2.3 Landscape elements

2.3.1 Introduction

Landscapes are composed of objects, units or elements of different nature. Interactions between them create a non-random organization in aggregates and patterns. Such patterns emerge at related spatial and temporal scales.

Functional qualities of landscape elements themselves are assigned to storage and transformation. Transport, storage and transformation are the major functional categories in ecological systems. They can be related to almost all ecological compartments and qualities. The quality and identity of landscape elements is thus determined by their spatial and temporal dimension and by their integration into the flow of energy, matter and information within a larger and more complex landscape matrix. The spatial organization of elements and their temporal performance reflects the functional interrelations that exist in a certain landscape. Area, form, distribution, age, longevity, and seasonal rhythm of landscape elements are helpful **parameters to characterize** them. These parameters are easy to detect or to measure. Their relations to neighboring elements of a different kind and the connectivity or fragmentation of elements of the same type will add other important information.

Distinct landscape elements can be observed at various scales, degrees of complexity and **levels of organization**. The term "level of organization" is based on works of Egler (1942) and Novikoff (1945), who originally proposed "integrative levels" of biotic systems. Their ideas were refined and integrated into a hierarchical system of natural organization by Allen and Starr (1982) and subsequently by O'Neill et al. (1986, 1989). Levels of organization reach from the cell, the tissue, the organ to the biome or the biosphere. However, only some levels are relevant in landscape ecology and can be used to differentiate or classify landscapes. These levels of ecological organization are species, communities and ecosystems.

Landscapes are not only distinguished by biotic properties. The interactions between living organisms and the physico-chemical framework are crucial qualities of the systems. Until now, this **geoecological perspective** has not sufficiently been incorporated into the concept of levels of organization, which seems to be bio-centric.

2.3.2 Concrete and abstract landscape elements

Concrete elements and the abstract unit or type, to which they belong have to be distinguished (Zonneveld 1974). The real conditions are differentiated due to criteria as relief form, species composition, vegetation structure, or disturbance regime. The **classification of elements** compares the actual objects with given types of a general system (Table 2.3-1). The quality of classification may differ to some degree among the elements recorded in nature. Some are quite close to a specific class or type and it is easy to assign them to a certain label, others are more or less intermediate between two or three types. The application of different criteria might result in varying classifications of objects and in non-identical boundaries in the maps. It depends on the choice of criteria, where boundaries emerge.

What is true for concrete landscape elements can also be found for abstract **landscape units** (see Chapter 2.2). They also loose distinction with increasing complexity. At higher levels of organization it becomes more and more difficult to assign a real object to a certain type. The individualistic character increases from communities (Gleason 1926) to ecosystems and landscapes.

Table 2.3-1: Concrete and abstract landscape elements

level of organization	concrete element	example	abstract element	example
	actually existing, real		type, class, term, label, name	
organism	individuum	plant	taxon	*Poa pratensis*
community	stand, biocoenosis	meadow	syntaxon	Nardetum
ecosystem	ecosystem	agriculturally cultivated slope	geosyntaxon	agroecosystem
landscape	landscape	Central Alps	landscape type	high mountain landscape

2.3.3 Heterogeneity and homogeneity

Landscape elements show internal homogeneity, which distinguishes them from adjacent elements. All natural elements exhibit a certain degree of heterogeneity, and a certain degree of dissimilarity between them. Homogeneity and heterogeneity are a major qualitative topic in landscape ecology.

The two aspects of homogeneity or heterogeneity within and similarity or dissimilarity between elements, represent important qualities of **ecological variability and diversity**. It reflects the degree of self-organization and functional interactions, and thereby the role of ecological fluxes. **Self-organization** is the product of functional interactions between ecological compartments. The more interactions occur, the higher the degree of organization will be. The variability within a landscape element is not only determined by the number of different objects of lower levels of organization, which contribute to the emergence of new qualities of such an element, but also by their similarity. Following Whittaker (1972), these two qualities of variability can be expressed as α-diversity (number of elements) and β-diversity (similarity of elements). Heterogeneity is very much determined by differences in qualitative properties of single objects.

The **structural arrangement and heterogeneity** of landscape elements strongly influences our perception of nature. Physiognomic differences in landform or vegetation are the most obvious properties of landscapes (Figure 2.3-1). Three-dimensional structures not only reflect ecological site conditions, they contribute themselves strongly to the performance of water and light regime and thus affect communities and ecosystem processes (Holt 1997).

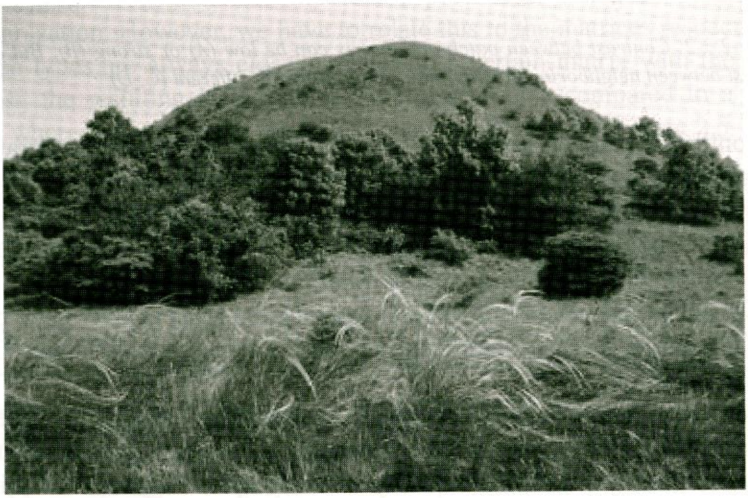

Figure 2.3-1: Structural heterogeneity within landscapes mainly addresses relief and vegetation: different vegetation types at the slopes of the hill Oblik (Bohemian Low Mountains, Czech Republic) (Photo: O. Bastian 1981)

Structural heterogeneity within landscapes mainly addresses relief and vegetation. Looking at **biotic structural heterogeneity**, different criteria for the description and analysis of spatial arrangements have been developed. At the level of organisms, life forms or growth forms became a successful tool for the description of spatio-temporal structures. Stands can be divided into different strata, which is conventionally done in forestry. At larger scale the physiognomy of vegetation can be classified to formations, dominated by certain life forms (e.g. forests) or showing a specific combination of life forms (e.g. savannah). Again, with increasing complexity **abiotic structures** as relief and interactions between plants and animals become more and more integrated.

The difference between an element and a neighboring element can be expressed as **contrast or β-diversity**. Contrast expresses the variability between two objects (Figure 2.3-2). Contrast is easy to measure with regard to some criteria, difficult with regard to others. The dissimilarity of species composition, nutrient supply, temperature, or inclination between patches can be calculated. Other criteria cannot or not completely be measured, such as ecological complexity, geomorphodynamics or climate.

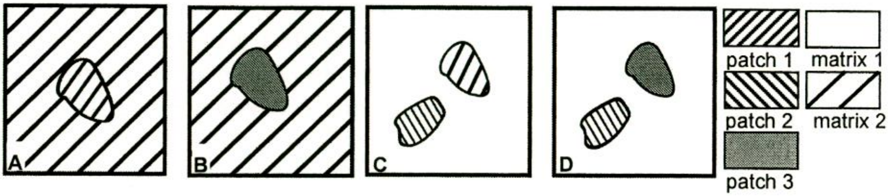

Figure 2.3-2: Contrast between patch and matrix can be low (A) or strong (B). But also the contrast between neighboring patches may be qualitatively different (C, D)

Contrast is scale dependent: with an increasing surface, the integration of elements and their individual variability grows. The same is true for patch internal heterogeneity expressing the texture of an element. Heterogeneity depends on scale (grain, resolution) and can be identified at different levels of resolution within one landscape (Kotilar and Wiens 1990).

We cannot discuss causes of heterogeneity and homogeneity here, but we have to point at the fact, that besides natural site conditions, human impact plays a major role.

Temporal heterogeneity cannot be separated from spatial heterogeneity. The seasonal variability of climatic factors, water regime, species occurrence and performance is a decisive quality of landscapes. If annual variability is low, the seasons and their effects on landscape elements are rather constant, which is true for tropical rainforests. Besides the occurrence of objects (e.g. species) and elements (e.g. communities) the time scale strongly determines the processes working within an ecosystem or landscape. If the ecological variability is concentrated on diurnal fluctuations and rhythms, this will influence the ecological relevance of certain processes, because species will adapt to this variability.

At longer time scales, ecosystem and community dynamics (including stability, see Chapter 5.1) can be observed. Ecosystems and most communities, though fluctuating during the year to a certain extend, show dynamic temporal changes within periods of several years or decades. Processes acting at this per-annual scale are population dynamics, growth, reproduction, soil erosion, land use changes. Looking at centuries and even longer times, long-term development of landscapes then includes evolution, geomorphological dynamics, soil development and phylogenetic evolution (see Chapter 4.1).

2.3.4 Patch, matrix and mosaic

Patches are concrete spatially delimited two-dimensional landscape elements at any hierarchical level and scale (Forman and Godron 1981). They can be differentiated from surrounding elements, which form a more or less uniform **matrix**. The contrast between patch and matrix ranges between completely dissimilar (no comparable objects or data) to nearly identical (only one or a few parameters differ). In addition, contrast can be considered between neighboring patches, embedded in the same matrix.

This contributes to landscape diversity. The number and the dissimilarity between patches characterizes important aspects of diversity at higher levels of organization. However, we have to relate this to the matrices respectively. If patch types are always closely related to a certain matrix with the same contrast, the resulting landscape will be less diverse compared to a landscape, where different patch types may occur in one matrix (Figure 2.3-3).

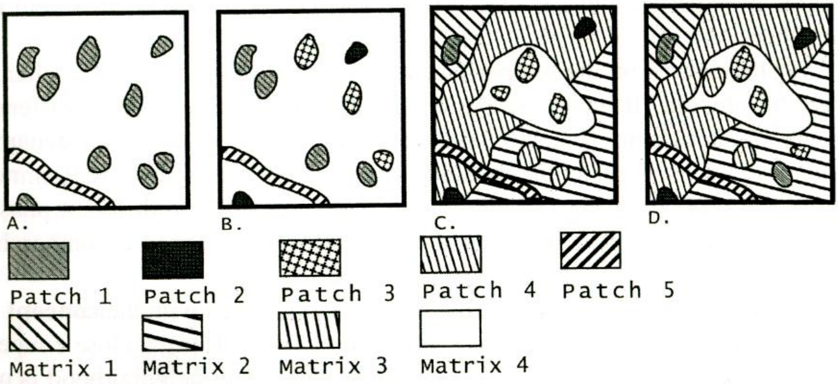

Figure 2.3-3: Heterogeneity relates to the number of patches, the patch/patch-similarity as well as to patch/matrix similarity. In a given number of patches occurs, which is qualitatively more diverse in B. In C and D the same number and the same types of patches occur, but they differ in their distribution to matrices. The same number and types of patches and matrices can produce a different landscape diversity

Landscape elements of a particular type may be rare or represented by numerous individual patches within a landscape. The same number of patches can be distant to each other or close. Distance is not correlated to the number of elements. Still, the relation between distance and number is modified by the size of the patches. And, apart from that, the distribution of patches follows ecological rules and is thus not stochastic. The size and the shape of patches within a landscape can be more or less uniform or different. This affects landscape heterogeneity.

Today, the patch-matrix model developed esp. by American ecologists is one of the most usual landscape models, besides the theory of geocomplexes elaborated mainly by Central and Eastern European physical geographers (see Chapters 1.1, 2.2 and 2.4).

In landscapes, patches, corridors and barriers are not mixed by hazard but arranged in a characteristic way. They form **mosaics of landscape elements** (Forman 1995, Wiens 1995), which develop under similar conditions in a comparable way. Natural examples are peat bogs, where different communities and vegetation structures form regularly similar vegetation complexes. In anthropogenic landscapes, land use will be determined by site conditions and result in comparable forms of land use techniques at comparable sites. This creates a mosaic of communities that will be found in a more or less similar composition at different places within landscapes. **Sigma-sociology**, derived from plant sociology, tries to identify these mosaics and to classify the corresponding vegetation complexes (Tüxen 1977). This sophisticated approach was aiming to be applied in nature conservation (Schwabe-Braun 1980), but could not become generally accepted, because it requires a high degree of experience and is biased when carried out by less trained field researchers.

If one focuses on the temporal development of mosaics, rules of change become obvious. In many ecosystems, we find a side by side of different stages of succession. A combination between spatial mosaics and dynamic changes in ecosystems is the **mosaic-cycle concept** propagated by Remmert (1991). It proposes a spatial and temporal relation between different phases of succession. Van der Maarel and Sykes (1993) developed a comparable model for vegetation units (the carousel model).

A more general model of change has been introduced with the **concept of patch-dynamics** (Jax 1994, White and Pickett 1985). Here, a close connection between the emergence of a patch and its history or neighborhood is not required. In contrast to the mosaic-cycle, within this patch dynamics concept, multi-disturbance occurrences at each stage of succession are considered.

2.3.5 Pattern and scale

Patterns are non-random spatial arrangements of objects within time or space (Collins and Brenning 1996). This means, that there must be a reason for this arrangement. It explains why the search for patterns is the major approach in landscape ecology (Turner 1989, Urban et al. 1987) and perhaps in ecology in general (May 1986).

Patterns emerge due to functional interactions between objects or elements. Patterns in European landscapes are mainly reflecting human activities (Burel 1995). As objects interact specifically, characteristic spatial arrangements of objects are probable. However, patterns are not only related to space. We find patterns in time series (e.g. Dunn et al. 1991), where, for instance, seasonal fluctuations follow regular patterns with correlation between data from neighboring patches. Pattern emergence cannot be separated from the problem of auto-correlation. Objects that contribute to the organization of a pattern will always be auto-correlated. As already mentioned, the detection of dissimilarities, and thereby of patterns as well, depends on criteria and scale (Turner et al. 1991). The identification of this scale is a task, which is difficult to meet. It is perhaps even more challenging to quantify landscape patterns (Gustafson 1998, O'Neill et al. 1988).

2.3.6 Connectivity, corridors, and fragmentation

Connectivity describes the degree of connection between similar landscape elements. It can be quantified via the number of corridors or vectors that can be related to an element (Tischendorf and Fahrig 2000). Connectivity between landscape elements may be strong or weak, spatial and/or merely functional (Figure 2.3-4). Strong spatial connectivity is produced by networks of corridors. Weak connectivity would be found within a landscape with only few linear elements bridging isolated patches. The necessity of spatial structures for the functional connection between isolated patches depends on the matrix and on the available vectors. Some vectors (e.g. birds, bees) are able to reach isolated patches without spatial corridors that connect them.

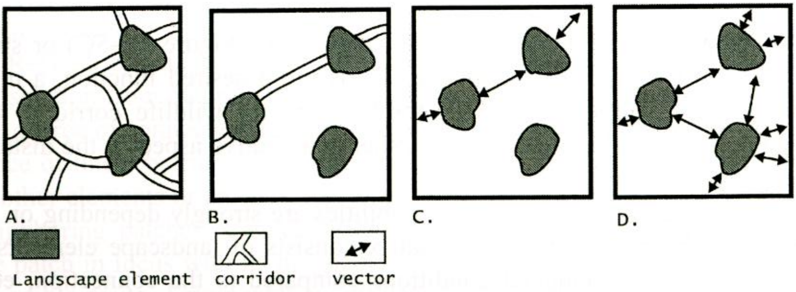

Figure 2.3-4: Spatial connectivity and functional connection A. strong spatial connectivity B. weak spatial connectivity C. strong functional connectivity D. weak functional connectivity

Spatial and (only) functional connections can be distinguished by the application of the terms "connectedness" and "connectivity" (in a narrow sense, see Chapter 2.8.4).

Corridors are spatial connections between landscape elements which are of functional importance for the interchange of species and for the flux of matter, energy and information. These functions can be bi-directional (Figure 2.3-5A). If the corridor connects two elements, fluxes and interbreeding can be effective in both directions. If we consider a network of patches and corridors, the interactions will be multidirectional. In these systems, movement and transport can be affected in any direction.

Some corridors, however, only work in one direction from source to sink (Figure 2.3-5B). This can be observed for river ecosystems and the drift of matter and diaspores they carry.

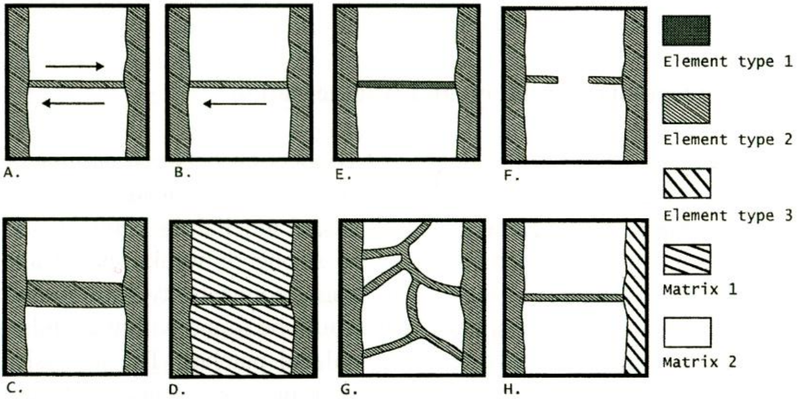

Figure 2.3-5: Different types of corridors: A. bidirectional corridor, B. unidirectional corridor, C. broad corridor with high capacity, D. corridor surrounded by similar matrix, E. Corridor with similar but not the identical conditions as source and sink, F. corridor not closed, G. corridor network H. leading to an similar but not identical sink

Corridors may be broad and cover large areas (Figure 2.3-5C) or small and of almost no spatial importance. To assure a desired function, a minimum corridor width is required, for instance for wildlife corridors that bridge motorways (Figure 2.3-6). Another quantitative aspect is the distance or length of corridors.

Corridors and their functional capabilities are strongly depending on the matrix they have to pass. If this matrix consists of landscape elements of very different environmental conditions compared to the connection, edge effects reducing their function will be stronger than if the matrix is rather similar to the corridor (Figure 2.3-5D).

Closed and entirely connected corridors (Figure 2.3-5E) are rare. Quite often corridors are dissected and comprise gaps (Figure 2.3-5F) resulting in functional restrictions. To improve the possibility for a specimen to successfully reach another patch, the number of connections between source and sink is of importance (Figure 2.3-5G). Finally, the functionality of corridors depends on the habitat quality of source and sink, which are connected. Similar patches are rare, so that exchange can be restricted by the capacity or attraction of the sink area (Figure 2.3-5H). The role of corridors for the mobility of organisms will be discussed in more detail in Chapter 2.8.4.

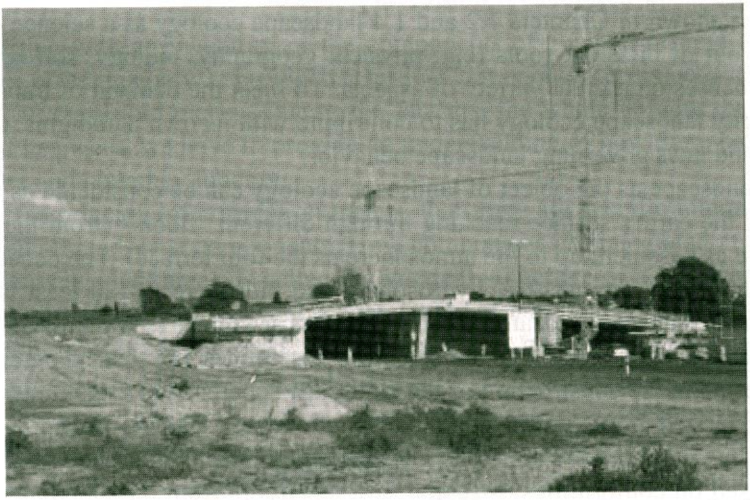

Figure 2.3-6: To reduce detrimental effects of fragmentation by motorways green bridges for the wildlife are built, e.g. near Dresden (Saxony, Germany) (Photo: O. Bastian 1999)

Fragmentation describes either a process or a status. Understood as a process, fragmentation depends on time and has to be related to landscape change. Then, fragmentation would describe the velocity of changes in connectivity. Fragmentation can also mean the separation of landscape elements that have been connected before. It can occur at different scales (Bowers and Dooley 1999).

Related to a surrounding matrix, fragmentation may describe the degree of isolation from other comparable patches. Related to corridors, it describes the degree of connection and the integration into a network. Here, the occurrence of linear barriers, which may be corridors for objects (species) bound to other elements or patches, has to be taken into account as well. Related to neighboring patches, fragmentation may describe the relatedness between the patch in focus with its neighbors and the distance to the next patch with favorable traits. Fragmentation influences the mobility of organisms, and thus, their survival, essentially (see Chapter 2.8.2).