The ecology of visual landscapes: Exploring the conceptual common ground of visual and ecological landscape indicators

G. Fry a,*, M.S. Tveit a, Å. Ode b, M.D. Velarde c

a Dept. of Landscape Architecture and Spatial Planning, Norwegian University of Life Sciences, PO Box 5003, N 1432 Ås, Norway
b Dept. of Landscape Architecture, Swedish University of Agricultural Sciences, PO Box 58, SE 230 53 Alnarp, Sweden
c School of Experimental Sciences and Technology, Rey Juan Carlos University of Madrid, C/Tulipan s/n, 28933 Móstoles, Madrid, Spain

1. Introduction

Landscape indicators are currently high on the policy agenda and are increasingly used in the assessment of different landscape values. While ecological values have been on the policy agenda for a long time, instance, through the Rio declaration, visual quality has until recently received less attention in Europe. However, a change occurred through the European Landscape Convention, which promotes an integrated view of the landscape were the visual, cultural and social qualities of the landscape are included along with ecological functions. The importance and challenges of integration in landscape studies have been highlighted by several researchers (Fry, 2001; Opdam et al., 2002; Tress et al., 2001, 2005, 2007; Wissen et al., 2008).

The development of landscape ecological indicators has been a very active research field that has resulted in a wide range of landscape metrics and composite indices with a strong conceptual base in landscape ecological principles. For the visual aspects of landscapes, however, this conceptual base is often missing and thus hindering progress in the development of indicators. This paper presents the results of an analysis of the correspondence between ecological indicators and visual indicators in order to explore whether there is common ground in both concept and operation. The conceptual level is presented for both ecological and visual indicators, as it is the concepts that define their aim and scope. We feel that transparency over this issue is crucial to the development and use of environmental indicators. The approach identified a candidate set of indicators that capture important aspects of both ecological and visual quality. The strength of the approach is that it forces us to focus on the identification of what we wish to indicate by means of landscape theory and assessment that are relevant to a specific landscape context. We believe that the approach presented here forms the basis for development of new methods for understanding the impact of landscape change in a management and planning context.

© 2008 Elsevier Ltd. All rights reserved.

doi:10.1016/j.ecolind.2008.11.008
majority of landscape indicators currently used for measuring different aspects of landscapes is land cover based, although other types of data (i.e. of ownership, production, soil chemistry) have also been used. Within Europe, there are several monitoring schemes that focus on landscape change using land cover based indicators to analyse the effect of changes (e.g. Dramstad et al., 2002; EEA, 2006; Eiden et al., 2001; Gallego, 2002; OECD, 2001). The availability of historical land cover data, as well as scenario development, makes land cover derived indicators useful in analysing the consequences of temporal landscape change.

In many ways this data driven development of landscape indicators has been a diversion, allowing us to neglect the important questions related to what indicators are meant to indicate (e.g. Lenz et al., 2000). We argue that it is necessary that indicators applied should have a clear theory base in order to make them transparent and easier to interpret. Indicators are needed to help us report on aspects of the state of the environment when we cannot (or cannot afford) to provide direct measurements of these. Efficient indicators can help us evaluate whether changes are going in a desirable direction or not. However, individual indicators may tell only part of the story, and only by combining several indicators can it be possible to gain a more comprehensive assessment (Weber and Hall, 2001).

The development of indicators for monitoring and analysis of landscape change has mainly focused on ecological indicators (e.g. Bailey et al., 2007; Lausch and Herzog, 2002). Because if its spatial dimension, this has lead to the adoption of indicators from landscape ecology for measuring other landscape functions and qualities. In current landscape assessment, the same landscape indicators are often applied in different contexts and for measuring different landscape qualities. This integrated use of particular landscape indicators makes it crucial to be aware of what the indicator is meant to indicate and have a solid theoretical base for its application.

The scope of landscape ecology has always included man as a central actor in landscape change and its impact. Hence landscape ecology has always included a cultural perspective and taken account of what is important for people. The definition of landscape ecology given by the International Association for Landscape Ecology shows its integrated approach: “Landscape ecology is the study of the interactions between the temporal and spatial aspects of a landscape and its flora, fauna & cultural components” (IALE, 2008).

The integrative approach to landscape ecology has caused some problems in defining the core of the subject (Moss, 2000) and has challenged internal communication between scientists from widely different disciplines and subject traditions. However, it has also been one of the great strengths of landscape ecology. The subject has evolved as an interdisciplinary subject that includes working methods and concepts from a wide range of academic approaches. This has opened the way for theoretical developments across subject boundaries. One such area of cross-over conceptual development is between landscape aesthetics and landscape ecology. Here, we find much common ground even though the terminology is often different. The role of trying to quantify the spatial structure of landscapes has been important for both disciplines.

Fig. 1 – Scope of this paper; exploring the conceptual common ground between visual and ecological landscape character, related to landscape structure.

To recognise and understand the relationship between ecology and aesthetics on a conceptual level is of importance to landscape planning and management. This is mainly for three reasons according to Gobster et al. (2007). In trying to identify the common ground between ecology and aesthetics Gobster et al. (2007) outlines a model for human-environmental interactions in the landscape. The focus of the model is the perceptible realm where “aesthetic experiences occur and where intentional actions towards landscapes can directly or indirectly affect ecological functions...[it] provides the most active intentional contact between environmental and human phenomena—where the process of perception leading to action most directly links human systems with ecosystems” (Gobster et al., 2007).

In this paper we explore the common ground between two aspects of landscape—visual and ecological character, and how indicators could be used for communicating both aspects. The scope is limited to aspects related to landscape structure (see Fig. 1). We suggest that visual and ecological character share dependency on landscape structure, and might also share a conceptual basis for landscape assessment. Exploring this common ground is one step in investigating how ecological and visual qualities co-vary with landscape change. A framework is used that links landscape indicators to theories pertinent to landscape ecology and landscape aesthetics. The framework is a development of that developed by Tveit et al. (2006) for visual landscape character. Identifying the theoretical common ground and the indicators useful for both landscape aspects can make possible an integrated approach to landscape assessment, monitoring programmes and provide the basis for development of new tools for analysing landscape change.

2. Theoretical framework

2.1. Overview

Although ecology and aesthetics share many common aspects they have also kept their own research worlds with ecology relying mainly on the natural science traditions while
aesthetics has held closely to humanistic research traditions. This remains one of the great challenges in developing indicators for both interests. Nevertheless, recent research has provided several exciting interchanges between disciplines and even different knowledge cultures within disciplines (Palang and Fry, 2003). Many of the approaches to visual landscapes, especially those relating spatial aspects of landscapes to human preferences, have been paralleled by conceptual developments of space use and resource exploitation in landscape ecology, e.g. the concepts of habitat complementation and supplementation (Taylor et al., 1993).

2.2. Visual character

Within the field of landscape aesthetics several theories for explaining landscape perception and preferences can be found. These can be broadly divided into evolutionary theories (Appleton, 1975; Kaplan and Kaplan, 1989) and cultural preference theories (e.g. Carlson, 2001; Tuan, 1974). Evolutionary theories explain visual landscape preferences as shaped by our common evolutionary history, claiming that we respond positively to features that enhance survival and well-being. On the other hand preferences are explained as shaped by cultural and personal experiences, with beauty essentially being in the eye of the beholder (Meinig, 1976). Lately, several researchers has argued for an integrative theoretical framework as the most appropriate (e.g. Bourassa, 1991; Norton et al., 1998), explaining landscape perception and preference as genetically based modified and changed by cultural influences and personal experiences. We agree with the integrative approach, and believe that due to our common evolutionary history there exists a common set of landscape features that are preferred across cultures and personal differences. Although cultural and personal differences in landscape preferences exist, it is useful to identify the commonalities in addition to exploring the forces that shape divergences. This can make important contributions to landscape planning and management, and is our basis for the development of visual indicators from a conceptual approach.

A review of landscape aesthetic literature identified nine key concepts, reflecting the dominant aspects of the visual landscape as presented in visual guidelines and the research literature (the full review is found in Tveit et al., 2006 with a summary of the concepts and their definition is found in Table 1).

2.3. Ecological function

Ecological indicators within landscape planning have their foundation and theoretical base in landscape ecology. This is related to three fundamental components of landscape: structure, function and change (Forman, 1995). Identifying the main structural elements in the landscape, and their relation to ecological processes are essential for our understanding of how landscape change will affect species and communities (Turner, 1989). Understanding the relationships between structure and function also enables us to predict the ecological consequences of proposed spatial solution(s).

A common classification of landscape structural elements is the Patch–Corridor–Matrix approach. The Patch–Corridor–Matrix model (PCM) is fundamental to landscape ecology theory, as it defines the spatial arrangement of elements in a landscape. This in turn directs the way we represent and measure landscape to assess how changes in landscape content and configuration affect ecological processes (Haines-Young, 2000). The Patch–Corridor–Matrix model has had widespread appeal and many scientific papers on landscape metrics base their theoretical assumptions on the Patch–Corridor–Matrix model. Although this model may be an oversimplification of landscapes and poorly represent mosaic landscapes, it has been validated through many studies in many contexts linking aspects of biodiversity to landscape pattern (Bennett, 1998; Burel and Baudry, 2003; Farina, 2007; Forman, 1995; Girvetz and Greco, 2007).

Within the landscape ecology literature on indicators, there has been a rapid and widespread development of metrics aimed at describing landscape structure. Landscape metrics enable us to quantify the spatial processes of attrition, fragmentation, etc., thereby capturing numerical descriptors of change (McGarigal and Marks, 1995). These metrics have commonly been grouped as describing patch area, edges, shape, diversity and configuration (e.g. Lausch and Herzog, 2002). However, very few attempts have been made to relate metrics to overarching concepts, ones that can be related to a wider range of landscape values such as natural heritage or aesthetics. Niemi and McDonald (2004) divide ecological

<table>
<thead>
<tr>
<th>Concept</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stewardship</td>
<td>Sense of order and care, perceived accordance to an “ideal” situation reflecting human care through active and careful management</td>
</tr>
<tr>
<td>Coherence</td>
<td>Unity of a scene, repeating patterns of colour and texture, correspondence between land use and natural conditions</td>
</tr>
<tr>
<td>Disturbance</td>
<td>Lack of contextual fit and coherence, constructions and interventions</td>
</tr>
<tr>
<td>Historicity</td>
<td>Historical continuity and historical richness, different time layers, amount and diversity of cultural elements</td>
</tr>
<tr>
<td>Visual scale</td>
<td>Landscape rooms or perceptual units: their size, shape and diversity, degree of openness</td>
</tr>
<tr>
<td>Imageability</td>
<td>Qualities of a landscape present in totality or through elements; landmarks and special features, both natural and cultural, making the landscape create a strong visual image in the observer, and making landscapes distinguishable and memorable</td>
</tr>
<tr>
<td>Complexity</td>
<td>Diversity, richness of landscape elements and features, interspersion of pattern</td>
</tr>
<tr>
<td>Naturalness</td>
<td>Closeness to a preconceived natural state</td>
</tr>
<tr>
<td>Ephemera</td>
<td>Changes with season, weather or other temporal effects</td>
</tr>
</tbody>
</table>
indicators into the different over-arching concepts: compositional—land use/cover; functional—landscape processes; structural—landscape patterns; integrative—index of environmental integrity. Tischendorf (2001) focuses on the interactions between landscape indices quantifying landscape structure and landscape processes as measured through response variables. We would argue, in accordance with Li and Wu (2004), that there is a need to distinguish components of spatial pattern and link them to their ecological functions.

2.4. Hierarchical structure for indicator development

Tveit et al. (2006) presented a hierarchical structure of four levels relating to levels of abstraction which was developed in relation to visual indicators; concepts > dimensions > landscape attributes > indicators (Table 2). Concepts are here referring to an abstract level with clear linkage to theory. These concepts could be seen as an umbrella term under which several dimensions of the concepts can be found. Each dimension is in turn formed by different physical landscape attributes that can be counted, measured and described through the use of metrics. This framework provides a hierarchical linking of landscape indicators with abstract concepts. This in turn makes clearer linkages with theory for specific indicators.

3. Exploring the conceptual common ground

3.1. Background

An underlying assumption in policy has often been that ecologically sound landscapes are also attractive and vice versa (Carlson, 2001; Gobster, 1999). Landscape ecology is concerned with the way animals perceive landscapes and how their behaviour responds to different landscape structures (Dover and Fry, 2001; Hehl-Lange, 2001). Research on animals, ranging from mammals to insects, has found that perceptual cues as often as physical barriers affect animal space use.

In this section we explore the conceptual common ground between visual character and ecological function to explore the ability of visual indicators to also inform us about ecological functions at the landscape level. Some indicators identified in the literature have already been applied to indicate several visual aspects. This explains why the same indicator sometimes appears under several of the conceptual headings in the framework presented below.

3.2. Stewardship

Stewardship as a spatial expression of landscape has significance both visually and ecologically (see Table 3). Traditional farming and forestry has given rise to many distinctive field systems, forests and settlement patterns often prized as attractive landscapes and valuable for biodiversity. In Europe, these are termed cultural landscapes and are characterised by their management regimes that are often labour intensive and important for both the ecological and visual aspects. In visual terms, stewardship has been defined as the sense of order and care, perceived accordance to an “ideal” situation, reflecting human care through active and careful management (Tveit et al., 2006). Stewardship is seen to have effects on human landscape perception and preference (Nassauer, 1995, 1997; van Mansvelt and Kuiper, 1999).

Equally, the stewardship in a landscape is important for its ecological properties. Studies have shown relationships between management and biodiversity, related to management type, frequency or intensity. Earlier studies show how over-managed landscapes may neither threaten a sense of order nor favour biodiversity (e.g. Bergstedt and Milberg, 2001; Donald et al., 2001; Virkkala et al., 2004). On the other hand, many species are adapted to landscapes as shaped through human activities. If such areas are abandoned, this lack of “careful” management may lead to secondary succession that modifies vegetation cover and subsequently changes animal assemblages (e.g. Jensen and Schrautzer, 1999; Laiolo et al., 2004).

3.3. Coherence

Coherence is a much used concept in landscape aesthetics describing the unity of a scene, repeating patterns of colour and texture and correspondence between land use and natural conditions (Kaplan and Kaplan, 1989; van Mansvelt and Kuiper, 1999). Visual coherence can also be defined as the lack of disturbance (Tveit et al., 2006). In landscape ecology, coherence has its parallel in connectedness, which is reduced by fragmentation and habitat loss (Quine and Watts, 2009). Connectedness is defined as the degree of physical connection between patches (Farina, 1998, pp. 68–70). Both connectedness is enhanced by corridors (Beier and Noss, 1998; Collinge, 1998) and hindered by barriers, such as roads or agricultural fields (Forman, 1995, pp. 145–176; Mader, 1984) and low edge permeability (e.g. Buechner, 1987; Collinge, 1996). Fragmentation is a common process of landscape change which impacts
negatively on connectedness and connectivity and species’ dispersal success (King and With, 2002) (see also (disturbance).

Land cover suitability can be seen as a dimension of visual coherence (van Mansvelt and Kuiper, 1999), and also as a dimension of ecological coherence expressed through land cover’s accordance to natural conditions. The characteristics of the inter-patch space (matrix) determines how important land cover is as an important factor determining species movement (Dauber et al., 2003; Umetsu and Pardini, 2007). Connectivity is a species-specific and defined inverse correlate of hostility of the inter-patch habitat. Connectivity is also dependent on the dispersal abilities of different species (e.g. Baguette and Dyck, 2007; Piessens et al., 2005). Naturally occurring lands cover is usually also of higher connectivity that e.g. intensively managed corn fields, which are both low on visual coherence and connectivity for most species.

Visual coherence and connectedness are related at the conceptual level (as seen in Table 4), and overlap in terms of intactness of vegetation and land cover suitability. There is also a partial overlap in terms of landscape elements of importance for the processes (see table Coherence). However, one landscape element may not influence the visual character and ecological function in the same way. A particular landscape element may be positive in terms of increased visual coherence e.g. a water body, while being a barrier to species movement, thus lowering the connectivity.

3.4. Disturbance

Disturbance within landscape aesthetics refers to lack of contextual fit and coherence (e.g. Bell, 1993). Kaplan and Kaplan (1989) identified coherence as one of the information factors in their Information Processing Theory and a high degree of disturbance is likely to result in a low degree of coherence. The consequences of human well-being in relation to disturbance are explained by the Biophilia thesis (Kellert, 1996).

Within landscape ecology, the role of disturbance is often seen as a discrete event in time that has a disruptive effect on the ecosystem and causes changes in the physical environment (Forman and Godron, 1986; Turner, 2005; Wilcox et al., 2006). For a disturbed landscape, the most significant ecological characteristic is its time lag or periodicity (Forman and Godron, 1986, p. 274). Examples of disturbance events could be both natural processes such as fire (Wang et al., 2007), flooding (Roe and Georges, 2007) and winds (Johnson and Beck, 1988) or human actions such as the introduction of invasive species (Higgins and Richardson, 1996), forest fragmentation
through clear felling (Hill and Curran, 2001) or production (Collinge, 1996). The character of the disturbance will determine whether the specific changes are part of the natural succession stages of the ecosystem or will lead to irreversible changes.

The dimensions found for the concept of disturbance in the literature show little overlap between visual character and ecological function (as could be seen in Table 5). Within the ecological literature there are two main dimensions of disturbance; degradation or lack of ecological integrity, and fragmentation. The visual dimensions we found for disturbance were lack of contextual fit and lack of coherence.

Ecological integrity is a measure of the ecological function of the landscape with limited overlap with visual disturbance. One of the disruptive effects of the process of disturbances is the degradation of ecological integrity, leading to (negative) long-term changes in habitat quality (Collinge, 1996). A disturbed area is often the foothold for exotic species and hence an area with chronic disturbance is often reflected by a high proportion of non-native species which can cause changes in the ecosystem balance (Forman, 1995).

The visual dimensions lack of coherence and fragmentation can be seen as closely associated with links to both ecological and visual disturbance. Fragmentation has three ecological components (according to Andrén, 1994): (i) loss of habitat (attrition); (ii) reduction in habitat size (shrinkage); and (iii) increasing isolation of habitat patches. The division of landscape elements into smaller pieces has been described as one of the biggest threats to biodiversity (e.g. Botequilha Leitao and Ahern, 2002). Fragmentation tends to affect visual character a lack of coherence.

Many of the elements introduced to cause both lack of ecological integrity and fragmentation are also often perceived as a visual disturbance. These include extractions (e.g. clear-cutting and quarries), natural disturbances (e.g. fire and windfall), as well as large-scale developments and constructions.

3.5. Complexity

Visual complexity refers to the diversity and richness of landscape elements and the interspersion of patterns in the landscape (Ode et al., 2008). In the Kaplan and Kaplan (1989) Informational Processing Theory, complexity provides content and possibilities for exploration. The Biophilia thesis emphasise the importance of diversity (both species and landscape types) in relation to nature (Kellert, 1996).

For visual character, diversity of landscape elements and land cover are two of the important dimensions (Tveit et al., 2006). The same is true for biodiversity, which often depends
on the diversity of ecosystem components at different scales and their arrangement in the landscape (Forman and Godron, 1986). Habitat heterogeneity is an important dimension of ecological complexity and has been identified as a strong contributing factor to species diversity pattern (Forman, 1995) and several studies have found a positive relationship between habitat diversity and species diversity (Honay et al., 2003; Jonsen and Fahrig, 1997; Luoto et al., 2002). This relationship seems to be stronger for generalist species while specialist species richness is stronger correlated to habitat quality (Luoto et al., 2002).

The complexity of shapes is a dimension for both ecological function and visual character (Forman and Godron, 1986; Tveit et al., 2006). Boundary shape influences ecological processes, and hence species composition and relative abundances (Turner et al., 2001) and also affects the spatial distribution of edge species and interior species (Forman and Godron, 1986).

Pattern complexity describes the spatial relationships between patches and is important for ecological functions with regards to for instance movement of species across landscapes (Forman, 1995). For visual character, complexity of patterns tends to focus on describing patterns of land cover at different scales. In ecological terms, complexity of patches providing habitat supplementation and complementation is essential for many species (e.g. Roe and Georges, 2007; van der Ree et al., 2004).

In Table 6 the relationship between ecological and visual complexity is outlined showing an overlap on the indicator level with the same indicators used for both aspects. This despite the differences in dimensions, where ecological complexity is concerned with habitat heterogeneity and the visual complexity is focused on the diversity land cover and element.

### 3.6. Scale

Scale is a central concept both in landscape ecology (see e.g. Burel and Baudry (2003)) and landscape aesthetics (Ode et al., 2008; Tveit et al., 2006). In assessment of ecological function and visual landscape quality, spatial scale is of vital importance (Lausch and Herzog, 2002; Li and Wu, 2004; Uuemaa et al., 2005). On a small scale, a landscape may appear to be homogenous visually or ecologically, whilst being heterogeneous on a larger scale.

In landscape ecology, scale is often referred to as grain size or patch size, while in visual scale is in related to the size of perceptual units or landscape rooms (see Table 7). Such landscape rooms are open areas bordered by e.g. forests, strips of taller vegetation, topography, creeks, etc. In landscape ecology, the patches are habitable areas surrounded by inhabitable or less habitable matrix areas. The size of patches affects the ecological function of individual patches through its affect on edge and core habitat. When studying species and sometimes communities, we choose the functional scale of the species and process in question. Functional scale in ecological terms may have very different threshold values depending on the species in question and their dispersal abilities and may differ greatly between e.g. beetles and large mammals. Functional grain is a key factor determining species movement and therefore landscape connectivity (Baguette and Dyck, 2007). Functional scale in ecological terms varies greatly between species. For some species, the functional scale may be very similar to the visual scale as perceived by humans. However, in the situation of overlapping human visual scale and ecological functional scale, the significance of changing degree of openness may be opposite. Visual scale is an expression of openness in the landscape, while the size of habitable patches for animals is usually the opposite, namely the size of forest patches. Openness in the landscape increases overview and visibility, which has been found to be related to human landscape preferences (Appleton, 1975; Kaplan and Kaplan, 1989; Zube, 1984). On the other hand, as the openness increases, the forest patches diminish and vegetation strips are fewer, which results in small and isolated patches in ecological terms.

Indicators of visual scale include viewshed size (e.g. Dramstad et al., 2006; Germino et al., 2001; Gulinck et al., 2001; Palmer and Lankhorst, 1998), depth of view (Germino et al., 2001; Gulinck et al., 2001) and degree of visual penetration of vegetation (Weinstoerffer and Girardin, 2000). Indicators with scale in common for visual and ecological aspects are proportion of open land (e.g. Palmer, 2004; Weinstoerffer and Girardin, 2000) and density of obstructing objects (Palmer and Lankhorst, 1998; Weinstoerffer and Girardin, 2000). Ecological indicators related to scale are e.g. patch size (Botequilha Leitão

### Table 7 – A hierarchical framework showing the concept of scale, with dimensions, landscape attributes and currently applied indicators.

<table>
<thead>
<tr>
<th>SCALE</th>
<th>VISUAL</th>
<th>COMMON</th>
<th>ECOLOGICAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visibility</td>
<td>Landscape rooms</td>
<td>Openness</td>
<td>Distance</td>
</tr>
<tr>
<td>Topography</td>
<td>Vegetation</td>
<td>Man made obstacle</td>
<td>Patch</td>
</tr>
<tr>
<td>Viewshed size</td>
<td>Depth of view</td>
<td>Degree of visual penetration of vegetation</td>
<td>Proportion of open land</td>
</tr>
</tbody>
</table>
et al., 2006, p. 52; Collinge, 1998; Cook, 2002; Drinnan, 2005; Forman, 1995, pp. 43–80), and distance between patches (e.g. nearest neighbour distance or proximity (Botequilha Leitão et al., 2006, pp. 53 and 140)). Drinnan (2005) studied processes of fragmentation, and found that size of remnant patches was by far the most important attribute in terms of predicting species richness for all taxa studied.

3.7. Naturalness

Naturalness can be understood as closeness to a natural state that expresses the level at which a process occurs without artificial influence, a gradient ranking from absolutely natural to completely artificial (Aplet et al., 2000; Machado, 2004). In visual terms, naturalness is the perceived closeness to a natural state, which can be different from naturalness in an ecological sense (Ode et al., 2008; Tveit et al., 2006). Researchers have assessed the relationship between ecological factors and preference, suggesting a relationship between the two (e.g. Purcell and Lamb, 1998). From the ecological point of view, a dimension of naturalness may be "ecological integrity", considered as the quality of an ecosystem which has all its native components and processes intact (Machado, 2004; Quigley et al., 2001). The degree of ecological integrity depends mainly on two landscape attributes, the state of the ecosystem and the intensity of management (see Table 8). Indicators of ecological naturalness include the occurrence of pristine biotopes (Hoffmann-Kroll et al., 2003), percentage of exotic vs. specialist species or intact habitat (Quigley et al., 2001).

A natural ecosystem would be one with no human influence. However, management can be performed without necessarily decreasing perceived naturalness. Management of protected areas is often done to maintain or increase ecological integrity, e.g. increasing naturalness (Machado, 2004). The result will depend on where we are on the naturalness gradient and on the intensity of management (which extreme of the gradient are we managing for). Other dimensions related to naturalness are intactness or wilderness, which have been reviewed in depth by Tveit et al. (2006) from the visual point of view.

3.8. Historicity

This is one of the concepts that have well-documented links between visual and ecological interests (see Table 9). Histori-
city relates to the historical richness of landscapes as can be expressed by the number of historical layers or continuity of land cover/land use. These are very similar to the ecological values associated with old ecosystems. Indicators may or may not be positively correlated with historical/cultural values. This is what we find, for example, in the case of old growth forest that has very high ecological value but its interior may not be prized from a visual perspective that sets a higher value on stewardship.

There are strong links between the location of historical sites and biodiversity. For example, many of the historical landscape elements such as stone walls, field systems, grave mounds, etc. are much valued from visual and ecological perspectives. Many of these relationships are mutual, with each being dependent on the other, e.g. old hay meadows and pastures survive only if the management is suitable. If management falls below a critical threshold, trees will invade meadows and both lose attractive half open wooded landscapes as well as the flora and fauna of meadows important for field species, ancient trees and other specialists or are dependent on them (pollinators, lichens, butterflies, etc.

### Table 10 – A hierarchical framework showing the concept of ephemera, with dimensions, landscape attributes and currently applied indicators.

<table>
<thead>
<tr>
<th>Ephemera</th>
<th>Visual</th>
<th>Common</th>
<th>Ecological</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seasonal change</td>
<td>Water</td>
<td>Land use</td>
<td>Land cover/vegetation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Weather characteristics</td>
</tr>
<tr>
<td></td>
<td>Projected and reflected images</td>
<td>Presence of land cover/vegetation with seasonal change</td>
<td>% area water</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Presence of weather characteristics</td>
</tr>
</tbody>
</table>

3.9. Ephemera

Ephemera refer to the degree of seasonal variation in a system. For visual aspects ephemera is believed to add to the perception of fascination which is important for the assessment of restorativeness (Kaplan and Kaplan, 1989). Kaplan and Kaplan suggest that ephemeral effects and features in the landscape enhance the ‘being away’ aspect of landscape experience. Important visual indicators for ephemera include the presence of projected and reflected images.

Ecosystems are constantly changing and not stable (Turner et al., 2001). Ephemeral changes or cyclical changes are examples of periodic variations to which species are adapted to (Forman and Godron, 1986). The periodic variation is often also an essential part of the system. The ability to adapt to these changes could be associated to the genetic memory of organism (Forman and Godron, 1986, p. 275). Ephemeral changes are to large weather and seasonal changes that effect ecosystem conditions and habitat conditions. These kinds of changes are a stabilizing force for the ecosystems (Turner et al., 2001). Specific ecological indicators include temperature and food availability (e.g. Table 10).

### Table 11 – A hierarchical framework showing the concept of imageability and key ecological structures, with dimensions, landscape attributes and currently applied indicators.

<table>
<thead>
<tr>
<th>Imageability and Key Ecological Structures</th>
<th>Visual</th>
<th>Common</th>
<th>Ecological</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sense of place</td>
<td>Iconic elements</td>
<td>Landmarks</td>
<td>Source patches</td>
</tr>
<tr>
<td></td>
<td>Presence of spectacular elements</td>
<td>Spectacular elements</td>
<td>Patch size</td>
</tr>
<tr>
<td></td>
<td>Presence of panoramic/ Long view</td>
<td>Panoramas/ Long view</td>
<td>Patch position</td>
</tr>
</tbody>
</table>

- Presence of spectacular/unique/iconic element
- Presence of water bodies
- Presence of moving water
- Presence of ecological significant elements
- Patch size
- Patch configuration
For ephemera there are indicators that could be used to describe both ecological and visual aspects (as outlined in Table 9). These include presence of cyclical farming activities, presence of land cover and vegetation with seasonal change, degree of water and the presence of specific weather characteristics.

3.10. Imageability—key ecological structures

Imageability is related to the key visual concepts of sense of place, iconographic and uniqueness of a landscape. Such unique and special visible elements can also interact with key ecological structures. Special visual features such as old solitary trees are also important for specialist species of e.g. lichens, insects, etc.

Landscape character is often based on the landscape features that give the landscape an identity and sense of place (Bell, 2001, p. 96; Countryside Agency, 2002). Many of the elements that visually characterise a specific landscape type or class are biological, e.g. old trees, special field systems such as olive groves, vines, boundaries, panoramic views and cliff top bird colonies.

Water is another element of large visual importance and a key role for biodiversity at the landscape level, e.g. the role of ponds (John, 1997). Increasing the number of ponds adds to the visual and ecological importance of an area.

A hierarchical framework showing the parallel concepts of imageability and key ecological structures, with dimensions, landscape attributes and currently applied indicators is shown in Table 11.

### 4. Discussion

4.1. Conceptual common ground

In the foregoing sections we have explored the existence of a conceptual common ground for landscape visual character and ecological functioning. As Tables 3–11 show, there is considerable overlap between the two at the concept level. The nine key concepts describing visual landscape structure identified by Tveit et al. (2006), have meaning also in terms of ecological functions. Many of the concepts are overlapping, e.g. upkeep is an important aspect both visually and ecologically, while some are parallel concepts, e.g. imageability has no direct overlap with ecological function, but is a parallel to the concepts of key patches, source patches and key ecological elements at a conceptual level.

While we have managed to map out a conceptual common ground with ecological aspects for most of the visual concepts suggested by Tveit et al. (2006), as shown in Table 12, the concept of imageability which encompasses important concepts in landscape aesthetics such as sense of place and uniqueness has as far as this study reveals no conceptual common ground with ecological aspects. However, the ecological concept of key ecological structures are a matching type of concept, but dimensions of the ecological concept such as source patches, key patches, and key spatial elements does not have any commonalities with imageability. However, at the landscape attribute level, we find that it can often be ecologically important landscape elements which also create imageability.

<table>
<thead>
<tr>
<th>Visual aspect</th>
<th>Conceptual common ground</th>
<th>Ecological aspect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stewardship</td>
<td>Active and careful management</td>
<td>Ecosystem management</td>
</tr>
<tr>
<td>Order and care</td>
<td>Upkeep</td>
<td>Habitat management</td>
</tr>
<tr>
<td>Coherence</td>
<td>Land cover suitability</td>
<td>Coherence</td>
</tr>
<tr>
<td>Unity/harmony</td>
<td>Intactness of vegetation</td>
<td>Connectedness</td>
</tr>
<tr>
<td>Holistic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Balance and proportion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Disturbance</td>
<td>Fragmentation</td>
<td>Disturbance</td>
</tr>
<tr>
<td>Lack of contextual fit</td>
<td>Lack of coherence</td>
<td>Lack of ecological integrity</td>
</tr>
<tr>
<td>Scale</td>
<td>Openness</td>
<td>Scale</td>
</tr>
<tr>
<td>Visibility</td>
<td></td>
<td>Isolation</td>
</tr>
<tr>
<td>Complexity</td>
<td>Complexity of shapes</td>
<td>Complexity</td>
</tr>
<tr>
<td>Diversity of elements</td>
<td>Pattern</td>
<td>Habitat heterogeneity</td>
</tr>
<tr>
<td>Naturalness</td>
<td>Intactness</td>
<td>Naturalness</td>
</tr>
<tr>
<td>Perceived naturalness</td>
<td>Wilderness</td>
<td>Ecological naturalness</td>
</tr>
<tr>
<td>Historicity</td>
<td>Natural</td>
<td>Continuity</td>
</tr>
<tr>
<td>Historical continuity</td>
<td>Continuity</td>
<td>Ecological continuity</td>
</tr>
<tr>
<td>Historical richness</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ephemera</td>
<td>Seasonality, temporal and cyclical change</td>
<td>Ephemera</td>
</tr>
<tr>
<td>Imageability</td>
<td></td>
<td>Key ecological structures</td>
</tr>
<tr>
<td>Sense of place</td>
<td></td>
<td>Source patches</td>
</tr>
<tr>
<td>Genius loci</td>
<td></td>
<td>Key patches</td>
</tr>
<tr>
<td>Uniqueness/distinctiveness</td>
<td></td>
<td>Key spatial elements</td>
</tr>
</tbody>
</table>
4.2. Common indicators; what do they indicate?

At the indicator level, we find that many indicators are currently applied to express both visual aspects and ecological functions. This is the case for all aspects of visual landscape structure except imageability. Many indicators are used to measure visual landscape character that have been adopted from landscape ecology, with sometimes scarce knowledge concerning their visual relevance (Ode et al., 2008). Complexity indicators for example have been widely adopted from landscape ecology to express visual aspects (e.g. Ayad, 2005), and although the concept of complexity is seen as a key aspect of visual landscapes (Kaplan and Kaplan, 1989; Litton, 1972), the visual relevance of the applied indicators remains uncertain. Some concepts have strong empirical evidence supporting their relevance in both aesthetics and landscape ecology, e.g. naturalness, which has been assessed both for visual preferences (Ode et al., 2009; van den Berg and Koole, 2006) and ecologically (e.g. Hoffmann-Kroll et al., 2003). However, little information has been found regarding the nature of the relationship between indicators as used to indicate aspects of both ecology and aesthetics. Further studies within both fields are needed to specifically explore the relationship between indicators and concepts in order to increase our understanding of the validity of the indicators in different types of landscapes (e.g. de la Fuente de Val et al., 2006).

However, indicators with known visual and ecological significance cannot necessarily be interpreted in the same way as indicators for each of the two interests. Changes expressed by one indicator may be negative in visual terms, but positive in ecological aspects. An example is scale, where human visual and ecological functional scales are often different (Lausch and Herzog, 2002). Even in situations where the terminology overlaps at the conceptual level the effects indicated may be very different. If referring to the openness in the landscape, this has been found to be perceived positively by people across a wide range of openness (Kaplan and Kaplan, 1989), while many ecological functions benefit from smaller scale open areas (Quine and Watts, 2009). More research is needed to assist interpretation of the identified common indicators and the possible conflicts, trade-offs and non-linear relationships between the two interests.

When applying indicators to express visual or ecological aspects of a landscape, the links back to the theoretical basis of the respective fields is of crucial importance to know what indicators indeed indicate. We believe the hierarchical structure from concepts to indicators presented in this paper, is helpful in keeping the links to theory, and can even contribute to creating new integrated theory of landscape aesthetics and landscape ecology.

4.3. Overlap between visual and ecological indicators is species dependent

For several of the aspects of landscape structure, assessed here, we found that the overlap between the visual and ecological aspects varied according to the species in the ecological assessment. For example, different species and species groups react differently to changes in landscape structure (Jonsen and Fahrig, 1997; Luoto et al., 2002). The relationship between species richness and landscape heterogeneity varies both with taxa and between generalists and specialists species (e.g. Atauri and Lucio, 2001; Jeanneret et al., 2003; Jonsen and Fahrig, 1997; Luoto et al., 2002). This means that for interpreting ecological concepts and indicators it is necessary to connect these to the ecological profiles of species as argued by Opdam et al. (2003).

The concept of stewardship is generally perceived positively by people and many species are adapted to and dependent on vegetation management. Hence there is an overlap between the effects indicated by visual and ecological indicators. However, other species are favoured by the lack of stewardship, and in the long term, biodiversity may benefit from abandonment processes perceived negatively by people.

Similarly, scale is a key aspect of both visual landscape expression and ecological functioning. Functional grain in ecological terms is, however, species dependent (Baguette and Dyck, 2007) and dispersal success is determined by both dispersal ability and spatial landscape structure (King and Wüth, 2002). This implies that the overlap between ecology and aesthetics in terms of scale is determined by the overlap of the human visual scale and the functional scale of the species in question. Scale in visual terms is also generally related to openness in the landscape while scale in ecological terms may as well refer to the size of forest areas or other habitat patches.

The scale of analysis will in fact affect all aspects, e.g. the complexity of a landscape. When applying landscape indicators to express visual or ecological aspects or both, it is therefore necessary to make sure that the scale is appropriate for the visual and ecological processes of interest and the species of importance.

4.4. Challenges in interpretation of indicators

The interpretation of many of the ecological indicators is species dependent and many of the visual indicators will be interpreted differently by different observers. At the same time, the interpretation of many of the indicators is context dependent, e.g. in terms of landscape type. An element of naturalness for example, can be interpreted very differently according to the surrounding environment, e.g. an intensively managed park can be perceived as a highly natural element in an urban setting, while as an artificial element if surrounded by “wilderness”. In an ecological sense the same occurs, as green elements in the city e.g. lawns and road verges become relatively more important due to their scarcity, while the same elements in a natural setting would be evaluated as less significant as habitat.

The visual indicators presented in this paper have the purpose of indicating aspects of the visual landscape in a transparent and repeatable way. It is, however, important to bear in mind that the interpretation of these visual aspects depends to a large extent on the observer’s interest and values. Group differences in preference ratings of landscapes have been found by several researchers (e.g. Coetier, 2002; Strumse, 1996; van den Berg et al., 1998). People have different perceptions when viewing a landscape, meaning that different people give different concepts different relative weighting. The relationship between the concepts will thus be different
and their relative importance in shaping the observed visual quality will differ according to the observers background and the purpose of the observation. Scientific knowledge of landscape preferences have been suggested by several researchers (e.g. Fudge, 2001; Gobster, 1999; Matthews, 2002). An ecologist could for example give more relative weight to naturalness than to historicity than an archaeologist assessing the same landscape. We would also expect some concepts to be less sensitive to cultural and personal background than others. Theory and empirical preference studies suggest some key drivers of visual landscape experience at a universal human level, such as features related to visual scale (openness) or complexity (readability) (e.g. Appleton, 1975; Kaplan and Kaplan, 1989). On the other hand, the relative importance of concepts like historicity and vividness/place identity in determining visual quality is probably more dependent on personal and cultural attributes of the observer.

Studies (e.g. Dramstad et al., 2006) have shown that educational background is a strong factor influencing preference. This can cause a problem when many studies that do exist rely on the linkage between landscape indicators and preference and are conducted using students with environmental science backgrounds (see, de la Fuente de Val et al., 2006).

4.5. A step towards an integrated tool

This review has uncovered considerable overlap between currently used indicators of landscape aesthetics and landscape ecology. This is partly due to active borrowing of indicators between disciplines, as well as the consequence of landscape structure affecting both ecological functions and the basis for landscape perception. The double interpretation of indicators identified in this paper does not necessarily represent a more successful approach than analysing the two aspects separately. What this paper does is to explore the conceptual common ground between these two fields of research that are already sharing indicators in practice. Our goal is that this paper can improve our understanding of what indicators indicate, and be a starting point in better understanding the overlaps and trade-offs between landscape functions. This understanding will enable the development of better landscape analysis methods and be a first step in the development of new tools for landscape planning and management. The need for such incorporation of ecological sustainability in landscape planning have been argued by several researchers (e.g. Botequilha Leitao and Ahern, 2002; Sheppard, 2001; Ternorshuizen et al., 2007), as well as the current limitations of using landscape pattern indicators to evaluate ecological consequences of alternative plans and designs (Corry and Nassauer, 2005).

Empirical studies are needed to assess how indicators of ecology and aesthetics overlap in practice and how trade-offs and win-win situations between different landscape functions can be identified and analysed. These empirical studies should include different landscape types as well as respondents to assess whether and aesthetics are landscape type specific. Among the currently used indicators identified in the literature, some are more concrete and closer to becoming part of an integrated tool than others. Indicators related to stewardship, coherence, historicity and ephemera particularly need further elaboration to provide concrete instructions for the development of a landscape tool. An unanswered question is also whether people can perceive and appreciate ecology as a part of landscape perception (Gobster et al., 2007). It has been suggested that such appreciation is enhanced by knowledge and education (Fudge, 2001; Matthews, 2002). Further empirical studies e.g. landscape preference studies should address the aesthetic appreciation linked to ecological function. Such empirical studies should test indicators across different landscape types and with different groups of observers.

5. Conclusion

The paper presents a hierarchical framework of concepts and indicators describing landscape visual qualities and ecological function. We have identified overlap between structural landscape indicators used for aesthetics and those used for ecology, both at the conceptual level and in analysing landscape indicators that are currently applied. We believe it is crucial to maintain strong links between landscape indicators and their theoretical basis. The hierarchical framework presented in this paper can be helpful to establish and strengthen such links between theory and indicator application. The paper provides an analytical groundwork offering a starting point for the development of new integrative landscape theory and tools for improved landscape analysis, monitoring and planning.

Acknowledgements

The authors would like to thank our colleagues in the VisuLand project for valuable discussions in the process of developing the paper. The work presented has been funded through the EU-project VisuLand (QLK5-CT-2002-01017) and the Swedish Research Council FORMAS.

References


Bell, S., 2001. Landscape pattern, perception and visualisation in the visual management of forests. Landscape and Urban Planning 54, 201–211.


