Chapter 5
Basic Concepts of a Complex Spatial System

Abstract The landscape is holistic, which is also referred to as 'the whole is more than the sum of its composing parts', and is related to the German concept of the *Gestalt*. Human perception also works by holistic Gestalt-principles and will be discussed in a separate chapter. The holistic principle means that the structural context of the composing elements defines their actual meaning in the whole and the relationships between the elements. System-theoretical models for landscapes introduced the concepts of holons and ecodevices as hierarchically structured building blocks of the landscape. Consequentially, context and scale are important factors in studying the landscape. Scale has different meanings according to the context it is used in and thus confusion is possible. Scale defines the hierarchical structure and the way features of the landscape can be represented on maps. To simplify data collection and to reduce the complexity of the landscape composition and configuration, landscapes are often decomposed in thematic layers. The combination of the thematic properties defines the landscape type that characterizes an area. The transition between landscape types and regions can result in crisp or fuzzy borders. Sometimes the transition zones form gradients and ecotones, which if large enough become landscape units themselves.

Keywords Holism • Gestalt • Scale • Heterogeneity • Palimpsest • Pattern and process • Connectivity

5.1 Introduction

The landscape as a complex spatial system is characterised by some specific concepts. Holism is the most basic of them and gives the fundament to the hierarchical system of landscape and its composition and configuration by holons. Landscape is a spatial system that is scale dependent. Also scale is a complex concept with multiple meanings and defines landscape heterogeneity and diversity, as well as the meaning of the borders between landscape components. The distinction between components that consist of discrete objects and the ones that are continuous phenomena is fundamental. To reduce the complexity, landscape can be conceived as consisting of different thematic layers that each should be studied by proper methods.

M. Antrop, V. Van Eetvelde, *Landscape Perspectives*, Landscape Series 23,
DOI 10.1007/978-94-024-1183-6_5

Holism forms also the basis of landscape character, identity and diversity through its relation to Gestalt-principles, which are fundamental to our perception of the landscape, and which will be discussed more in details in the next chapter.

5.2 Holism

The expression “*Landschaft ist der Totalcharakter einer Erdgegend*” (‘landscape is the total character of a region’) was attributed (but not proven) to Alexander von Humboldt (Hard 1970; Zonneveld 1995; Küster 2008). The *Totalcharakter* fits well in the Gestalt concept and holism. Although Alexander von Humboldt did not use the concepts holism and Gestalt and refers to landscape mostly as scenery, he was the first to demonstrate that nature forms a whole interacting system and that ‘the whole is more than its composing parts’ (von Humboldt 1807; Wulf 2015).

Holism is a philosophical principle that was introduced by the South African statesman Jan Smuts in his book *Holism and Evolution* (Smuts 1926), defining holism as the “tendency in nature to form wholes that are greater than the sum of the parts through creative evolution.” He refers to the hierarchical organisation and structure of the cosmos, as it also shown in the evolution theory (Zonneveld 1995). The holistic principle is commonly described as ‘the whole is more than the sum of its composing parts’. The German concept is *Gestalt* (Fig. 5.1). Gestalt-psychology studies also the human perception and learning processes, which both are significant in understanding how humans perceive the landscape (see Chap. 6). Generally, we first discern wholes, as forms or patterns without details, to which we assign immediately a meaning or eventually identify. It is what happens when we see a person from a distance and his figure, posture, way of walking etc. allows us to identify him. Only during successive observations, details become apparent. When no immediate identification is possible, we may feel uneasy, uncertain. Then the brain will attempt to find alternative meanings to reduce that uncertainty and this process continues until a satisfactory meaning or identification is obtained. This may cause ambiguous interpretations, which also show our ability to switch alternatively and mentally foreground and background to find other solutions.

Perceiving the landscape as a Gestalt means that our ‘natural’ experience of landscape is holistic. This is obvious in artistic representations, in studies on landscape aesthetics, perception and preference, as well as when considering landscape as a social construct. In landscape architecture, planning and heritage conservation, often the term *ensemble* is used to denote holistic entities. These aspects will be elaborated more deeply in following chapters.

However, holism in the sense that ‘the whole is more than the sum of the composing parts’ poses a paradox. In principle, it is not possible to reconstruct the ‘whole’ from a detailed analysis of all its parts and the ‘more than’ will always be missing. Also, it is unlikely that everything can be studied to approach the ‘whole’ as complete as possible. This was the main criticism from the exact sciences and the argument to reject the holistic idea and to promote instead a

Fig. 5.1 Example of a Gestalt. Our mind always attempts to give some meaning to the observed pattern, which may lead to the interpretation of different realities

reductionist and experimental approach. As a consequence, the approach to landscape analysis in natural sciences became reductionist, while in social sciences it remained more perception-oriented and phenomenological. Anyhow, both approaches studied different aspects of the landscape, and none the 'whole'.

Theoretically, holism remains an important principle, which regained significance with the development of systems theory in ecology. System-theoretical models for landscapes were formulated, such as the one by Jan Zonneveld (1985), who sees the landscape as an organised open ecosystem of interdependent components (Fig. 5.2).

An important concept is a *holon*. Zev Naveh and Arthur Liebermann (1994) developed this concept in the landscape context, fitting it in a multi-scale hierarchical structure of the *Total Human Ecosystem* (THE) (Fig. 5.3). Holons are seen as subsystems having a certain degree of freedom in functioning, thus are more or less autonomous. Each holon can consist of holons of a lower level and can be embedded in holons higher in the hierarchy.

Holism and holons can easily be understood when referring to the human body. The body is also composed of interacting subsystems working more or less autonomously, such as the digestive system, the cardiovascular system, the movement system, each of the senses, etc. Each of them can be studied using special methods but is improbable that merging all this knowledge will result in a complete understanding of a person. Similarly, each individual fits as a holon in larger social systems, as family, community, culture and nation.

The concept of a hierarchically organised system of holons helps to overcome the holistic paradox. To understand a holon in a comprehensive way, it is not necessary trying to analyse and understand everything, but only the significant context of the holon at the appropriate scale. Thus, scale and context are essential variables to set the conditions for the landscape analysis (Fig. 5.4). In the example of the human body, one could say that the ophthalmologist will look at the eye and

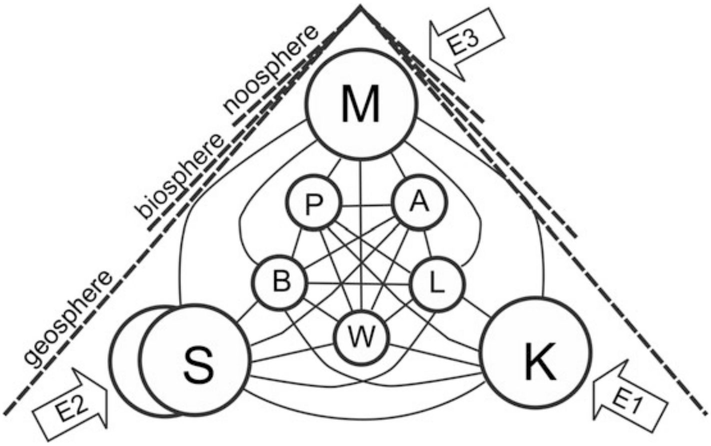
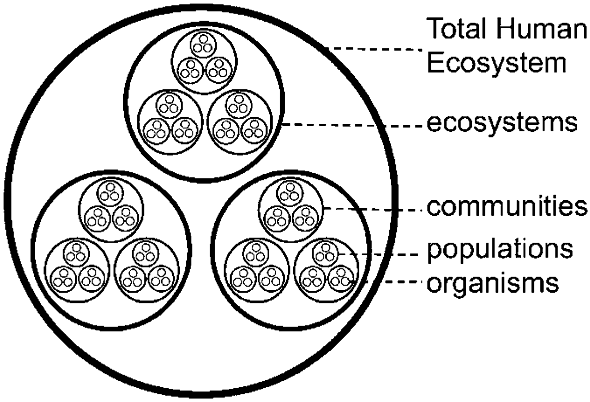


Fig. 5.2 The landscape as an open system. The circles represent the components of the landscape. Primary components are the substrate (S), which consists of the geology and landform, the climate (C), and humans (M). These components get external input by the energy of the sun (E1), the heat of the Earth (E2) and knowledge and information (E3). The primary components determine the functioning of the secondary components: plants (P), animals (A), soil (S), air (O) and water (W). All components are mutually interdependent. They can be grouped in three spheres with increasing complexity: the abiotic sphere, the biosphere and the noetic sphere (Model of J. Zonneveld 1985)

Fig. 5.3 The *Total Human Ecosystem* (THE): application of the holon concept in the hierarchy in ecology (After Naveh and Liebermann 1994)



the whole context that relates to its functioning, but it is unlikely that he needs information about the digestive system to make an adequate diagnosis.

Understanding how landscapes function and how they developed, demands a multiscale approach by which the overall complexity is reduced at the appropriate level. It is what Richard Dawkins (1996) calls "hierarchical reductionism". Forman and Godron (1986) refer to the approach as "shuttle analysis", zooming in from space to the smallest element in the landscape, thus revealing stepwise the details necessary to understand.

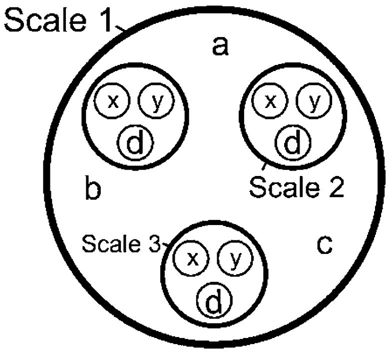


Fig. 5.4 Hierarchy of holons: holons are open systems that have a certain freedom and autonomy; they can be part of larger holons and can consist of smaller holons. The whole forms a hierarchical structure. Each holon has its proper scale and context, which become essential variables to study the holon in a comprehensive way. Scales and letters refer to the entities in the example of the Grande Brière (Fig. 5.5)

Ies Zonneveld (1995) considered the land units, defined in land evaluation and landscape classification, as holons and regarded these as complex, hierarchical wholes. At the initial stage of a study, these can be considered as 'black boxes', meaning they still are 'opaque' to us as far as internal processes are concerned. Nevertheless, they allow us to describe and order rapidly the complex variation in the landscape. Our 'natural' ability to recognise, name and classified such Gestalt-entities "follows millennia-old wisdom, derived from common practices of pre-technological land users like hunters, farmers, and herdsmen who invented this principle at the dawn of humanity's struggle for life in the landscape. A major testimony to this is the wealth of information represented by the ecologically inspired land toponyms." (Zonneveld 1995).

The following example of a multiscale landscape analysis of the Grande Brière marshland (Western France) demonstrates the principle of hierarchical reductionism (Fig. 5.5). The analysis uses three scales (Fig. 5.4) and zooms in from the small reconnaissance scale showing the whole region, to the scale of individual objects and elements. Scale 1 shows two main holons: the swamp and the islands with settlements. Scale 2 zooms in on one of the settlements revealing its internal structure and composition. Scale 3 looks at the elements that characterise the landscape. The typical elements and selected village are used to construct the settlement model for the area. An adequate understanding of the whole landscape system can be achieved without having to study all settlements in detail.

The second example analysis one of the landscape types on the island Lanzarote and illustrates the holon concept as an ecodevice, which was used to create a unique cultural landscape (Antrop 2006). It also demonstrates that not only ecological knowledge is necessary to understand the creation of this landscape, but also the societal, political and economic context is essential.

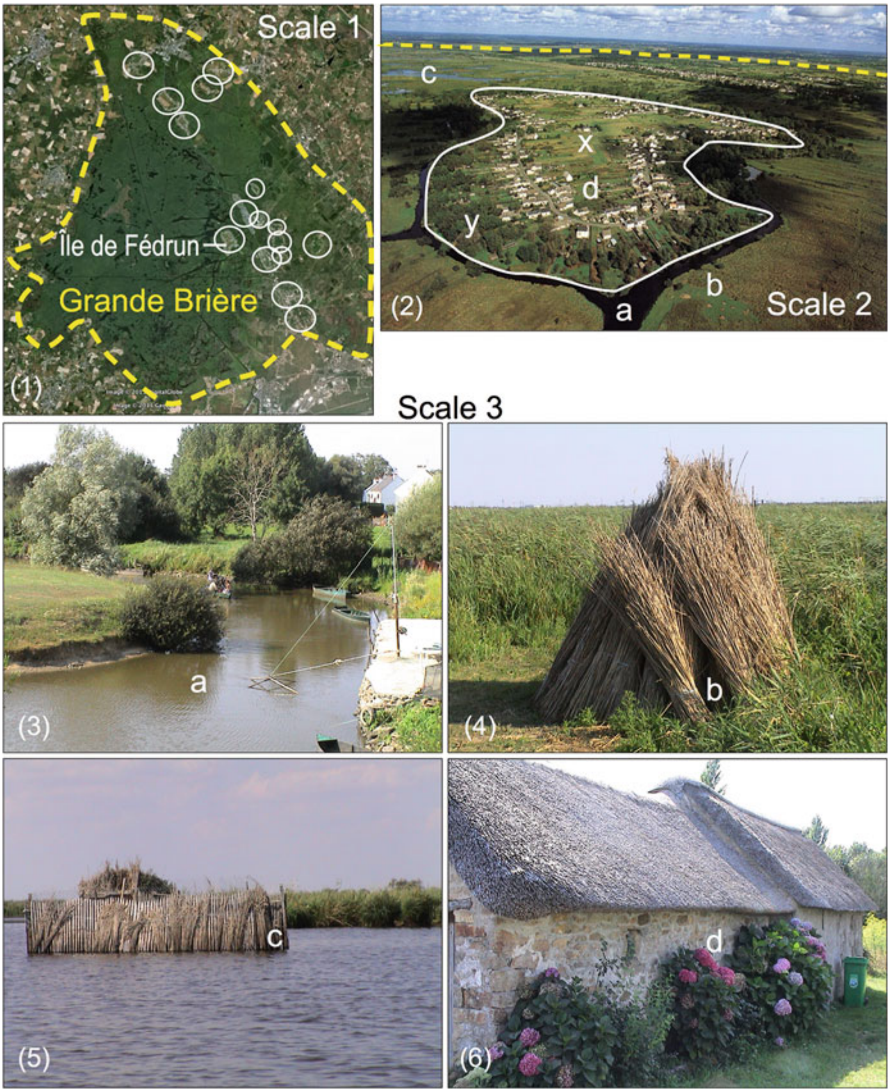


Fig. 5.5 The hierarchical structure of landscape holons is particularly apparent in aerial photographs as in this example of the Grande Brière (France). (1) Scale 1: in the vast swamp covered with reeds, sandy outcrops form islands suitable for settling. The Île de Fédrun is a holon that can be used as a model for all settlements in the region. (2) Scale 2: the village Fédrun forms an outer ring on the edge of the island. Fields occur at the highest central part (x). The outer fringe (y) consists of gardens and orchards stretching to surrounding water channels, forming a natural windscreen. Scale 3: each house has its own pier and the water channels are the main transport ways in the marshland (**a**). Traditionally the villagers subsisted from eel fishing and reed cutting (**b, c**). The low, traditional loam houses have reed roofs and the typical architecture (**d**) contributes to the local identity of the place. ((1) Google Earth, photos (2–5) M. Antrop 2006))

Lanzarote is an active volcanic island of the Canaries (Spain) and recent lava and ash fields cover most of the land. The climate is subtropical with almost no rainfall and a continuous, dry north-eastern trade wind. Consequently, the island has almost no tree cover and agriculture is difficult. La Geria is a wine-producing valley between volcanic cones and is covered by black volcanic ashes (tefra) and lapilli. Somehow, people did not leave the unfriendly environment and transformed this pristine natural landscape in the eighteenth century into the main production area of the sweet malvasia wine. Several, enchaining events determined this history.

From 1730 to 1736 a series of violent volcanic eruptions produced 32 new volcanoes and lava covered a quarter of the island's surface, including the most fertile soils and eleven villages (Borisch 2007). People began to give up hope and many migrated. Fearing that an abandoned island could become lost for the crown, king Philipp V issued a decree forbidding leaving the island on penalty of death. The 'stay or die' rule forced the farmers to find solutions to regain arable land. The initial solution was to dig pits in the volcanic ashes to recover the fertile soil. Soon they discovered that the mixture of volcanic ashes with the original sandy soil improved its fertility and that plants in the pits grew better as they were protected from the wind. This technique of making artificial soil is called *enarenado artificial* and soon became popular over the whole island.

The choice for the sweet wine can also be explained by the historical context. Sweet wines, such as the Portuguese Port and Madeira, were very appreciated in Britain that was then a political world power. During the Napoleonic Wars (1806–1814) and the Continental Blockade, the Canaries were a free trade zone. Therefore, the farmers of Lanzarote found it profitable to fill in the market and started to produce malvasia wine transforming the volcanic landscape of La Geria into a vineyard. Thus, they dug ten thousands of small pits in the ashes to reach the soil beneath and planted in each one vine. To protect the plant from the drying wind, they built open stone walls along the north-eastern edge of the pit. The open construction acted as a windbreak, reducing the wind speed and avoiding turbulence in the pit. The whole system is oriented to capture the solar energy most effectively. During the day, the black volcanic soil is heated intensively, but cools rapidly after sunset. The volcanic lapilli are highly hygroscopic and absorb moisture from the air during the night, which is collected by the plant at the bottom by gravity. Each pit is an artificial ecodevice and repeating it thousands of times over the whole area created a unique, sustainable cultural landscape with a pronounced identity.

This technique of *enarenado artificial*, making artificial soil, also known as 'lithic mulching agriculture', was so successful that it was applied all over the island in various forms and with a multifunctional use of the fields having different crops. The unique combination of nature and sustainable agriculture was one of the factors to designate Lanzarote as a World Biosphere Reserve (Fig. 5.6).

Van Wirdum (1981) applied the holon concept on the water regulation in the Dutch polder system but called it an *ecodevice* (Fig. 5.7). It is a functional interpretation of holons and joins the more recent concept of ecosystem services (see also Chap. 4).

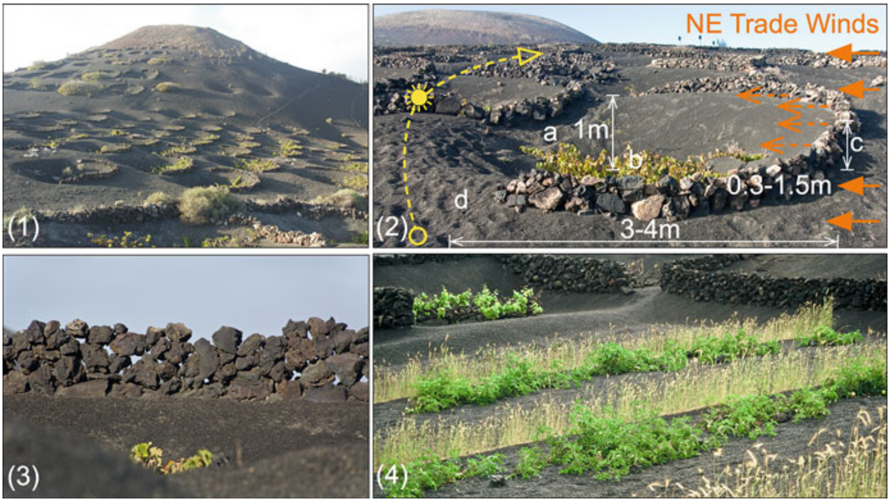


Fig. 5.6 The wine region La Geria on the island of Lanzarote. (1) La Geria forms a valley between volcanic cones and is covered by black volcanic ashes (tefra) and lapilli. (2) To recover arable land after the volcanic eruption, farmers dug ten thousands of small pits (*a*) in the ashes (*d*) to reach the soil beneath and planted in each one vine (*b*). (3) To protect the plant from the drying trade winds, they built open stone walls along the north-eastern edge of the pit (*c* and 4). These windbreaks reduce the wind speed and avoid turbulence in the pit. The whole system is oriented so the solar energy is captured most effectively. During the day, the black volcanic soil is heated intensively but cools rapidly after sunset. The volcanic lapilli is highly hygroscopic and absorb moisture from the air during the night, which is collected by the plant at the bottom by gravity. This technique of *enarenado artificial* is nowadays applied all over the island in various forms and with a multifunctional use of the fields having different crops (4) (Photographs M. Antrop 2009)

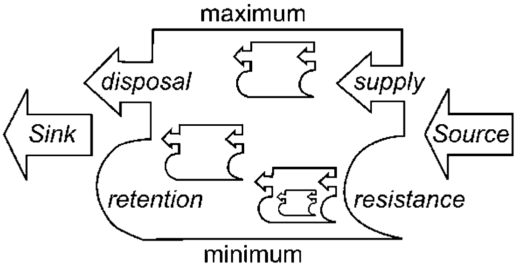


Fig. 5.7 The ecodevice is a holon model of an ecosystem controlled by a series of functions. It is an open subsystem and has an input (*source*) and output (*sink*). The ecodevice is controlled by for functions: *supply*, *resistance*, *disposal* and *retention*. The balance between these functions keeps the ecodevice between critical thresholds (*minimum*, *maximum*; carrying capacity) that define its survival (After van Wirdum 1981)

5.3 Scale and Heterogeneity

5.3.1 A Source of Conceptual Confusion

The word scale acquired different meanings according to the discipline and context it is used in. In geography and cartography, the scale is the ratio between the represented length on a map or photo and the real length on the terrain. Thus, a small scale map (i.e. 1: 100,000) has a large extent covering a large area, but shows little detail. A large scale map (i.e. 1: 5000) has a small extent and covers a small area, but shows many details at their accurate position and with high precision. Other disciplines, in particular in planning and policy use scale in the opposite meaning. A large-scale project means an extensive one, covering possibly a large area. To represent it as a whole, a small-scale map will be used. Here scale means the geographical scope. Similarly, small-scale projects refer to projects with a small extent. Confusion can be avoided by speaking of a fine or detailed scale and a coarse scale.

Clearly the scale concept consists of two components: (1) the degree of detail of the representation, and (2) the extent of the representation. This concerns the spatial scale as well as the temporal scale and scale of organisation and management (Agarwal et al. 2002) (Table 5.1).

5.3.2 The Spatial Scale

The cartographic meaning of scale dates from the printed maps and is basically static and categorical. With digital mapping and new visualisation techniques, scale became dynamic and continuous. Zooming in and out became a standard procedure in exploring landscapes as represented on maps and imagery. The limiting factor is the resolution. In landscape research in general, and in landscape ecology in particular, scale properties became important explanatory variables in the analysis of landscape patterns and processes. In landscape ecology, the concept of scale is also species dependent (Wiens and Milne 1989).

The spatial scale is defined by the spatial resolution or *grain*, and the *extent* or area covered for the analysis. The grain does not necessary correspond to the resolution of the documents used; it is the smallest unit of observation which is chosen for the intended analysis. An aerial photograph may have a spatial

Table 5.1 Dimensions of the scale concept

Application domain	Degree of detail	Size-extent
Spatial (geometric)	Resolution, grain	Extent
Temporal	Time interval	Duration
Organisation and planning	Actor, 'agent'	Domain

resolution of less than 1 m, the smallest observation unit can be 1 ha or even a field. However, the grain cannot be finer and more detailed than the spatial resolution of the base document. For analogue maps and vector maps a grain corresponds to the *Minimum Mapping Unit* (MMU). For example, for CORINE Land Cover, the MMU is 25 ha.

The scale becomes a variable that determines the observation of the landscape and this has important consequences. Many properties of the landscape are scale-dependent, such as diversity, heterogeneity and the correlation between the components.

5.3.3 The Temporal/Time Scale

Studying temporal changes demands observations on successive times that can be compared. The interval between observations is equivalent to the *grain*. Two editions of maps or aerial photographs representing the situation at a 10 year interval for example, show the global and cumulated changes between the year Y and Y + 10 but not the duration of the individual changes, nor changes that can be reversed. Typical examples are deforestation-reforestation within the time interval. The duration is equivalent to the *extent* and encompasses the time period of investigation, for example from 1700 to 2012 (see also Chap. 7).

5.3.4 The Organisation and Planning Scale

The lowest level of decision-making lies with the individual. The complexity of the decision-making increases with the number of actors involved. Different levels of organisation in the process of decision-making can be recognised and actors are sometimes referred to as *agents*. The domain of competence of an agent varies spatially and temporally. In most countries, at least three levels can be recognised: the national, the regional and local level or scale. Often additional levels exist as inter-communal and inter-regional co-operations, some which are specific for the management of landscapes that stretch over several administrative units. Federal states often have a federal level. Above this lies the international level and also here some hierarchy and differences in competences can be found (see also Chap. 12).

5.3.5 Landscape Heterogeneity Is Scale Dependent

When looking at the landscape from a distance, the field of view, degree of detail and heterogeneity depend on the distance of the observation, thus upon the scale. When the observation distance increases, the field of view and the extent of the landscape viewed increases, while the degree of detail decrease. Heterogeneity changes when zooming in and out. Forman and Godron (1986) studied this using a technique they called the 'shuttle analysis', and made the distinction between landscapes with micro and macro heterogeneity.

Landscape heterogeneity is fundamental in understanding the interaction between landscape structure and ecological processes and human activities. It is related to concepts such as fragmentation, complexity, diversity, coherence and order. It influences biodiversity (Fahrig et al. 2011; Katayama et al. 2014) and landscape ecosystem services (Turner et al. 2013). Landscape diversity is considered a distinctive feature of the identity or regions (Stanners and Bourdeau 1995). Many methods were developed to quantify spatial heterogeneity (Li and Reynolds 1995; Garrigues et al. 2006; Mander et al. 2010) (see Chap. 8).

5.4 Discrete Objects and Continuous Phenomena

A landscape consists of discrete objects, such as buildings, trees, and of continuous phenomena, such as land form and soils. Discrete objects are often referred to as landscape *elements*, while the continuous features are called *components*. They show a great variety and have many functions. Consequently, they can be coded, modelled and mapped in several ways (see also Chap. 8).

Discrete spatial observations can result also from sampling continuous phenomena, which can then be modelled into continuous *geographical surfaces* (Unwin 1981) or *fields* (Longley et al. 2001), representing one or several variables. Geographical surfaces are often visualized as *isopleth maps*. Digital elevation models (DEM) or digital terrain models (DTM) have become common representations of the topographical surface.

Spatial sampling is scale dependent. For instance, the distance between the observations (*lag*) is important to understand the spatial autocorrelation between the measurements. Spatial autocorrelation influences landscape heterogeneity (Forman and Godron 1986; Burel and Baudry 2003) and the coherence and fragmentation of landscape patterns (Mander et al. 2010).

Discrete values can also be assigned to spatial units represented by polygons on a map. This technique is used in the construction of *choropleth maps*. Often administrative units such as municipalities or census tracts are used, but also geometric patterns such as quadrants and grids with a regular tessellation of squares can be used. For example, the percentages of different land use categories can be assigned to each square kilometre grid, to be used in defining the landscape type for each cell.

5.5 Landscape in Layers

Although we perceive the landscape in a holistic way, we also instantly discern differences in its composition. Differences in shape, size and colour characterise different kinds of features. Intuitively these are grouped in themes, which receive different degrees of attention according to the intention and background of the observer. This way of ordering mainly reduces the complexity.

Geographers adopted a method to decompose the landscape in superimposing layers of different kinds of features. Each of these can be mapped and described more easily using the most appropriate data and methods. This resulted in the parametric approach in landscape evaluation and in the thematic map overlaying in GIS-analysis (see also Chap. 10).

The features in the different landscape layers are often studied by different disciplines. For example, landform is the domain of geologists and geomorphologists, land cover the one of botanists and ecologists, and human settlements belong to the domain of historical geographers. The landscape-in-layers perspective stimulates highly specialised, reductionist approaches and causes loss of synthesis and holistic perspective (Fig. 5.8).

5.6 The Map Is Not the Landscape, Nor Is Its Representation

The Polish-American scientist and philosopher Alfred Korzybski (1933) noted that many people do confuse maps with territories, hence his expression “the map is not the territory”. He used this to illustrate that an abstraction derived from something tangible, or a reaction to it, is not the thing itself. The same holds for maps and landscapes, and for all kind of aerial images of landscapes as well. People tend to confuse models of reality with reality itself. Maps are tools for inventory, analysis and communication, and the result of the mapmaker’s intention, vision and choices. Mark Monmonier (2005) called it “selective truth”. Even when the mapmaker has good intentions, the result can be wrong. Monmonier (2005) formulated it like “watch out for the well-intended mapmaker who doesn’t understand cartographic principles yet blindly trusts the equally naive software developer determined to give the buyer an immediate success experience— default settings are some of the worst offenders.” Maps have been used also to manipulate and deceive people (Harley 1988). Monmonier (2005) confessed he was inspired by Darrell Huff’s *How to Lie with Statistics* (Huff 1954) when writing his *How to Lie with Maps* (1991, 1996). Both books should be compulsory literature for landscape researchers reaching out for techniques of mathematics, statistics and cartography. Olwig (2004) used the famous painting of the Belgian surrealist René Magritte of a pipe with the subtitle *“Ceci n’est pas une pipe”* (“This is not a pipe”) to express the same idea in relation to all pictorial landscape representations.

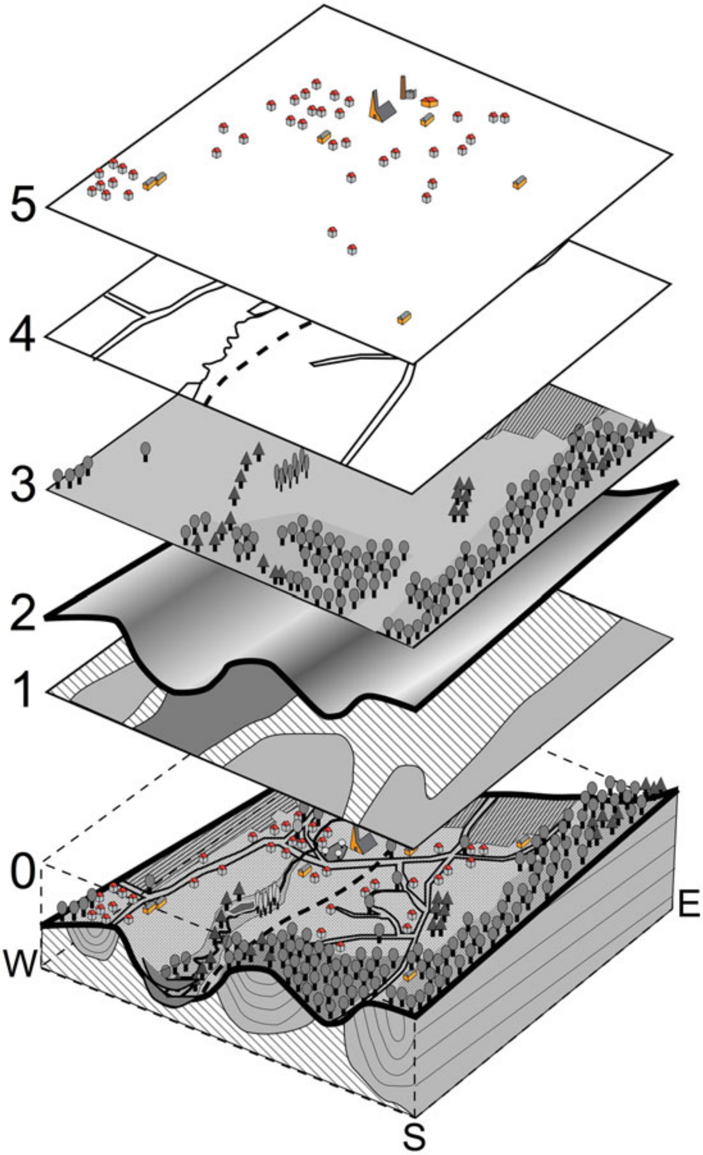


Fig. 5.8 Landscape in layers: (0) the landscape synthesized in a block diagram, (1) substrate layer (geology, soils), (2) landform layer (relief, topography), (3) land cover layer, (4) network layer (roads, river, etc.), (5) settlement layer (Presented as such, no relations between layers are shown)

There are several reasons why reading the landscape from maps can be tricky. First, there is geometry, scale in particular. The geometry of maps is the result of a cartographic projection at a predefined scale, which defines the codified representation of features, using cartographic rules and semiology (Bertin 1983). The older historical maps and cadastre plans are based on a local reference system and seldom fit in a general cartographic projection. Hence, their geometry is distorted and their coverage fragmentary. With the advances in triangulation since the second half of the sixteenth century, maps became an instrument to define, administer and control territories and people, and as such an instrument in constructing space (De Keyzer et al. 2014). Moreover, landowners commissioned maps for attesting their possessions and for tax purposes, and only features were mapped that fitted that purpose. Often, features not fitting in the profit of the landowner were added or omitted, such as disputed land. It is only with the coming of the national cartographic surveys in the nineteenth century that homogeneous and geometrically accurate coverage for the whole of a country became available. Nevertheless, geodetic reference systems still vary between regions and countries, and also between successive map editions. Since the Second World War map making is based on aerial photogrammetry and for each edition of a map exists a simultaneous aerial photo cover, offering a holistic and not interpreted view on the land.

People not trained in cartography are rarely aware that objects can only be located accurately and represented in their true size and shape on maps with scale not smaller than 1: 20,000. To keep the map readable, generalization according to different rules is applied on smaller scales, causing displacement, selecting and simplifying objects, smoothing shapes and the use of symbols. (see Chap. 8) Many landscape features on maps are delineated as objects. In reality, some features have crisp borders, and others have fuzzy gradients to neighboring features.

With the coming of GIS, maps became more dynamic, multilayered data sets ‘on demand’. Geometry became universal, scales are not fixed any more, and nor are semiology and visualization properties (Kraak and Ormeling 2010). Map creation is now available to the creativity of everyone.

5.7 Borders, Fuzziness, Gradients and Ecotones

Defining landscape entities and the delimitation of regions are old problems in geography. As spatial units, landscapes and regions do seldom have crisp borders, rather forms fuzzy transition zones with the adjacent units. An important part of Granö’s work (Granö 1922, 1935, 1952) was devoted to solve the problems related to mapping core landscape types and their transitional borders using cartographic overlay techniques (see Chap. 10). Recognizing the transition zone as a separate landscape unit is a matter of its width and the threshold set by the researcher considering the mapping scale used.

In landscape ecology, edges (*ecotones*), border transitions and gradients (*ecoclines*) receive special attention (Naveh and Lieberman 1994; Forman 1995; Arnot et al. 2007; McGarigal and Cushman 2005). Fuzzy set theory and fractals have been used in studying borders in the landscape, with applications in landscape ecology (Farina 2012), landscape change (Syrbe 1997; Leyk and Zimmermann 2007), landscape archaeology (Mink et al. 2009; Ďuračiová et al. 2013), in perception studies (Hägerhall et al. 2004), and in landscape design (Bell 2004).

5.8 Interaction Between Spatial Patterns and Processes

Landscapes are structured by spatial patterns of diverse discrete elements and variations of continuous features. Similar elements can spatially be clustered or distributed in a random or regular manner. Patterns of different features can relate to each other in a functional way and may show spatial association, i.e. they covariate in space. We perceive and experience this coherence as order. When no relationships between the different elements can be recognised, or no clear structure can be identified, we experience the landscape as chaotic. Order stands for functional coherence and processes ruled by causal dependency. Chaos stands for randomness. Both refer to the degree information that is present to allow us to understand landscape structures and their functioning (see also Chap. 8).

The importance of the analysis of patterns, spatial association and covariation between landscape features is based on a fundamental paradigm in landscape ecology, i.e. the dynamical interaction between spatial structures and the ecological functioning, as expressed by Forman and Godron (1986):

> An endless feedback loop:
> Past functioning has produced today's structure;
> Today's structure produces today's functioning;
> Today's functioning will produce future structure.

Basically this means that the actual spatial structure controls the actual dynamics in the landscape, which simultaneously transform the structure into a better-adapted new one. This also means that a structure that is not functional anymore will gradually become void and vanish. This process can be observed in all traditional agricultural and pastoral landscapes where the practices that shaped the landscape and defined its identity and character became lost. Applied to spatial planning, this paradigm means that there are two options to change the actual situation into a planned one: taking structural or functional measures, or both. An example is given in traffic control and safety: to reduce accidents and speeding one can take structural measures such as making roundabouts, or take measures that affect the functioning, such as setting speed limits and raising fines.

The study of spatial landscape patterns and their relationship to ecological processes and functioning of the landscape became the core business of landscape ecology (Turner et al. 2003; Wu and Hobbs 2002, Wiens and Moss 1999, Gardner et al. 1990; Turner 1989, Turner et al. 2001). A great variety of methods and techniques were developed to study this complex relationship (Burel and Baudry 2003; Turner et al. 2001; Klopatek and Gardner 1999; McGarigal and Marks 1995; Turner and Gardner 1990; Farina 1998).

5.9 Connectivity and Connectedness

The fundamental holistic nature of landscape is well expressed in first law of geography according to Tobler (1970): "Everything is related to everything else, but near things are more related than distant things." Relations often mean connections. Hence, the concepts connectivity and -to a lesser extend- connectedness are widely used in landscape research in diverse contexts and several methods have been developed to describe and measure the degree of connectivity (see Chap. 8).

Both concepts became popular in conservation biology and landscape ecology, using the patch-corridor-matrix-mosaic model to study spatial landscape patterns. A wide range of literature is available on this subject (Forman and Godron 1986; Antrop 1988; Baudry and Merriam 1988; Turner and Gardner 1990; Metzger and Décamps 1997; Burel and Baudry 2003). Merriam (1984) introduced the concept of *landscape connectivity*, which he defined as the degree to which the landscape facilitates or impedes movement of species among resource patches. Baudry and Merriam (1988) use the term *connectedness* to refer to the fact that two adjacent patches of the same type are spatially joined, and use the term *connectivity* for the possible movement of an individual of a given species between patches, whether or not they are spatially connected. However, both concepts were often used without clear distinction. Therefore, to remove the ambiguity, the concepts of structural and functional connectivity are used instead (Vogt et al. 2009). *Structural connectivity* refers to the physical arrangement of landscape elements, i.e. determines connectedness. *Functional connectivity* refers to the species-specific movement potential through a landscape. A spatial analysis of the structural connectivity is used to assess or predict the functional connectivity (Goodwin and Fahrig 2002). However, measures of structural connectivity often have no link to movement behaviour (Metzger and Décamps 1997).

However, both concepts are also used in other contexts of landscape analysis. Networks analysis developed from mathematics and topology and became popular in geography for the study of hydrographical networks, settlement patterns, in transportation networks and in the analysis of the visual landscape. In landscape design and architecture, these concepts refer to visual relations between spaces and objects. Similar uses are found in landscape archaeology.

In all cases, both concepts have different meanings and sometimes the definitions are vague and generic. Often, in domains without a formal definition of connectivity, the word is as a synonym for connectedness, while in other disciplines the difference is important. In modern computer science and information technology, both concepts are basic. Here, the common noun form is connectivity, but the common adjectival form is connected.

Connectivity is a basic concept of graph theory and important in the study of network flow problems, e.g. in hydrographical networks and in some cases also in transportation networks.

Another example of connectivity is found in regular tessellations. Here, the connectivity describes the number of neighbours accessible from a central tile. This form is used in space-time geography (see for example Christaller 1933) and diffusion modelling (see for example Hägerstrand 1967). Examples are found in the study of territorial patterns of settlements and also in spatial planning for optimizing service zones and accessibility (see also Chap. 10).

5.10 Multifunctionality

A consequence of the holistic nature of landscape is the multifunctional potential of the land. This is most clearly expressed by the multiple ecosystem services of the landscape, in complex land use forms and in rights in using the land. Although the term 'multifunctionality' was not used as such, the principle was present in many traditional land use systems, such as many agro-pastoral systems, and created landscapes with a very distinct character. Examples are many of the Mediterranean landscapes, such as the *montado* and *dehesa*, the *cultura promiscuita* (Pinto-Correia and Vos 2004), chesnut-forest landscapes (Vos and Stortelder 1992), and wooded meadows (Emanuelsson 2009). In general, this kind of multifunctionality is often considered being positive (Vos and Meekes 1999) and the knowledge of managing these landscapes belongs to our heritage (Austad 2000). Nevertheless, many of these traditional landscapes have been threatened by modern developments and are rapidly vanishing and so is the knowledge that maintained them (Pinto-Correia 1993; Vos and Stortelder 1992; Vos 1993).

Hence, the concepts 'multifunctionality' and 'mulifunctional landscapes' as such gained a renewed attention around the beginning of the new millennium, as demonstrated by the international conference on the matter held in 2000 in Roskilde, Denmark (Brandt and Vejre 2004). Multifunctional landscapes can be seen as one of many strategies towards a sustainable development at the landscape level (Brandt and Vejre 2004; Haines-Young and Potschin 2004). Different types of multifunctionality can be recognised based on spatial and temporal criteria (Brandt and Vejre 2004) and scale (Antrop 2004) (see also Chap. 12).

5.11 Reading a Palimpsest

The landscape has been compared to a palimpsest, a manuscript on expensive parchment that has been scraped off several times so that it can be re-used. It refers to successive time layers in the development of the landscape, where older ones are only vaguely and partially visible compared to the present ones. Understanding the landscape is like reading such an ancient manuscript, written in fonts and a language different from the one we use today. Deciphering the manuscript demands careful and systematic reading and the method consists of reading different layers in succession. There are four main layers in reading the landscape:

- a scene offering an experience.
- a natural, physical system that forms the substrate of the land
- a cultural system with places and territories and land use
- a history that remains in successive, incomplete layers

The first layer is the scenery, which can 'read' as a work of art, as a painting, although it is more like experiencing a theatre play. Perceiving and experiencing the landscape will be discussed in Chap. 6.

Following layers demand a more systematic, 'scientific' reading.

The natural, physical system the substrate that gave opportunities and restrictions to humans to live on the land and shape it into a landscape. It carries the cultural layer. Both will be discussed in detail in Chap. 9.

All these layers are essentially dynamic and transform in different ways, speed and scale influenced by a series of equally dynamic driving forces. Successive time layers make the palimpsest of the unique history of each landscape unit. This will be treated in Chap. 7.

References

Agarwal, C., Green, G. M, Grove, J. M., Evans, T. P., & Schweik, C. M. (2002). *A review and assessment of land-use change models: Dynamics of space, time, and human choice*. Gen.Tech. Rep. NE-297. Newtown Square, PA:U.S. Radnor: Department of Agriculture, Forest Service, Northeastern Research Station, 67 pp. http://www.fs.fed.us/ne/newtown_square/publications/technical_reports/pdfs/2002/gtrne297.pdf

Antrop, M. (1988). Invisible connectivity in rural landscapes. In K.-F. Schreiber (Ed.), *Proceedings of the Second International Seminar of IALE, connectivity in landscape ecology* (pp. 57–62). Münster: Münsterische Geographische Arbeiten 29.

Antrop, M. (2004). Assessing multi-scale values and multifunctionality in landscapes. In J. Brandt & H. Vejre (Eds.), *Multifunctional landscapes*, *Theory, values and history* (Vol. I, pp. 165–180). Southampton: WIT Press.

Antrop, M. (2006). From holistic landscape synthesis to transdisciplinary landscape management. In B. Tress, G. Tress, G. Fry, & P. Opdam (Eds.), *From landscape research to landscape planning: aspects of integration, education and application*, *Wageningen UR frontis series, N° 12* (pp. 27–50). Dordrecht: Springer.

Arnot, C., Fisher, P., 2007. Mapping the ecotone with fuzzy sets. In: Morris A. Kokhan S. (eds.), Geographic uncertainty in environmental security, Springer, Dordrecht, 19–32.

Austad, I. (2000). The future of traditional agriculture landscapes: retaining desirable qualities. In J. Klijn & W. Vos (Eds.), *From landscape ecology to landscape science*, *WLO* (pp. 43–56). Wageningen: Kluwer Academic Publishers.

Baudry, J., & Merriam, H. G.. (1988). Connectivity and connectedness: Functional versus structural patterns in landscapes. In K. F. Schreiber (Ed.) *Connectivity in landscape ecology* (pp. 23–28). Proceedings of the 2nd International Association for Landscape Ecology. Münstersche Geographische Arbeiten, 29.

Bell, S. (2004). *Elements of visual design in the landscape*. London: Spon Press.

Bertin, J. (1983). *Semiology of graphics*. Madison: University of Wisconsin Press.

Borisch, W. (2007). *When the volcanoes… "Notes about the occurrences between the years 1730 and 1736" written by the Priest of Yaiza, Don Andrés Lorenzo Curbelo* (32 pp). Lanzarote: Editorial Yaiza S.L.

Brandt, J., & Vejre, H. (2004). In J. Brandt & H. Vejre (Eds.), *Multifunctional landscapes. Theory, values and history* (Vol. I, 3–32 pp). Southampton: WIT Press.

Burel, F., & Baudry, J. (2003). *Landscape ecology: Concepts, methods and applications* (362 pp). Enfield/New Hampshire: Science Publishers, Inc..

Christaller, W. (1933). *Die zentralen Orte in Süddeutschland*. Jena: Fischer.

Dawkins, R. (1996). *The blind watchmaker*. London: Norton.

De Keyzer, M., Jongepier, I., & Soens, T. (2014). Consuming maps and producing space. Explaining regional variations in the reception and agency of mapmaking in the Low Countries during the medieval and early modern periods. *Continuity and Change, 29*, 209–240.

Ďuračiová, R., Lieskovský, T. Stopková, E., & Kročková, K. (2013). *The benefit of fuzzy logic to protection of cultural and historical heritage*. GIS Ostrava 2013 - Geoinformatics for City Transformation.

Emanuelsson, U. (2009). *The rural landscapes of Europe. How man has shaped European nature*. The Swedish Research Council Formas, p. 383.

Fahrig, L., Baudry, J., Brotons, L., Burel, F. G., Crist, T. O., Fuller, R. J., Sirami, C., Siriwardena, G. M., & Martin, J.-L. (2011). Functional landscape heterogeneity and animal biodiversity in agricultural landscapes. *Ecology Letters, 24*, 101–112.

Farina, A. (1998). *Principles and methods in landscape ecology*. London: Chapman & Hall. 235 pp.

Farina, A. (2012). *Landscape ecology in action*. Dordrecht: Springer. 317 pp.

Forman, R. T. T. (1995). *Land mosaics: The ecology of landscapes and regions*. Cambridge: Cambridge University Press.

Forman, R., & Godron, M. (1986). *Landscape ecology* (619 pp). New York: Wiley.

Gardner, R. H., & O'Neill, R. V. (1990). Pattern, process and predictability: The use of neutral models for landscape analysis. In M. G. Turner & R. H. Gardner (Eds.), *Quantitative methods in landscape ecology* (pp. 289–307). New York: Springer-Verlag.

Garrigues, S., Allard, D., Baret, F., & Weiss, M. (2006). Quantifying spatial heterogeneity at the landscape scale using variogram models. *Remote Sensing of Environment, 103*, 81–96.

Goodwin, B. J., & Fahrig, L. (2002). How does landscape structure influence landscape connectivity? *Oikos, 99*, 552–570.

Granö, J. G. (1922). *Eesti maastikulised üksused*, Loodus I, 2, pp. 105–123; 4, pp. 193–214; 5, pp. 257–281.

Granö, J. G. (1935). Geographische Ganzheiten. *Petermanns Mitteilungen, 81*, 295–301.

Granö, J. G. (1952). *Régions géographiques et une méthode pour les délimiter*. Compte Rendu du XVIè Congrès International de Géographie, Lisbonne 1949, 11 pp.

Hägerhall, C., Purcella, T., & Taylor, R. (2004). Fractal dimension of landscape silhouette outlines as a predictor of landscape preference. *Journal of Environmental Psychology, 4*, 247–255.

Hägerstrand, T. (1967). Innovation diffusion as a spatial process (A. Pred, Trans.). Chicago: University of Chicago Press.

Haines-Young, R., & Potschin, M. (2004). Valuing and assessing of multifunctional landscapes: An approach based upon the natural capital concept. In J. Brandt & H. Vejre (Eds.), *Multifunctional landscapes. Theory, values and history* (Vol. Vol. I, 181–192 pp). Southampton: WIT Press.

Hard, G. (1970). Der 'Totalcharakter der Landschaft'. Re-Interpretation einiger Textstellen bei Alexander von Humboldt. Erdkundliches Wissen, 49–71.

Harley, J. B. (1988). Maps, knowledge, and power. In D. Cosgrove & S. Daniels (Eds.), *The iconography of landscape* (pp. 277–312). Cambridge: Cambridge University Press.

Huff, D. (1954). *How to lie with statistics*. New York: Norton.

Katayama, N., Amano, T., Naoe, S., Yamakita, T., Komatsu, I., S-i, T., et al. (2014). Landscape heterogeneity–biodiversity relationship: effect of range size. *PloS One, 9*(3), e93359.

Klopatek, J. M., & Gardner, R. H. (Eds.). (1999). *Landscape Ecological Analysis. Issues and Applications* (400 pp). New York: Springer-Verlag.

Korzybski, A. (1933). *Science and sanity: An introduction to non-aristotelian systems and general semantics, supplement III: A non-aristotelian system and its necessity for rigour in mathematics and physics* (pp. 747–761). New York: Institute of General Semantics.

Kraak, M.-J., & Ormeling, F. (2010). *Cartography: Visualization of geospatial data* (p. 198). Harlow: Prentice Hall/Pearson Education Limited.

Küster, H. (2008). *Kulturlandschaften: Analyse und Planung* (p. 180). Frankfurt: Peter Lang.

Leyk, S., & Zimmermann, N. E. (2007). Improving land change detection based on uncertain survey maps using fuzzy sets. *Landscape Ecology, 22*, 257–272.

Li, H., & Reynolds, J. F. (1995). On definition and quantification of heterogeneity. *Oikos, 73*(2), 280–284.

Longley, P. A., Goodchild, M. F., Maguire, D. J., & Rind, D. W. (2001). *Geographic information systems and science*. New York: Wiley, & Sons.

Mander, Ü., Uuemaa, E., Roosaare, J., Aunap, R., & Antrop, M. (2010). Coherence and fragmentation of landscape patterns as characterized by correlograms: A case study of Estonia. *Landscape and Urban Planning, 94*(1), 31–37.

McGarigal, K., & Cushman, S. A. (2005). The gradient concept of landscape structure. In J. A. Wiens & M. R. Moss (Eds.), *1999. Issues in landscape ecology*, *Studies in landscape ecology* (pp. 112–119). Cambridge: Cambridge University Press.

McGarigal, K., & Marks, B. J. (1995). *FRAGSTATS: Spatial pattern analysis program for quantifying landscape structure*. USDA For. Serv. Gen. Tech. Rep. PNW-351.

Merriam, G. (1984). Connectivity: A fundamental ecological characteristic of landscape pattern. In J. Brandt & P. Agger (Eds.), *Proceedings of the 1st international seminar on methodology in landscape ecological research and planning* (pp. 5–15). Denmark: Roskilde University.

Metzger, J.-P., & Décamps, H. (1997). The structural connectivity threshold: an hypothesis in conservation biology at the landscape scale. *Acta Oecologica, 18*(1), 1–12.

Mink, P. B., Ripy, J., Bailey, K., & Grossardt, T. H. (2009). *Predictive Archaeological Modeling using GIS- Based Fuzzy Set Estimation: A Case Study in Woodford County, Kentucky*. Kentucky Transportation Center Faculty and Researcher Publications. Paper 12. http://uknowledge.uky.edu/ktc_facpub/12

Monmonier, M. (2005). Lying with maps. *Statistical Science, 20*(3), 215–222.

Naveh, Z., & Lieberman, A. (1994). *Landscape ecology: Theory and application* (360 pp). New York: Springer Verlag.

Olwig, K. R. (2004). "This is not a landscape": Circulating reference and land shaping. In H. Palang, H. Sooväli, M. Antrop, & S. Setten (Eds.), *European rural landscapes: Persistence and change in a globalising environment* (pp. 41–66). Dordrecht: Kluwer Academic Publishers.

Pinto-Correia, T. (1993). Threatened landscape in Alentejo, Portugal: The 'montado' and other 'agro-silvo-pastoral' systems. *Landscape and Urban Planning, 24*(1–4), 43–48.

Pinto-Correia, T., & Vos, W. (2004). Multifunctionality in mediterranean landscapes – Past and future. In R. Jongman (Ed.), *The new dimensions of the European landscape*, *EU Frontis Series*. Wageningen: Springer.

Smuts, J. C. (1926). *Holism and evolution*. New York: The Macmillan Company.

Stanners, D., & Bourdeau, P. (Eds.). (1995). *Europe's environment. The Dobris assessment*, *EC DG XI and Phare* (p. 676). Copenhagen: European Environment Agency.

Syrbe, R.-U. (1997). *Landscape evaluation of heterogeneous areas using fuzzy sets*. Cybergeo: European Journal of Geography [online], Dossiers, 10ème Colloque Européen de Géographie Théorique et Quantitative, Rostock, Allemagne, 6–11 septembre 1997, document 40, http://cybergeo.revues.org/1564

Tobler, W. (1970). A computer movie simulating urban growth in the Detroit region. *Economic Geography, 46*(2), 234–240.

Turner, M. G. (1989). Landscape ecology: The effect of pattern on process. Annual review of Ecology and Systematics, 20,171–197. In J. H. Wiens, M. R. Moss, M. G. Turner, & D. J. Mladenoff (Eds.), *2007. Foundation papers in landscape ecology* (pp. 545–571). New York: Columbia University Press.

Turner, M. G., & Gardner, R. H. (Eds.). (1990). *Quantitative methods in landscape ecology*. New York: Springer-Verlag.

Turner, M. G., Gardner, R. H., & O'Neill, R. V. (2001). *Landscape ecology in theory and practice: Pattern and process*. New York: Springer-Verlag.

Turner, N. J., Davidson-Hunt, I. J., & O'Flaherty, M. (2003). Living on the edge: Ecological and cultural edges as sources of diversity for social–ecological resilience. *Human Ecology, 31*(3), 439–461.

Turner, M. G., Donato, D. C., & Romme, W. H. (2013). Consequences of spatial heterogeneity for ecosystem services in changing forest landscapes: Priorities for future research. *Landscape Ecology, 28*(6), 1081–1097.

Unwin, D. (1981). *Introductory spatial analysis* (212pp). London: Methuen.

Van Wirdum G., 1981, Design for a land ecological survey of nature protection. In: Tsjallingii & de Veer (eds.), *Perspectives in landscape ecology*. Proceedings of the Intern (pp. 245–251). Wageningen: Congress of the Netherlands Society for Landscape Ecology, Centre for Agricultural Publishing and Documentation

Vogt, P., Ferrari, J. R., Lookingbill, T. R., Gardner, R. H., Riitters, K. H., & Ostapowicz, K. (2009). Mapping functional connectivity. *Ecological Indicators, 9*, 64–71.

von Humboldt, A. (1807). *Ansichten der nature*. eBook-Originalausgabe, eClassica, Aurabooks. www.aurabooks.de.

Vos, W. (1993). Recent landscape transformation in the Tuscan Apennines caused by changing land use. *Landscape and Urban Planning, 24*(1–4), 63–68.

Vos, W., & Meekes, H. (1999). Trends in European cultural landscape development: perspectives for a sustainable future. *Landscape and Urban Planning, 46*(1–3), 3–14.

Vos, W., & Stortelder, A. H. F. (1992). *Vanishing Tuscan landscapes, landscape ecology of a submediterranean-montane area (Solano basin, Tuscany, Italy)*. Wageningen: Pudoc.

Wiens, J. A., & Milne, B. T. (1989). Scaling of "landscape" in landscape ecology, or, landscape ecology from a beetle's perspective. *Landscape Ecology, 3*, 87–96.

Wiens, J. A., & Moss, M. R. (eds.) (1999). *Issues in landscape ecology*. International Association for Landscape Ecology, Fifth World Congress, Snowmass Village, Colorado, USA.

Wu, J., & Hobbs, R. (2002). Key issues and research priorities in landscape ecology: An idiosyncratic synthesis. *Landscape Ecology, 17*(4), 355–365.

Wulf, A. (2015). *The invention of nature – Alexander von Humboldt's new world* (p. 473). New York: Alfred A. Knopf.

Zonneveld, J. I. S. (1985). *Levend land. De geografie van het Nederlandse landschap*. Scheltema & Holkema/Utrecht/Antwerpen: Bohn.

Zonneveld, I. S. (1995). *Land ecology* (199 pp). Amsterdam: SPB Academic Publishing bv.