Note

A Quantitative Method for Analysing Landscape Structure

Lene Møller Jensen, Pernille Hobitz, Anette Reenberg & Jonas Lawesson

Abstract

The present paper sketches out a method for a quantitative description of landscape structure, which can be used for biologically optimal landscape management. The approach suggested is based on a landscape ecological framework and emphasis is laid on spatial characterisation of the landscape. It aims at supplementing conventional landscape descriptive parameters of biological importance, which are derived from a range of empirical data, with a spatial characterization. The method is implemented in a vector-based GIS (ArcView) and allows quantification of landscape structure in different landscape types. Suggestions to further development of the method are discussed.

Keywords

Landscape structure, countryside planning, vector-based GIS.

Lene Møller Jensen, M.Sc. Ph.D.student, Institute of Geography, University of Copenhagen, Østervoldgade 10, DK-1350 Copenhagen K, Denmark and Danish Forest and Landscape Research Institute, Hørsholm Kongevej 11, DK-2970 Hørsholm, Denmark.
Pernille Hobitz, M.Sc., Institute of Geography, University of Copenhagen, Øster Voldgade 10, DK-1350 Copenhagen K, Denmark.
Anette Reenberg, Associate Professor, Institute of Geography, University of Copenhagen, Øster Voldgade 10, DK-1350 Copenhagen K, Denmark.
Jonas Lawesson, Senior Research Fellow, Department of Landscape Ecology, National Environmental Research Institute, Grenåvej 12, DK-8410 Rønde, Denmark

Background

Landscape analysis has for centuries been used by geographers to characterize landscapes (Haber 1990, Haggett 1990, Zonneveld 1995). Globally valid criteria for landscape description have, however, not yet been suggested and a general landscape classification therefore not established (Zonneveld 1990). Nevertheless, the landscape approach has in many cases provided valuable insight into human resource management strategies beyond the information which can be obtained from statistics (Reenberg and Pinto-Correia 1993).

The interest for analysis of landscape patterns and dynamics has in recent decades increased significantly with the emergence of landscape ecology. One of the most used definitions of a landscape is presented by Forman and Godron (1986): "A heterogeneous land area composes of a cluster of interacting ecosystems that is repeated in similar form throughout". From this definition it is obvious that a main subject in landscape analysis must be the spatial arrangement of landscape elements and landscape structure is considered important for shaping the different flows of energy, matter and species (Zonneveld 1995).

Several empirical studies show that both flora (Zacharias and Brandes 1990, Bunce and Hallam 1993) and fauna (Fahrig and Merrian 1985, Komdeur and Gabrielsen 1995) are affected by the spatial arrangement of the landscape elements. One theory that explains this is the metapopulation theory (Levins 1970), in which landscape structure is identified as an important factor for the survival of species richness in a particular area.

Landscape structure is therefore vital when investigating connections between species richness and different landscape elements at the landscape level. Thus, to give guidelines for protection of the biological values of the landscape it is useful to be able to quantify the landscape structure. In that way it will be possible to evaluate which landscape elements should be protected in order to maintain or increase the biological value of a particular landscape.

Methodological approaches – existing approaches

With the increased interest in landscape patterns and dynamics a wide range of different methods for describing the landscape and its structure has been developed (a selected list is given in Tabel 1).

Basically two main types of characterisation methods can be distinguished. One type characterises the landscape statistically by using a list of parameters that describe the different landscape elements. Typical components are the areas, the numbers, the shape, etc of the landscape el-

Table 1: Methods for quantification of landscape structure.

Authors	*Measured Parameters*	*Quantitative Measures*
Forman & Godron (1986)	Number of links	Network, connectivitet
O'Neill et al. (1988)	Land use type	Dominance, contagions, fractal geometric
Turner & Ruscher (1988)	Patch: Areal, Number	Diversity, dominance, contagions
Dunn et al. (1991)	Landscape elements: Number, Area, Perimeter, Distance to nearest patch, interior area	None
Selman (1992)	Patch: Number, Area	Circuitry, connectivity, shape index
Jurgens (1993)	Network	Three models for spreading
Syrjänen et al. (1994)	Patch: Number, Area, Distance to nearest neighbour, Edge type	Heterogeneity, edge characteristics
Brandt & Holmes (1995)	Landscape elements: Number, Area	Diversity, negentropy, dominance, redundancy, complexity
Hulshoff (1995)	Land use type, patch: Area, Number, Average size, perimeter-area	dominance, patch shape
Riitters et al. (1995)	Patch: Area, Perimeter, Shape, Number of classes	Contagions, large-patch density-area scaling

ements as well as the distance between them. The landscape structure is thus quantified by use of a set of parameters, sometimes by help of GIS (Dunn et al. 1991, Syrjänen et al. 1994, Riitters et al. 1995). An inherent weakness of these methods is that they do not address the spatial complexity of the landscape.

Another type of methods establish one, or a few, indices to characterise the total landscape structure, e.g. diversity, dominance and contagions (Turner and Rusher 1988, O'Neill et al. 1988, Kienast 1993). These kinds of measures often end up with complicated and impenetrable measures which are not easily workable from a planning perspective (Selman and Doar 1992), and they may not always be able to separate landscapes even when the landscape structure differs markedly (e.g. Brandt and Holmes 1995). Neither are such indices always useful for comparison of different landscapes. They might be useful to measure change in a particular landscape, e.g. by use of the "linesamping" method (Kienast 1993). Yet, they fail to retain any information of the spatial distribution of the landscape elements (e.g. if the landscape elements are evenly distributed in the landscape or if they are located in a separated part of the landscape), and the methods are consequently of limited use to compare structures of different landscapes.

One of the latest and most comprehensive methods to address some of the short-comings of these studies is presented in the FRAGSTATS programme (Mcgarigal and Marks 1995). It is capable of handling both raster and vector images and deals with the spatial aspects of landscape structure in two measures; 'the contagion index' and 'the interspersion and juxtaposition index'. Both are based on adjacencies (cells and patch adjacencies) and do not contain any measures of distance. The 'interspersion and juxtaposition index' measures the extent to which patch types are interspersed, but is not directly affected by the number, size, contiguity or dispersion of patches (as is the contagion index): 'A landscape containing four large patches, each a different patch type, and a landscape of the same extent containing 100 small patches of four patch types will have the same index value if the patch types are equally interspersed' (Mcgarigal and Marks 1995, p 53). The 'contagion index', measures the extent to which landscape elements (patch type) are aggregated or dispersed. Unfortunately this is done by cell adjacencies and thereby only capable of analysing raster images.

A modified approach

The present paper suggests a method for landscape characterization that combines the use of targeted, statistical landscape parameters with a description of the mutual, spatial distribution of the landscape elements.

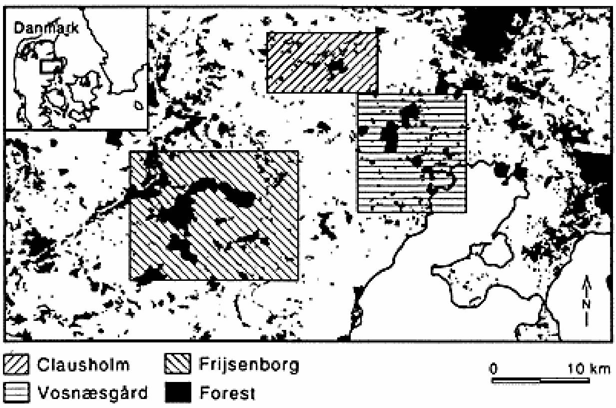

Figure 1: Study area.

The case selected to illustrate the method consists of three study areas in eastern Jutland, see Figure 1. A visual inspection of the topographical map reveals big differences of the landscape structure in the three areas. The area called "Clausholm" is a typical river valley landscape with a mosaic of small and various landscape elements. "Frijsenborg" is a moraine landscape dominated by large homogeneous landscape elements. "Vosnæsgård" consists partly of a dead ice area, partly of areas dominated by terminal moraines, and the landscape elements are of medium size.

The method is developed in the context of a biological project (Opdam 1994). The main focus is to analyse landscape structure parameters controlling the flows of species within the landscape, thus, the quantification of the landscape structure is based on biological parameters of importance.

The actual selection of landscape parameters is inspired from empirical studies based on metapopulation theories. Such studies are mostly based on single species or species groups and are thereby restricted in their usefulness when working at the landscape level. Therefore, it has been necessary to rely on a wide range of works presenting these empirical studies in order to identify the entire set of relevant parameters (for the used list of references see Hobitz and Jensen 1996). Based on the empirical experience in these works, the following parameters are identified to describe landscapes in terms of their ability to sustain distribution and survival of various species:

-Number of landscape elements
-Area of landscape elements
-Shape of landscape elements
-Isolation of the landscape elements
-Network between the landscape elements
-Matrix of the landscape
-Age of the landscape elements
-Historical use of the landscape elements

The spatial parameters can more or less directly be derived from the GIS (ArcView) data base provided that it contains the needed information on the land use in the area of interest. Area and number of landscape elements are measured directly. The proportion to the landscape matrix can be calculated for landscape element types that constitute a patch. The shape of landscape elements is calculated as patch perimeter in proportion to patch area.

Characterization of the isolation of the landscape elements is less straightforward. A simple and frequently applied solution is to measure the average minimum distance between landscape elements. This measure does not, however, mirror the spatial distribution of landscape elements that might be of vital importance to the biological quality of the landscape. Furthermore, it is influenced by the total area of the landscape under investigation and comparisons between different landscapes can therefore be complicated.

As an alternative, it is suggested to measure distances from a fixed, regular point layer to the closest landscape element. The distances from a fixed point layer (here named "point distances") are obtained by placing a grid of points (1 km between each point) over the entire landscape, and calculating the minimum distance from each point to the landscape elements. The point distances are illustrated graphically, by indicating the distance of respectively 25%, 50%, 75% and 100% of the ranked point distances. In this way the point distances can be compared even though the landscapes considered are not of the same size. The interpretation of the point distance graphs is illustrated in Figure 2.

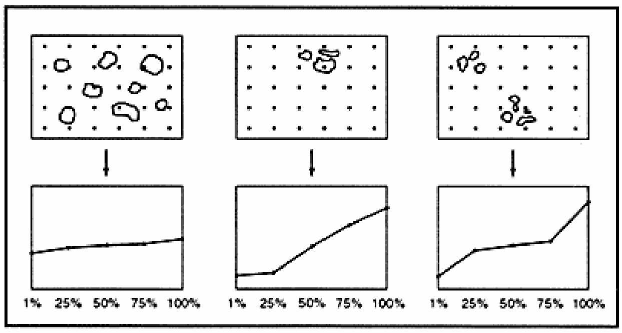

Figure 2: Interpretation of point distance.

Table 2: Statistical indicators of Landscape structure.

	Clausholm			Frijsenborg			Vosnæsgård		
	Number and area of landscape elements								
	%	No	No/km²	%	No	No/km²	%	No	No/km²
Matrix	11	-	-	27	-	-	25	-	-
Forest	6.5	91	1.4	20.1	141	0.6	17.7	126	1.0
Lake	0.1	14	0.2	0.4	61	0.3	0.4	58	0.4
Pond	-	62	0.9	-	214	1.0	-	150	1.1
Tree	-	32	0.5	-	300	1.4	-	206	1.6
	Average distance between landscape elements in meters								
Forest		170			173			172	
Lake		1089			761			445	
Pond		626			338			309	
Tree		457			395			365	

Application of the method

The landscape structure of the study areas has been analysed by use of the above suggested characterization method. Selected results of the simple, statistical indicators are shown in Tabel 2. Some correspondence with a visual map interpretation is obvious. Frijsenborg has few but large landscape elements (Forest cover is 20.1% of the total area, but there are only 0.6 forest pr. km²), Clausholm has many but small landscape elements (Forest cover is only 6.5% of the total area but there are 1.4 forest pr. km²), while Vosnæsgård is somewhere in between (Forest cover is 17.7% and there are 1.0 forest pr. km²). But important information about the actual distribution of landscape elements is missing. When looking at the figures for the average distance between forest in the three areas, no particular differences appear (170, 173 and 173 metres). The point distance curve shown in Figure 3 reveal the significantly different distributions of forests in the three areas. In Clausholm, the forests are evenly spread over the whole landscape as expressed by the slowly increasing graph. In Vosnæsgård this is also the case for 75% of the landscape, but the steepness of the last part of the graph indicates that there are a few areas where forests are not present. In Frijsenborg, the distribution of forests is very uneven as indicated by the steep graph. This distribution pattern corresponds very well with the observed pattern in the visual map interpretation.

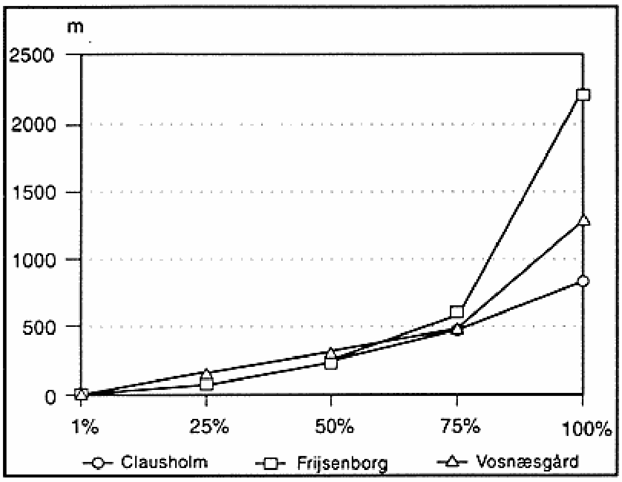

Figure 3: Distribution of forests patches.

Discussion

Thus, by combining the different, suggested measures, a detailed description of the landscape structure is achieved. This composite, quantitative description is suitable for a largely computerbased handling. And it is to a large degree capable of capturing some of the important spatial characteristics of landscapes that constitute an often important advantage of the visually based analysis of maps. The use

of GIS makes the description more precise and more manageable than the traditional interpretation of maps because it thereby becomes possible to handle large amounts of information. One of the greatest achievements is that the method measures the spatial distribution of the different elements of the landscape. The point distance tool is able to improve the characterization given by average distances significantly. The method has, however, to be further developed. This could, for example, include development of a quantitative description that enables distinction between different point distance graphs to replace the visual interpretation used in this context.

Furthermore, there is a need to include measures of the landscape network and their biological implications. In that respect it is found important not only to focus on specific species as has often been the case (e.g. Jurgens 1993). Also, the age and former use of landscape elements are important parameters that deserve to be taken into consideration, when the biological values of the present day landscapes are evaluated. These data can easily be combined with the spatial data in a GIS, if such information on the areas exists.

From the point-of-view of planning, it is important to quantify landscape structure in an easily understood and workable manner. Landscape structure is an important factor for the survival of species richness in a particular area. Therefore, a quantification of the landscape structure can be a useful tool in proper landscape management. Yet, an optimal trade off must be obtained between a low and manageable number of measurements and a satisfactory description of the landscape structure if such a method should be applicable in daily management of the landscape.

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