation Map of Europe (Conseil de l'Europe, 1987), on which the Netherlands are entirely covered by only very few forest types. In fact, only 11% of the Netherlands is covered by forest, and the map is an interpretation of a geological map. The lithological differences reflected on this map are ecologically relevant alright, but the map ought never have been called Vegetation Map.

Reflecting on the above, we may state that a perfect combination of a really comprehensive nomenclature and an unambiguous relation between the use of differentiating characteristics and the scale aspects of ecosystem components is seldomly found or not at all. Below, we will firstly propose a comprehensive nomenclature which is closely connected with the conceptual framework we shall present next.

***Table* 3.** Nomenclature proposal for hierarchical ecosystem classification at various spatial scales.

	INDICATIVE MAPPING SCALE	BASIC MAPPING UNIT
ECOZONE	1: > **50.000.000**	> 62.500 km2
ECOPROVINCE	1: 10.000.000 – 50.000.000	2.500 – 62.500 km^2
ECOREGION	1: 2.000.000 – 10.000.000	**100** – 2.500 km^2
ECODISTRICT	1: *500.000* – 2.000.000	625 – 10.000 ha
ECOSECTION	1: 100.000 – 500.000	25 – 625 ha
ECOSERIES	1: 25.000 – 100.000	1,5 – 25 ha
ECOTOPE	1: 5.000 – 25.000	0,25 – 1,5 ha
ECO-ELEMENT	1: < 5.000	< 0,25 ha

3.2. Nomenclature proposal

As to a relatively simple and unambiguous nomenclature, there are two options: either the ecosystem component which determines the pattern of ecosystems we perceive must be specified, or we should use a relatively neutral nomenclature in combination with a blueprint or framework as to the classification and mapping procedure.

As to the first option, Walter (1979) may be referred to as a good example. He uses the words zonobiome for climatically determined patterns, orobiomes for physiographically determined patterns and pedobiomes for patterns determined by differences in soil. However, the biome concept considers the biotic ecosystem components, predominantly vegetation, as the one and only subject of concern. This does not match our ideas on ecosystems fully comprising abiotic components.

As to the second option, the United States' and Canadian systems (Bailey *et al.* 1985) can be considered good examples of relatively neutral nomenclature. In these systems, the classification criteria are defined very explicitly from the beginning onward (see Bailey 1981). This is also the case with the classification system of Leser (1976).

Mainly for reasons of simplicity and comprehensiveness, Klijn (1988; Klijn and Udo de Haes 1990) proposed a nomenclature according to the second option (Table **3).** The stress on simplicity and comprehensiveness was required to reach policy makers and to demonstrate the importance of ecosystem classification for environmental policy. Also, the first option would inhibit all flexibility as to the choice of classification or mapping characteristics even in parts of the world where deviating would be practicable. The nomenclature is largely copied from the Canadian and United States' nomenclatures (Wiken and Ironside 1977; Lands Directorate Environment Canada 1981; Bailey 1981; Omernik 1987; Hughes and Larsen 1988), which it almost entirely follows with the exception of ecoseries and ecotopes. These two concepts are already too commonly used and approved in Central Europe (Wagner 1968; Miiller 1970; Leser 1976; Haase 1989) and have proved practicable in classification and mapping. Consequently, the nomenclature is merely the result of a selection and combination of what we consider 'the best of two worlds'.

The proposed nomenclature has the following advantages:

- it is clearly related to the subject classified, since it begins with eco- indicating entire ecosystems in a holistic sense, and not merely vegetation or whatever other component;
- it is related to commonly used nomenclature for areas of different size (region, district, etc.), which are used in land classification all over the world;
- it is easily translated to almost all European languages.

The most appropriate mapping scales are also indicated in the table. These mapping scales show 'jumps' of four to five times, which is the common jump between frequently used mapping scales.

3.3. Classification characteristics

Ecosystem classification and mapping requires the determination of differentiating or mapping char-

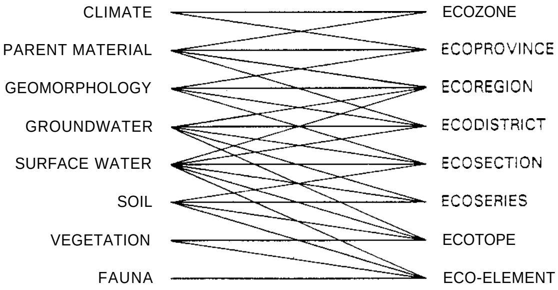

Fig. **5.** The relation between spatial scales and the ecosystem components which may yield the most adequate mapping characteristics.

acteristics. In other words: 'How to define discrete ecosystems and how to map their pattern on the surface of the earth?'.

Although at each scale level all ecosystem components are relevant, their relative importance may differ with different spatial and temporal scales. Hence, not all ecosystem components may be equally appropriate as mapping characteristic. As already referred to, climate is the cause of the differentiation of vegetation zones at a global scale, geological and geomorphological differences cause a subdivision, etc. etc. It appears that the sequence of ecosystem components can be traced down as a subsequent subdivision of ecosystems in reality. This is important for practical ecosystem classification, since it enables us to use the hierarchical model of an ecosystem as a guiding principle. Depending on the spatial scale, mapping characteristics must be derived from those ecosystem components which determine the observed spatial pattern. With this, we more elaborately follow the ideas already advocated by Bailey **(1985; 1987),** who also emphasized the use of factors controlling the distribution of ecosystems rather than those reflecting their ecological significance. Instead of his three levels to be distinguished, we recognize more levels with their own mapping characteristics, but on the same principles. This implies that relatively stable components such as parent material and physiography are most suited for mapping at small mapping scales **(1: >** 100.000), while for detailed mapping **(1 : < 50.000)** also soils and vegetation may be used as mapping characteristics. A guideline is visualised in Fig. **5,** using the nomenclature for the spatial scale levels and the hierarchical model of an ecosystem (Fig. **1)** for the ranking of ecosystem components. This guideline for ecosystem classification closely resembles a figure concerning the correlation between controlling factors and plant community boundaries by Van der Maarel **(1976,** p. **426).** The main difference is that Fig. ***5*** concerns a classification guideline for ecosystems, while Van der Maarel's figure can be understood as a generalisation of empirical findings which relates the hierarchical levels of plant community classification to controlling factors. Of course, our guideline is based on findings and generalisations of this kind.

The vertical relations between ecosystem components (Fig. **1)** guarantee the ecological relevance of the classification resulting in a large degree of correspondence between the patterns of the different ecosystem components. In fact, it is always 'correlative complexes' (Kwakernaak **1982)** we are concerned about in classification and mapping even if we can only use some ecosystem components as mapping characteristics at a certain spatial scale.

However simple this guideline, we would not suggest that either the precise selection of mapping characteristics or the characterization of legend units is a simple procedure. The accurate definition of classes and limits (legend units) remains a subject for correlative (*e.g.* Kwakernaak **1982)** and analytical research into the relations between ecosystem components, especially those between biotic and abiotic variables.

4. Brief characterization of the various classification levels

Ecozones

Ecozones are related to the world-embracing climate zones. They can be distinguished on the basis of, for example, the Koppen system for regional climates (Trewartha **1968).** The pattern is reflected by the zonal pattern of soils (Dokuchaev Soil Institute **1963;** FAO **1988)** and vegetation (Walter **1979;** Bailey **1987).** Hence, ecozones correspond largely with the zonobiomes of Walter **(1979)** or the domains and some divisions of Bailey **(1989).** The main well-known ecozone types are the arctic, the subarctic with tundra vegetation, the boreal zone with taiga coniferous forests, the temperate zone, the mediterranean, the (semi-)deserts, the dry tropical zone with savannas and the wet tropical zone with rain forests.

Also in the oceans, ecozones can be distinguished. These are determined by the interaction of climate and largescale ocean currents.

Ecoprovinces

Ecoprovinces are related to geological and geomorphological characteristics at very large scales and climatic variations resulting from large physiographic differences. The pattern of ecoprovinces would largely correspond with the pattern of the provinces as distinguished by Bailey (1989). Also the orobiomes and some pedobiomes of Walter (1979) are comparable.

As examples, mountain ridges such as the Rocky Mountains or the Alps may be mentioned, or the Scandinavian Shield or Great Plains.

Ecoregions

Ecoregions are homogeneous with respect to again geological and geomorphological characteristics. However, the geological subdivion may be more detailed, distinguishing between different rock types in large groups. For example a distinction between sandstones, calcaric rocks, marls, and various igneous rocks may be relevant at this scale level. Also, a further subdivision as to relative height (geomorphology) and the main surface water and groundwater flows may be made.

Typical examples from the Netherlands' ecoregion mapping are the slightly undulating Pleistocene sandy region, the Holocene alluvial plains and the Coastal Dunes (Fig. **6).**

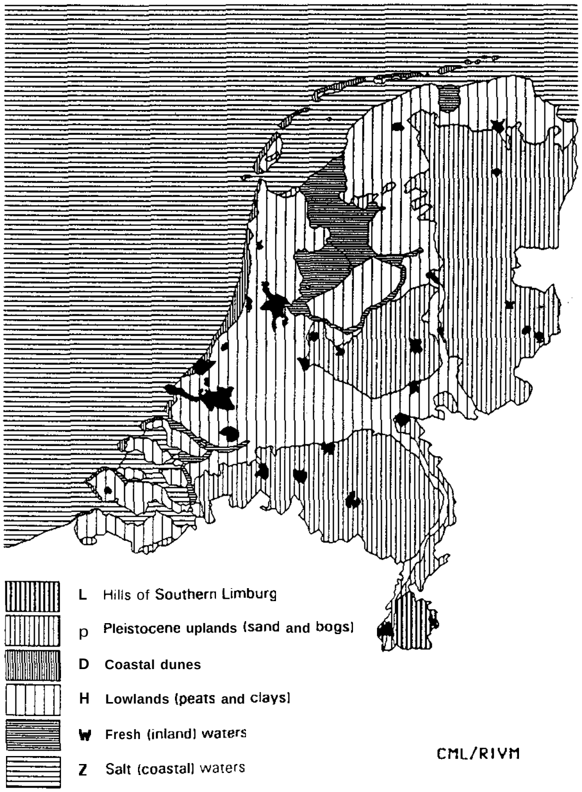

Fig. 6. Ecoregions of the Netherlands: an example of an ecosystem classification at an original scale level of appr. 1: 5 000 000, with geological and geomorphological characteristics as differentiating characteristics.

Ecodistricts

Ecodistricts are spatial units which are homogeneous as to slowly changing geological, geomorphological groundwater and surface water characteristics. These largely correspond with soil groups as determined by parent material. The geohydrological character of ecodistricts is relatively homogeneous with respect to infiltration and discharge of surface water on the one hand or upward seepage and concentration of surface water on the other. At this scale we may distinguish physiographic units such as large valley systems with Fluvisols, individual volcanoes with Andosols, deltas with Inceptisols, or salt lake plains with Solodic Planosols.

Typical examples from the Netherlands' ecodistrict mapping are Polders, Drained Lakes, Calcareous Coastal Dunes, Lowland Peats and Isolated Ice-pushed Ridges (Fig. 7).

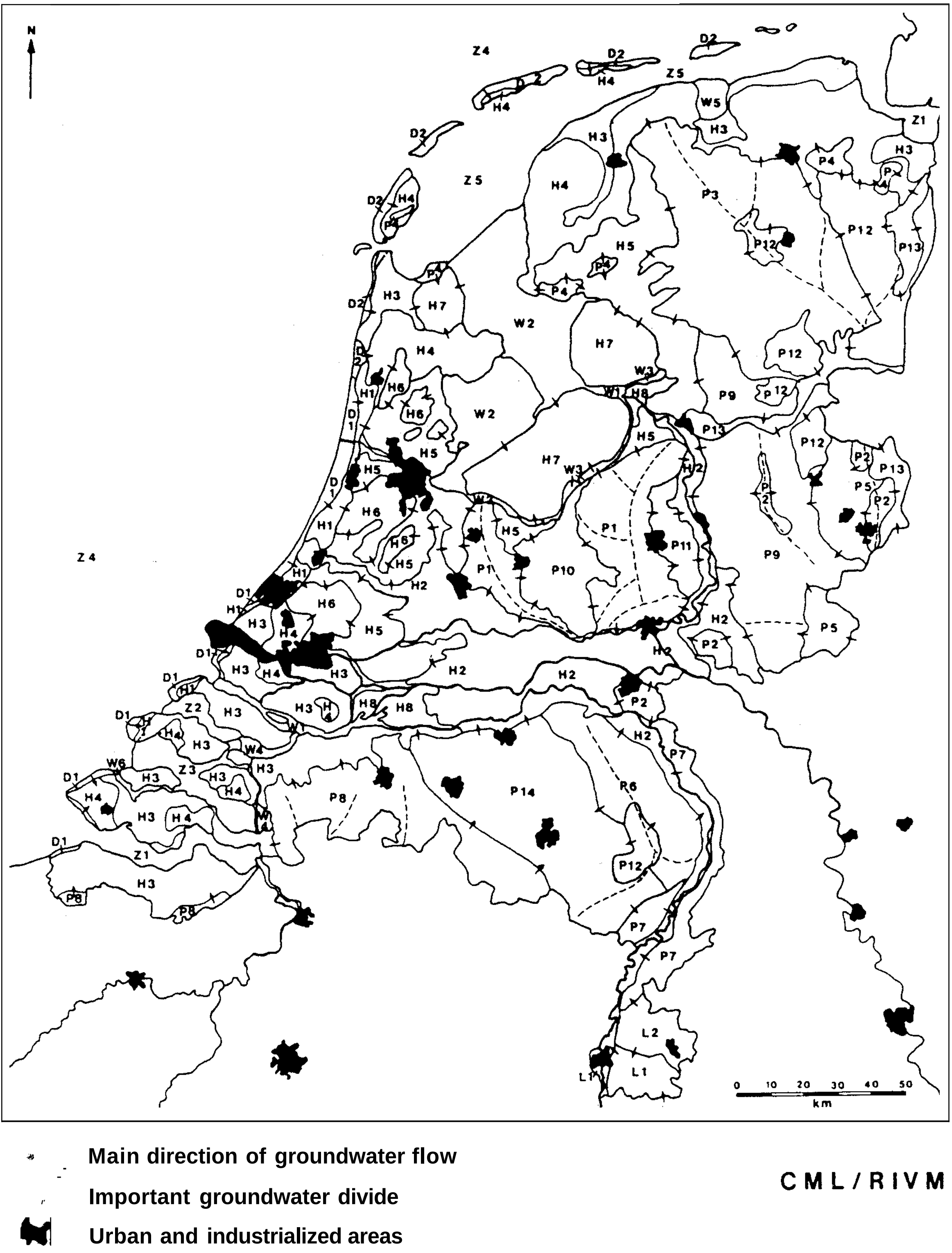

Fig. 7. Ecodistricts of the Netherlands: an ecosystem classification at a scale level one step below the ecoregions illustrating that ecodistricts are nested within the ecoregions (indicated with capitals as in the former figure). Geological, geomorphological, groundwater and surface water characteristics were used as differentiating characteristics.

Legend Figure 7

L1	Cretaceous hardrock landscape
L2	Loess landscape
P1	Ice-pushed ridge complexes
P2	Isolated ice-pushed ridges
P3	Till plateau
P4	Isolated till elevations
P5	Other till areas
P6	Tectonic ridges
P7	Old river terraces
P8	Fluvial sands landscape
P9	Eastern cover sands landscapes
P10	Glacier lobe valleys
P11	Sandr landscape
P12	Bogs and bog reclamation landscape
PJ3	Lowland brook complexes
P14	Tectonic subsidence area
D1	Calcareous coastal dunes
D2	Non-calcareous coastal dunes
H1	Beach barrier landscape
H2	Fluvial landscape
H3	Sub-recent dikings
H4	Marine clay inversion landscape
H5	Lowland peats
H6	Drained lakes
H7	Polders
H8	Deltas
W1	Sedimentation basins
W2	Fresh inner seas
W3	Lakes
W4	Closed estuaries
W5	Diked sea intrusions
W6	Brackish lakes
Z1	Estuaries
Z2	Saline lakes
Z3	Sea branches
Z4	Coastal seas
Z5	Wadden seas

Ecosections

Ecosections are spatial units which are homogeneous with respect to individual geomorphological features, such as lowland brook valleys, water divides, individual slopes, slumps, mud-flows, debris cones, etc. They are distinguished on the basis of geomorphology, soil groups and groups of groundwater regime (leaching or upward seepage). -

Ecoseries

Ecoseries are homogeneous as to abiotic site conditions which are relevant for plant growth. They are distinguished on the basis of abiotic characteristics of soil, groundwater and surface water, which can be determined without instruments other than a hand auger. The site characteristics used for classifying ecoseries must preferably be relatively stable for periods of tens of years when not disturbed by man. This almost automatically implies a kind of ecological soil classification, because the soil may be considered the most important site factor for plant growth in most parts of the world.

Within ecoseries, vegetation types can be encountered which differ in vegetation structure. These can be understood as succession stages, or semi-permanent stages due to land use practices, thus forming series of vegetation types related in time. Hence, an ecoseries classification and mapping is especially valuable for estimating potential or climax vegetations or for forecasting vegetation developments.

Ecotopes

Ecotope is a generally accepted term for the geographical extension of an ecosystem in Europe (Neef 1967; Haase 1973, 1989; Van der Maarel and Dauvellier 1978). The use of this concept by the above mentioned authors reveils that ecosystems of a certain dimension are referred to, such as a raised bog, an agricultural field, a small forest patch or a dune slack grassland. Hence, a certain spatial scale can be attached to the ending – tope. Stevers *et al.*

(1987) have specified the ecotope concept as: ‘‘... a spatial unit which is homogeneous as to vegetation structure, succession stage and the main abiotic site factors that are relevant for plant growth”. They distinguish ecotope types of relatively homogeneous site factor classes in combination with a homogeneous vegetation structure. The site factor classes are reflected by the species composition which is characteristic for the ecotope type (Runhaar *et al.* 1987). All species which can be encountered in a certain ecotope type together compose an ecological species group.

The definitions and descriptions by Stevers *et al.* (1987) do not take into account practical requirements of mapping. Their classification scheme is primarily focused on mere classifying. Consequently, ecotopes may be as small as ditch banks or road margins. We would rather advocate the incorporation of a criterion of spatial scale concerning ecotopes, thus following Van der Maarel and Dauvellier (1978) who refer to ‘a certain extension’. In fact, most vegetation mappings take into account such a criterion implicitly, as linear or point elements are left out.

Eco-elements

For the spatially most restricted ecosystems the term eco-element is suggested. Eco-elements may develop by vegetation processes such as string-formation in bogs, dominance of certain species with rhizome-multiplication, but also hedgerows or termite mounds may be regarded as eco-elements. These small-scale ecosystems may be mapped as patches, but only at very detailed mapping scales (1: < 10 000).

5. Discussion

In this article we have presented a framework for ecosystem classification and mapping at different spatial scales related to a hierarchical model of an ecosystem. This model is based on a generalization of the results of empirical research concerning correlative relations between ecosystem characteristics in spatial and temporal context. Notwithstanding the background of empirical research, the model is largely conceptual. In this context, we shall discuss two main requirements as to such conceptual models and the use of the related framework.

Firstly, the model and the resultant classifications and mappings ought to fit in overall landscape ecological theories and concepts currently accepted. This topic will be gone into first.

Secondly, the models and the framework derived from it should also be practicable to apply. In this context we shall briefly go into the classifications and mappings carried out so-far in the Netherlands, and glance at their applications in environmental policy analyses.

5.1. Landscape as a result of topological overlay **or** *as chorological complex?*

In landscape ecology, two main groups of relations are distinguished: topological or vertical relations and chorological or horizontal relations. The recognition of this ecological relation network is the major theoretical paradigm of landscape ecology.

The hierarchical classification scheme presented in this article is entirely based on topological relations between ecosystem components. These topological relations allow the recognition of the individual ecosystems at the earth’s surface on the basis of relative homogeneity. The landscape we distinguish may be considered the result of an overlay.

A view of landscape, which could be considered as perpendicular to this approach is the one that emphasizes spatial or chorological relations (for example Haase 1989; Forman and Godron 1986). Chorological relations are processes *within* an ecosystem component but *between* geographical units, such as groundwater flow or animal movements. From that viewpoint, landscape is a mosaic of patches (Urban *et al.* 1987) and corridors within a matrix (Forman and Godron 1986) or a chorological conglomerate (Zonneveld 1984). When taking a close look at this approach two groups of chorological relations may be distinguished. The first one concerns relatively simple physical processes within or between mapping units while the second one focusses on relatively autonomous movements of animals (Vos *et al.* **1982).**

As to the first group of chorological relations, it may be stated that these are subject to simple physical laws. Groundwater or surface water flow, the resulting displacement of sediments or seed, the movement of air or oceanic currents are examples of such relations. In general, the movements are from relatively high potential (elevated positions or high pressure) to relatively low potential (low position or low pressure). Because of this being subject to simple physical laws, it is easy to incorporate these relations within the framework of the hierarchical ecosystem classification. The chorological relations can be regarded as movements of matter or energy within an ecosystem component, but between mapping units at the appropriate mapping scale. Thus, air mass movements cause relations between ecozones and between ecoprovinces, groundwater and surface water movements can be mapped between ecosections and between ecoseries, and seed dispersal by wind between ecotopes. In fact, this group of chorological relations concerns the surpassing of limits between mapping units.

The second group of chorological relations are relations by animals, moving in heterogeneous landscapes between habitats or functional sites. Since many animals have the means of autonomous movement, these relations are not subject to merely simple physical laws of differences in potential. Such animals use the landscape in a sense which would rather require the approach as a chorological conglomerate. For small animals, it may be stated that they move mainly between ecotopes which are distinguished on the basis of vegetation structure. So this would not result in opposed views as to the nature of landscape. Large animals or birds with large home-ranges, however, may use large geographical areas which in some cases must be heterogeneous; *must* be heterogeneous in the sense of it being a habitat requirement of the species under consideration. The mapping units (landscapes) which are distinguished in this approach may be defined on the basis of specific heterogeneity or specific pattern characteristics which differ from those in other landscapes. This approach to landscape cannot be matched very easily with the hierarchical ecosystems classification, in contrast to the group of chorological relations treated above. Therefore, a specific approach to landscapes from a faunal point of view may remain necessary. An example of such a chorological approach at different spatial scale levels is the classification scheme presented in Landscape Ecology by Haase **(1989).** Even in its nomenclature, which includes nano-, micro- and mesogeochores, it reflects a chorological approach.

So, we would argue that the topological approach of ecosystems classification according to the framework which is derived from the hierarchical model can be matched with the majority of chorological relations without any trouble. However, for research on animals with larger home-ranges a deviating approach to landscape may be required.

5.2. State of affairs in the Netherlands

In **1988** both ecoregions and ecodistricts of the Netherlands were mapped (Klijn **1988)** for the National State of the Environment Study ‘Concern for Tomorrow’ (RIVM **1989).**

Ecoregions were the least detailed scale level for which a classification within the Netherlands was considered useful. The ecoregion classification comprises 4 terrestrial types and **2** aquatic types (Fig. **6).** Ecoregions of approximately the same character have also been mapped in the United States, where the most recent developments are the **EPA** elaborations (Omernik **1987;** Hughes and Larsen **1988).** In fact, ecoregions can be regarded as the ideal scale level for (parts **of)** continents, such as the United States or Europe. This explains the small number of ecoregions discerned in the Netherlands.

The ecodistrict classification for the Netherlands has resulted in **26** types of terrestrial ecodistricts and **11** types of aquatic ecodistricts. This makes up to **37** ecodistrict-types in total, as a subdivision of the **6** ecoregion-types (Fig. **7).**

An ecoseries classification for the Netherlands has been worked on since **1988. A** second approximation for terrestrial ecoseries has recently been released (Klijn *et al.* **1992).** Aquatic ecoseries are still subject to study.

The ecotope classification has been worked on since the early eighties. It is still further developed (Stevers *et* ***al.*** 1987; Runhaar *et* ***al.*** 1987), now covering the whole of the Netherlands. A preliminary classification of aquatic ecotopes has just been published (Verdonschot *et* ***al.*** 1992), also specifying macro-fauna, and soil fauna is being incorporated in the terrestrial ecotope classification (Sinnige *et al.* 1991).

5.3. Applications

The various classifications each have their own specific applications. These applications are partly determined by the spatial scale the policy level is concerned with. Also, the spatial scale of the environmental problems under concern is important. Most importantly, the desired accuracy of the results of, for example, environmental impact assessments or predictive modelling may play a role in the decision on what classification level to use.

Some applications will be referred to, viz. susceptibility assessment, predictive modelling and environmental quality assessment.

Susceptibility assessments require data on values and spatial variability of the values of a number of relevant parameters. For example, for assessing the susceptibility of an ecodistrict to acidification, parameters such as primary CaCO3 content of the parent material, the depth of decalcification through pedogenetic processes, the content of weatherable silicates, the clay content, the quality and quantity of upward seepage and others are relevant (Klijn 1991a). Data on such parameters may be stored individually (as single parameter data) in a GIS, but often it is desired to achieve some kind of regionalization, that is to ecoregions or ecodistricts.

The data on single parameters may be used for more sophisticated modelling purposes in behalf of policy analyses. So-far, only a model to predict the effects of water management measures has been developed, using ecoseries and ecotopes as conditional and effect-parameters respectively (Witte *et* ***al.*** 1992).

The ecodistricts and ecoregions are intended mainly for integrating data or modelling results for policy purposes, such as region-oriented environmental policy (Klijn and Laansma 1990; Ministry of Housing, Physical Planning and Environmental Management 1990). In this context, they provide a comprehensive framework for regionally differentiated ecological standard setting, and associated environmental quality assessments. This implies the formulation of policy objectives in terms of ecological parameters or endpoints (Suter 1990, *a.o.*), covering all relevant abiotic and biotic components. Such policy objectives may be specified in terms of standards concerning the value of each parameter. Then, it is possible to compare data on the present state of these parameters with the desired state. A method for environmental quality assessment, according to this approach, has been elaborated in cooperation with the National Institute of Public Health and Environmental Protection (Nip *et al.* 1992). Also, the quantification of both standards and actual values for two ecodistricts has been carried out to test the method (Latour *et* ***al.*** 1991). For this quantification, both areal data and point data (from monitoring networks) have been used.

Primarily, the ecoregions and ecodistricts provide an ideal basis for presenting results of the above. Both ecoregions and ecodistricts enable map presentations concerning recognizable and often well-known geographical units. This is important because these are comprehensible for policy makers. Thus, the ecoregions and ecodistricts may be a powerful tool in getting messages on environmental degradation across. In fact, the ecoregions and ecodistricts were designed for this purpose in the first place. Ecotopes and ecoseries, on the contrary, may be more appropriate as analytical tools in environmental quality assessments and environmental impact assessments.

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