

# Structural elements of the visual landscape and their ecological functions

Sigrid Hehl-Lange\*

*Institute of National, Regional and Local Planning, Swiss Federal Institute of Technology,  
ETH Zürich, 8093 Zürich-Hönggerberg, Switzerland*

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## Abstract

Agricultural policies in Switzerland provide for financial incentives to encourage biological diversity in the use of landscapes. These can support the management of existing, or the addition of new, structural elements in the landscape which are significant for their value in both the ecological and visual landscape.

A method for the 3D-visualization of spatial-functional relationships in the landscape, based on ecologically important structural elements, has been implemented in a geographic information system. To demonstrate spatio-functional relationships in the landscape, certain animal species were selected as indicators. The subsequent description is based upon the specific habitat requirements of these species, and information extracted from topographic map data such as buildings, lakes and streams, and vegetation structures. The role of 3D-visualization in emulating the use of the landscape features by the selected species is presented, discussed and examples given to illustrate comparisons between the derivation of habitat areas and the use of such areas by different species. © 2001 Elsevier Science B.V. All rights reserved.

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## 1. Structural elements

The protection and management of certain structural elements in the landscape contributes to both the visual and ecological value of the area. Consequently, the proposal of new structural elements gives landscape planners the opportunity to improve the visual, and the ecological value of the landscape. It is essential to base such proposals on a well-founded understanding of the data that are used to represent the landscape, and the species selected as indicators of its

ecological functionality. There is an opportunity to improve the consideration given to spatio-functional relationships given the requirements of certain current agricultural policies in operation in Switzerland. This paper presents a method for modeling the ecological functionality of the landscape in terms of the contribution structural features make to the visual landscape.

Article 31b of the Swiss Federal Agricultural Law provides for direct payment to farmers when they make a positive contribution to the environment (Curry and Stucky, 1997). These contributions range from increasing the biological diversity of the farmland through extensive grassland cultivation, orchards (high stem fruit trees), hedges and ecological farming with integrated production or organic farming. For

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\* Tel.: +41-1-633-29-51; fax+41-1-633-11-02;  
E-mail address: hehl@orl.arch.ethz.ch (S. Hehl-Lange).  
Web address: <http://www.orl.arch.ethz.ch/~Lange/sigi.html>

example, if the farming is done with integrated production or organic farming, at least 5% of the farm is to be retained for nature conservation purposes. To date, the choice of the area of land to be used for nature conservation purposes is at the discretion of the farmers. Typically, farmers do not choose those areas with the highest potential value for conservation, rather, they select those areas which are the most unproductive or the most inaccessible, and there are no quality control protocols associated with their implementation.

Studies by Asseburg et al. (1985) and Hoisl et al. (1992) show that vegetation structures, such as forests, groups of trees, hedges and single trees contribute positively to the quality of the visual landscape. Similarly, features such as orchards and trees along the banks of streams and lakes make contributions to the visual quality of the landscape. A test site has been selected for which 3D-models have been constructed to represent those features in the landscape that are of high ecological significance when assessed with respect to the contribution they make to the habitats of selected species.

The spatial distribution of the structural features, and the resultant patterns in the landscape is largely explained by the historical development of the land use in an area. In the test site, for example, orchards are traditionally located near villages and farm houses, whereas forests are mainly found on steeper slopes, not suitable for agricultural land use.

## 2. The ecological functionality of the structural elements

The ecological functionality of the structural elements, such as woodlands, can be related to individual vegetation types, or patches of such vegetation. However, the mobility of fauna necessitates an analysis of the spatial context of the vegetation types, and their connectivity.

The significance of the spatio-functional patterns of land use with respect to the breeding, feeding or foraging habitats of different species can be demonstrated using indicator species (Hehl-Lange, 2001). The indicator species, which are used for this study are selected from the following animal groups: bats, amphibians and birds. The greater mouse-eared bat

(*Myotis myotis*), the common toad (*Bufo bufo*), the grass frog (*Rana temporaria*), the palmate newt (*Triturus helveticus*), the alpine newt (*Triturus alpestris*) and the green woodpecker (*Picus viridis*).

The connectivity of these habitats in the landscape, and the extent to which different land uses inhibit movement, has to be analyzed with respect to the requirements of each species. For example, for birds, the issue of connectivity of vegetation patches is significant only at a different scale to that of mammals. However, those species which are relatively immobile are more affected by barrier effects caused by different land uses, and even for bats, lines of traffic can represent a hindrance to movement (Table 1).

In this paper, a method for analyzing the importance of certain biotopes in the orientation of animals is presented, that employs a combination of landscape visualization tools and geographic information systems (GIS), with use made of the three individual species in turn.

### Study site

The test site used in this study comprises the watershed of Lake Lauerz at the northern border of the Alps, in central Switzerland. A visual representation of the landscape of the area is assembled from several elements, as listed below:

1. the Digital Terrain Model (DHM 25), of the Swiss Federal Office of Topography, with a resolution of 25 m;
2. a LANDSAT TM satellite image, also with a resolution of 25 m (re-sampled from 30 m);
3. an orthophotograph, with a resolution of 2.5 m;
4. features recorded on the digital topographic map, such as all buildings, single trees and forests;
5. thematic layers, such as the calculated flight-path of the bats or their foraging habitats.

## 3. GIS-based analysis and visualization of a potential foraging habitat for bats

Fig. 1 shows different habitats for bats. The winter habitat is found in caves. The nursery colony is located in the tower of the church. Long or short flights, depending on the species, take place in spring and autumn between both habitats. The foraging habitats

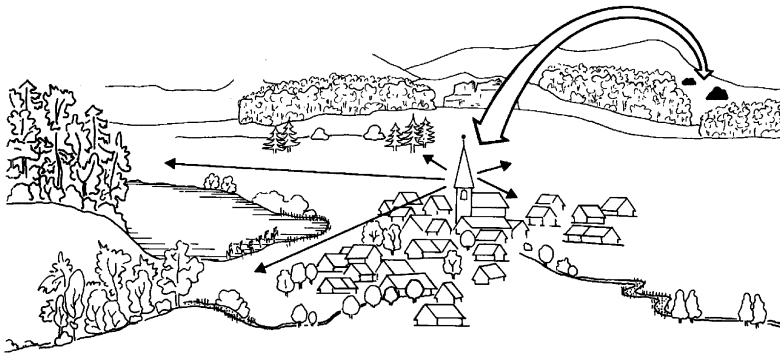


Fig. 1. Different habitats of the population of *Rhinolophus hipposideros* (from Blab, 1993).

of this population are the surrounding fields and the forest edges.

#### Model creation

The representation of the vegetation and habitat data is from the digital topographic map (the so-called 'Pixelmap', scale 1:25 000) of the Swiss Federal Office of Topography. Pattern recognition techniques, developed by the Institute of Geodesy and Photogrammetry of ETH Zürich (Stengele, 1995), are used to extract this information. The output is a 2D-dataset that can be manipulated in ARC/INFO. The vegetation data is transformed into the 3D-environment by overlaying it on the terrain surface and creating polygonal objects on which the appropriate feature texture (e.g. a tree) can be mapped using the Polytrim software from the Centre for Landscape Research, University of Toronto (Hoinkes and Lange, 1995).

#### Bat movement

The greater mouse-eared bat (*Myotis myotis*), used as an indicator species in this paper, is a structure-oriented bat (Stutz and Haffner, 1991) which emits short calls that go through a large range of frequencies in a few milliseconds. Bat species emit unique signals, which are associated with characteristic habitat types and foraging strategies (e.g. Neuweiler, 1989; Richarz and Limbrunner, 1992). Previous research (Limpens and Kapteyn, 1991; and references cited therein) shows that there is a relationship between landscape structure and bat flight routes (see Fig. 2). Species, which forage in open space use echolocation signals,

which are low in frequency (24–32 kHz) and long in duration (9–14 ms). Whereas species which are dependent upon structures for orientation use signals which are shorter in duration (10 ms) and higher in frequency (42–56 kHz).

The nursery colony of the greater mouse-eared bats is located in the tower of the church in Steinen village. There, the females form large nursery colonies. During the day, they lodge in the roof of the church and at dusk, they fly out to their foraging habitat.

Greater mouse-eared bats prey mainly on beetles, catching them in the flight directly from the ground, therefore, they need forests without undergrowth. Their main foraging biotopes, the surrounding forests, are within a radius of 15 km of the church. Instead of a time-consuming telemetric approach, in this research project (see Hehl-Lange, 1998), a GIS-model is used for the calculation and mapping of potential foraging habitats, based on the known site — the nursery colony. Essential data sources for this modeling are the specific radius of activity of the bat species and certain structural elements of the landscape, which the bat needs for orientation purposes in order to reach the foraging habitats.

The model is based on the assumption that the bats can only navigate from one point in the landscape to another if structural features in the landscape are at a maximum of 20 m apart. Therefore, the structural elements are buffered to a distance of 10 m. All grid cells containing no elements serving for orientation, function as barriers, and inside the calculated area a possible flight path connecting the nursery colony with the foraging area can be assumed (Fig. 3).

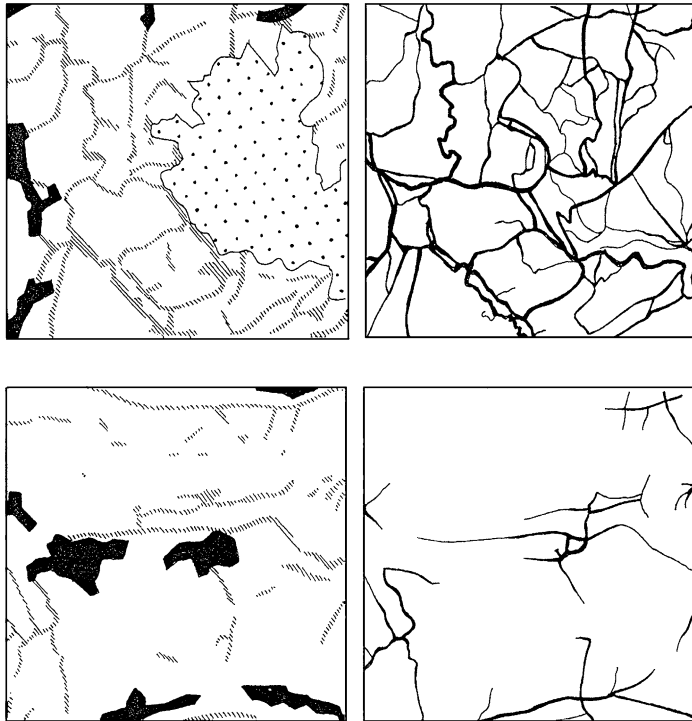


Fig. 2. Relationship between landscape structure on the left site and bat flight routes on the right site once above in an area with a dense network of linear landscape elements and below in an open landscape with only a few connecting landscape elements (Limpens and Kapteyn, 1991). Hatched: linear landscape elements with trees, stippled: woodland, black: built up area.



Fig. 3. Possible flight path connecting the nursery colony with the foraging area, 3D.

#### 4. GIS-based analysis and visualization of amphibian habitats and their potential barriers

Amphibians are relatively immobile in comparison to bats. The spawning sites are the center of their life cycle to which the animals return each spring. The habitat, the furthest away is the summer habitat (see Fig. 4). Those amphibians, which migrate between different habitats during their annual life cycle, can be used to demonstrate functional relationships in the landscape.

The common toad (*Bufo bufo*), which has the largest home range of the amphibians, is used as an example species to illustrate the range of habitats, and the potential barriers, caused by different land uses. The summer habitat of the common toad comprises woodlands, wood edges and hedges. Based on the location of the spawning sites, the potential summer habitat is calculated using buffering functions in the GIS. It reaches far beyond the protected area (see Fig. 5).

With the exception of the grass frog all amphibians are in the Red Data book of endangered species in Switzerland (Grossenbacher, 1994). Therefore, the amphibians themselves are protected, but not their

habitats. In those cases where the habitats are protected, the protected area is restricted to spawning sites.

To ensure the functional integrity of the annual life cycle of amphibians, it is not only the preservation, maintenance and planning of spawning sites that is important, but also all elements of the landscape, or proposed measures that could function as spatial obstacles. Roads, highways and railway lines close to the spawning sites are the most serious barriers especially for the common toad and the grass frog.

A section of the test site, where the spawning sites of several amphibian species are to be found, is designated as an area of national importance for amphibians. A highway, a local road and the most important and most frequented railway route running north–south through the Alps are located north of the spawning site. The highway offers a greater hindrance to the common toad than the railway line because the common toad stops in the face of oncoming danger, with the result, that it falls prey to traffic on the road. This behavior prevents the toad from being carried by the draft caused by passing trains (Barandun, 1991).

In a similar manner to the calculation of the potential flight path of the bats, the distribution of the

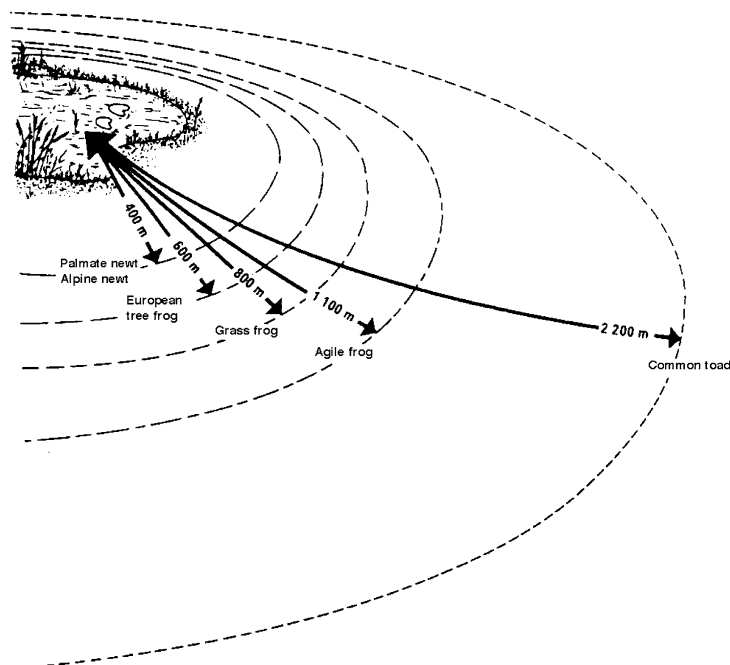


Fig. 4. Size of the annual habitat of amphibian populations, from Blab (1993).



Fig. 5. Potential summer habitat of the common toad, 3D.

amphibians is calculated based upon existing knowledge about their preferred habitats using a cell-based GIS approach. The land uses are then also classified according to the extent to which they act as a barrier to movement (see Table 1).

Linear land use features, such as roads and railway tracks are classed as greater barriers to movement than most areal land uses, such as settlements. On south facing slopes, a dispersal of the common toad is very unlikely or even impossible, because with the highway,

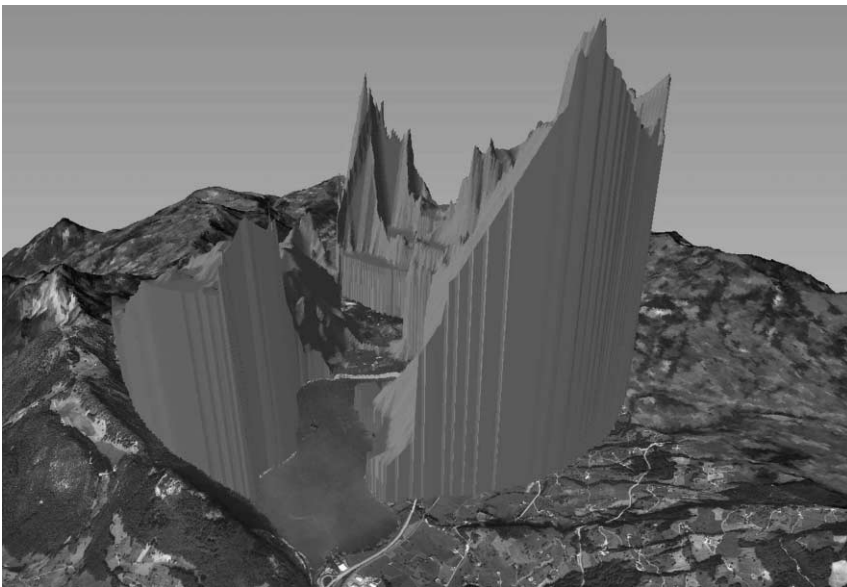


Fig. 6. Cumulative barrier effect and possible dispersal, common toad.

Table 1  
Values for calculating the barrier effect for the common toad

Land use	Common toad
Highway	300
Major road	150
Secondary road	100
By road	50
Gotthard railway	100
North-east railway	25
Rigi railway	10
Settlement	30
Agricultural priority area	15
Meadow	10
Forest	0
Bog	0
Lake Lauerz	–

several other roads and the railway, there are too many barriers. Whereas at the north facing slope, a dispersal is possible, once the barrier of the major road running along the lake can be crossed successfully (see Fig. 6).

## 5. GIS-based analysis and visualization of potential habitats of the green woodpecker

There is a strong correlation between the occurrence of birds and vegetation features, one obvious

example being the dependence of woodpeckers on the presence of trees.

Green woodpeckers (*Picus viridis*) used the stage of decline in primeval forest as habitats for foraging and reproduction. However, the structure of commercial forests does not meet the requirements for the green woodpecker as a suitable biotope. Nowadays, these birds are dependent on replacement biotopes, which correspond to their original habitat. An ideal interconnected habitat for the green woodpecker is achieved by a mosaic of wood edges, orchards, hedges and single trees (e.g. Pechacek, 1996).

As a typical ant-eater, the green woodpecker forages on the ground in grasslands, meadows and orchards. The woodpecker does not fly over open areas for distances greater than 250–300 m (Imhof, 1984) and the land beyond remains unused for feeding. Only those areas occupied by structures, such as hedges or orchards are within reach, and as such are used for feeding (Fig. 7). In the study area, the feeding habitat is located mainly on the south side of the site.

Potential habitats for breeding for the green woodpecker are the older trees in orchards and wood edges (Fig. 8). Both habitat types, for feeding and breeding, have to be closely spatially related. Therefore, the potential habitats for breeding are also restricted to the south facing slopes of the site.

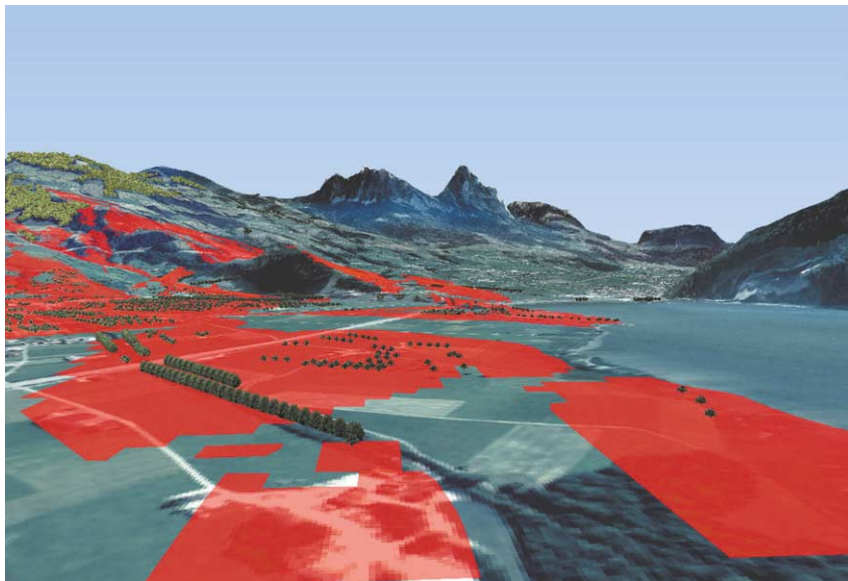


Fig. 7. Potential feeding habitat of the green woodpecker.

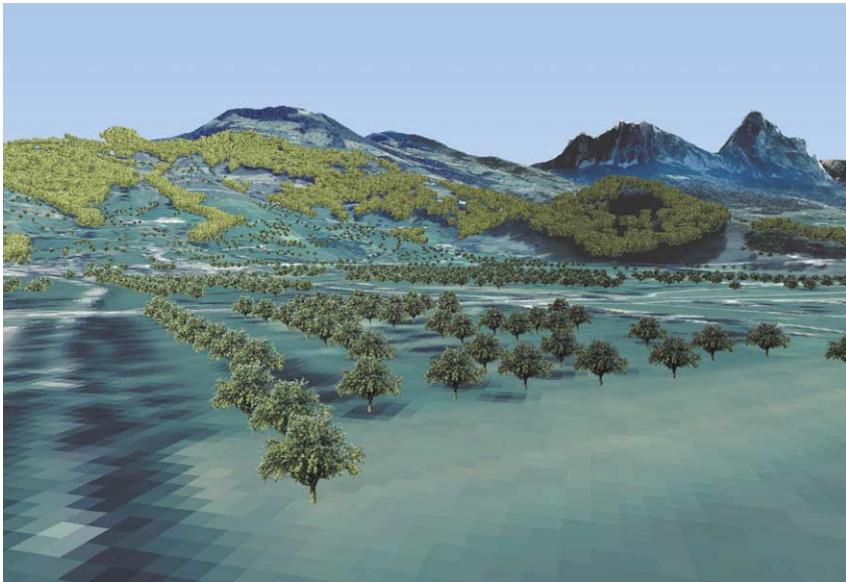


Fig. 8. Potential breeding habitat of the green woodpecker.

## 6. Discussion

Certain animal species use different, but spatially inter-related, parts of the landscape on a seasonal, or daily basis. Because of this behavior, they are dependent upon the connectedness of these habitats. In order to be able to demonstrate this connectedness in the landscape, taking into account different categories of structural elements, information about the spatial behavior and the autecology of animal species is required.

Such data is generally not available. An exact mapping of suitable species could provide the desired information. However, this mapping cannot be done for the landscape as a whole or for individual species, as this is too time-consuming and, therefore, too costly. By using information about the use of habitats by certain animal species, based on information derived from different data sources, it is possible to demonstrate the spatio-functional relationships of the landscape and its structural elements. Unfortunately, there are only very few animal species for which sufficiently detailed information is available on habitat requirements, to enable their translation into a GIS, as illustrated with the species presented in this paper.

At a larger scale, i.e. using indicator species with a comparatively small habitat, the information extracted from the topographic map is not sufficient. To represent the use of the landscape by such species, it would be necessary to acquire data through detailed field or photogrammetric mapping.

Currently, visualization technology is applied to landscapes, for demonstrating possible landscape change or impacts on the visual landscape. If a GIS-based visualization approach is pursued, the same base data can be used for the analysis of spatio-functional relationships of different habitats as well as for the visualization of these abstract relationships.

By implementing the results of the analyses for the three indicator species, it would be possible to fulfil not only the quantitative requirements of Article 31b of the Swiss Agricultural Law but also to fill the gap of the missing qualitative aspects. This approach may produce a valid contribution to the sustainability of the land use.

## 7. Conclusions

To date, 3D-visualization is used principally in relation to project assessment, such as EIA, or for

visualizing landscape change. Relatively little use is made in relation to landscape ecology, landscape planning and nature protection purposes. Yet, high quality landscape visualizations and moving sequences of imagery appear to be readily understood by public audiences, and such materials can be effective as a communication media. Where the objective is to advocate nature protection plans to a wider public audience such a medium is needed, which is understood more easily than an abstract 2D-plan, to encourage public participation in the broader issues of the planning process. The 3D-representation of landscapes, with associated representations of spatio-functional relationships, such as movement of animals through an area has been demonstrated to show promise in conveying a complex issue in easily understood terms. However, further work will be required to test the level of understanding with respect to the significance of individual structural features that are present in the landscape.

### Acknowledgements

Digital orthophoto © Swissphoto Photogrammetry and Surveying DHM25 © Swiss Federal Office of Topography (BA013197) LANDSAT TM scene courtesy of Image Science Division ETH Zürich.

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