VISUAL LANDSCAPE ASSESSMENT FOR LARGE AREAS — USING GIS, INTERNET SURVEYS AND STATISTICAL METHODOLOGIES

IN PARTICIPATORY LANDSCAPE PLANNING FOR THE FEDERAL STATE OFMECKLENBURG-WESTERN POMERANIA, GERMANY

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The European Landscape Convention (CoE, 2000) defines landscape as "an area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors". Thus, both empirical data on landscape perception and GIS-available data on physical landscape structures were incorporated in GIS-based models to generate an area-wide assessment of scenic quality for the federal state landscape programme of Mecklenburg-Western Pomerania.
A broadly based photographic documentation (> 2000 photographs) was created as basis for over 24 000 assessments by more than 3000 participants using advanced and validated Internet survey methodologies (cf. Roth, 2006). By using a 3D-GIS system and large datasets of area-wide accessible data, the photographs' sites/views (located by GPS) were simulated in a virtual environment. Taking the participants landscape assessment and the visible landscape elements within the GIS representation, statistical models for visual preference and its components beauty, visual diversity, uniqueness and perceived naturalness were developed. These models were then applied area-wide within the GIS.
The approach developed is innovative in several ways: First, the area of investigation (> 23 000 km^2) is much larger than in comparable projects. Second, the empirical basis is unique in size and composition. Whereas conventional studies tend to use dozens to few hundreds of landscape architecture or psychology students, the subject sample of this study is varied in geographic origin, age, education and profession due to the immense outreach of the online survey. Third, the statistical methodology of ordered logistic regression allows overcoming restrictions that traditional approaches (using linear regressions) faced. Fourth, the method allows the judgement of its validity, which is a huge advantage compared to traditional expert methods in landscape planning.
It is shown how the research methodology was developed starting from a theoretical analysis of the research problem, and a critical judgement of the role of GIS in visual quality assessment/modelling and participatory landscape planning is given.

Introduction

Landscape Planning in Germany uses a four level hierarchical planning system (cf. Riedel and Lange, 2009; von Haaren, 2004; Auhagen *et al*., 2002; Gruehn, 2006). The top level is located at the federal state (landscape programme), followed by the planning region (regional landscape plan or landscape framework plan), the municipality ([local] landscape plan) and parts of the municipality (green structures plan). One of the overall aims of nature protection and landscape management is to protect, maintain, further develop and — if necessary — restore the visual diversity, uniqueness/distinctiveness and beauty of landscapes (German Federal Nature Conservation Act § 1 Section 1). One task of landscape planning — on all four levels described — is to assess the present and anticipated state of nature and landscapes according to the overall goals and their spatially downscaled refinements, an area-wide visual landscape assessment is a core part of all landscape plans. Since landscape planning in Germany is subjected to participation procedures according to SEA Directive (European Parliament and the Council of the European Union, 2001) internet surveys as basis for visual landscape assessments could be regularly implemented in planning processes to foster participation processes at an early stage.

In the case described in this paper, the Ministry of Agriculture, Environment and Consumer Protection of Mecklenburg-Western Pomerania (Ministerium für Landwirtschaft, Umwelt und Verbraucherschutz, MLUV) as environmental planning authority on the federal state level, is responsible for providing the landscape programme, the plan setting out the "supra-local requirements and measures of nature conservation and landscape management" (German Federal Nature Conservation Act § 10 Section 1). Part of this programme is an area wide evaluation of scenic quality. In 2008, the chair of landscape ecology and landscape planning at Dortmund University of Technology was commissioned to develop a scenic quality evaluation method and to perform the scenic quality assessment mentioned above. This paper presents some of the results of the research conducted in that project.

Different requirements had to be fulfilled when developing the new scenic quality evaluation method:

- The method had to be developed on an empirical basis, making public participation in landscape planning and research (cf. Lange and Hehl-Lange, 2011; Höchtl *et al*., 2007; Höppner *et al*., 2007; Lange and Hehl-Lange 2005; Sheppard, 2005; Buchecker *et al*., 2003; Dearden, 1981), as for example requested in the Aarhus Convention (UNECE 1998), European Landscape Convention (CoE 2000) and SEA Directive (European Parliament and the Council of the European Union, 2001), both an integral part of the research progress and the foundation for the actual evaluation results.
- Scientific quality criteria had to be taken into account. The reliability (cf. Hull and Buhyoff, 1984) and validity (cf. Hull and Steward, 1992; Palmer & Hoffmann, 2001; Roth, 2006; Gruehn, 2010) of the method and its results had to be investigated and communicated.
- The scenic quality components of visual diversity, uniqueness/distinctiveness and beauty used in the Federal Nature Conservation Act had to be assessed as well as perceived naturalness (cf. Purcell and Lamb, 1998; Ode *et al.* 2009) and overall scenic quality/overall preference.
- The whole method had to be compatible with GIS (in this case ESRI's ArcGIS used at the MLUV). State-wide accessible geodata had to be used for the assessment and there was no possibility of mapping new data due to financial and time constraints, apart from the photographic documentation described below.

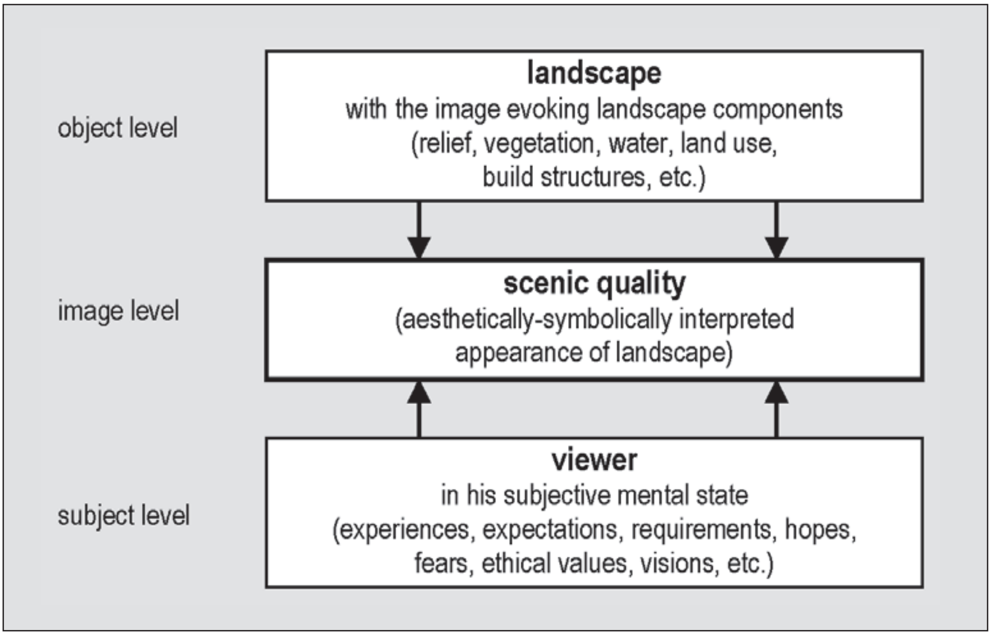

Fig. 1. Interdependence of landscape, viewer and scenic quality. Source: Nohl, 2001, p. 44, modified

When developing the theoretical concept for the research design, the definition of scenic landcape quality set in the psychological-phenomenological approach (Nohl, 2001, 43 et seq.) was followed (see Fig. 1). This allows the inclusion of both physical landscape elements and subjective human landscape preferences.

Material and methods

Within the research design employed in this study (see Fig. 2), following the psychological-phenomenological approach described above, it was assumed that landscapes (real landscapes or their photographic representation) evoke perceived scenic quality "in the eye of the beholder". These reactions can be captured by means of surveys and analysed in terms of their interrelation to physical landscape components, which has been done in landscape preference research for several decades (cf. e.g. Shafer *et al*., 1969; Daniel and Boster, 1976; Carlson, 1977; Shafer and Brush, 1977; Brush, 1981; Daniel and Vining, 1983; Lothian, 1999; Daniel, 2001; Roth and Gruehn, 2005; 2010).

The image evoking landscape components are represented in the digital landscape data set and can be measured objectively within a GIS by using 3D viewshed analysis, putting the virtual observer at the same spot where the photograph was taken. If statistic analysis reveals a significant and validated interrelationship between GIS-based landscape components and the participants' scenic quality ratings, this result can then be used for the area-wide modelling of visual quality within the GIS.

After the theoretical preparatory work was finished, a photographic documentation of landscapes in Mecklenburg-Western Pomerania was conducted during 18 days of fieldwork distributed over 18 months. 2014 photographs were taken at 381 sites,

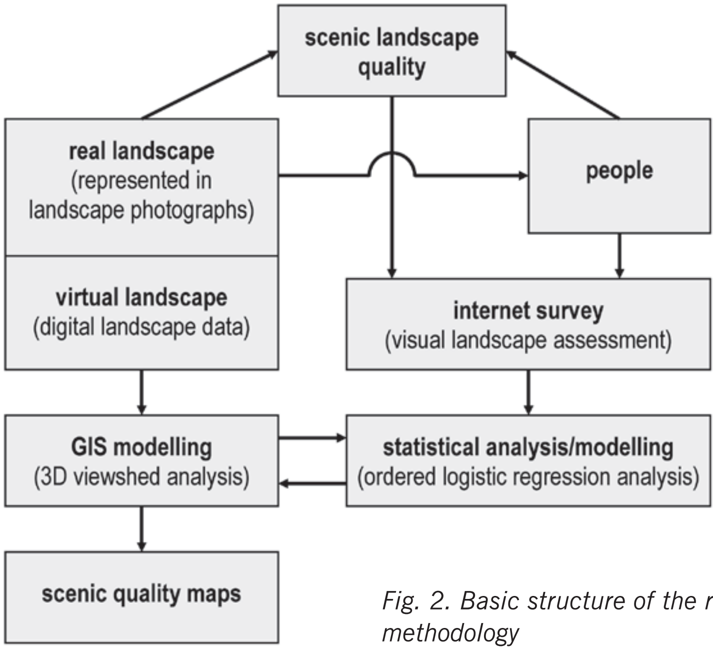

Fig. 2. Basic structure of the research methodology

distributed over all natural regions (as classified by Meynen and Schmithüsen, 1953–1962). A fully digital workflow was used: to exactly locate the viewpoints, GPS recordings were taken. Additionally, the view directions and the site descriptions were recorded in a database linked to a GIS and all metadata were as well stored in the image files' EXIF data to be permanently linked to the photograph. Up to 30 pictures were taken at each site, covering both different view directions and different seasons (up to three site visits).

To record the participants landscape ratings and landscape preferences, an online questionnaire was developed, using the method described by Roth (2006), which was empirically validated using on-site surveys as external correlation criteria. Apart from the participants' landscape assessment, socio-empirical data (age, sex etc.) and technical metadata (reaction times, technical setup etc.) were recorded. During the nine months the survey was online, more than 3300 participants took part and more than 24 000 complete photo assessments (according to the five criteria presented) were carried out.

To link the participants' photograph-based ratings (based on a perspective view of three dimensional landscape) and the 2D and 3D digital geodata (for the content of the dataset used, see Table 1) in order to establish algorithmic relations between landscape components and landscape preference, a GIS-based, 3D viewshed analysis was used, putting a virtual viewer at exactly the same position where the landscape photographs were taken. Figure 3 shows an example of this analysis. By overlaying the viewshed with the landscape elements geodata, both absolute amounts and relative shares of certain landscape components visible in the respective scene/image could be measured.

Based on the results of the survey, the interrelation between the participants' photograph-based ratings in the main survey (over 24 000 photograph ratings for more than 500 different views) and the landscape

Table 1. **The dataset used for viewshed analysis/visual quality modelling**

Dataset	**Content**
ATKIS DLM 25 (official topographic cartographic information system)	digital, vector based topographic land use data, original scale 1 : 25 000
ATKIS DGM (digital terrain model)	digital elevation model, grid, horizontal resolution 20 m, vertical resolution 0.1 m
CIR-based habitat mapping	digital, vector based habitat data, point, line and polygon layer, recording scale 1 : 10 000
additional thematic data layers	wind turbines, power plants, overhead lines, dumpsites etc.
nature protection areas	different types of nature reserves according to nature conservation law

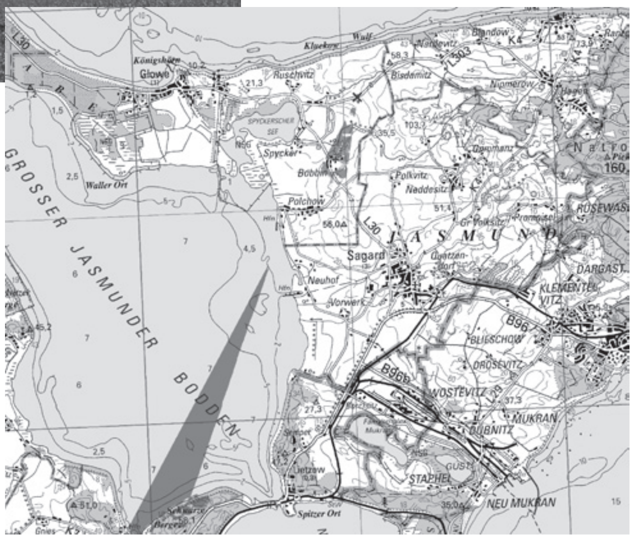

Fig. 3. Example of 3D viewshed analysis (left: landscape photograph, photo: Michael Roth right: viewshed shown on topographic map).

components in the digital dataset (as seen by the virtual viewer) was computed. To perform the statistical analyses, the GIS dataset/geodatabase and the MySQL database containing the empirical ratings of landscape quality and landscape preference from the Internet survey were both linked with the statistical software package SPSS (IBM 2011). Using methods of ordered logistic regression analysis, it was possible to develop a statistical model for different scenic qualities (visual diversity, uniqueness/distinctiveness, landscape beauty, perceived naturalness as well as overall scenic quality). This model then was applied to the whole area of the federal state of Mecklenburg-Western Pomerania, using a grid of 2500 m resolution as spatial basis.

Results

The questionnaires used, including all the socio-empirical variables, allow the testing of hypotheses and the analyses of correlations of wider relevance than just for the area wide assessment of visual quality of landscapes in Mecklenburg-Western Pomerania. Due to the limited space in this paper, only the most important results of these pretests are described in the following paragraphs:

- Previous research (e.g. Hershberger and Cass, 1973; Nohl, 1974; Daniel and Boster, 1976; Hull and Stewart, 1992; Scott and Canter, 1997) has empirically proven that colour photographs can be taken as surrogates for the real landscape experience visual landscape quality studies. For the method applied (questionnaires with the respective criteria investigated) an on-site comparative study has been conducted (cf. Roth and Gruehn, 2005; 2010) to validate this approach in the very specific context. The specific tool (online questionnaire), has also been validated using an on-site comparative study (Roth, 2006).
- The reliability of the methodological approach and specific tool has also been tested and verified in previous studies (Roth and Gruehn, 2005; 2010; Roth 2006).
- In practical settings in landscape management, it is a relevant question whether landscape assessments conducted by experts are different from those of lay people, especially local inhabitants. Out of the 23 761 landscape quality assessments in the study presented, 6392 (i.e. 27%) have been conducted by people with an expert background on scenic quality assessment. This allows analysing the influence of the expert status on the assessment. For four of the five criteria investigated (visual diversity, uniqueness/distinctiveness, scenic beauty, overall preference), the average differences were less than 0.15 out of ±10 units possible deviation. When judging the perceived naturalness, the average difference (on a 10 step scale) was 0.73. This illustrates, that there might be different mental constructs of naturalness influencing experts' and lay persons' assessments. The analysis of variance indicates that overall, the influence of the expert status on the variance of landscape assessment is no more than 1.2% (i.e. eta-squared maximum for all five criteria investigated is 0.012). Thus, unlike with single expert or lay person judgements, if taking large numbers of experts' and/or lay persons' assessments, the expert status has no considerable effect.
- Some authors, for example Winkelbrandt and Peper (1989) developed scenic quality models, which require landscape analysis through the entire course of one year. As this means a huge burden for any researcher or practitioner, it was tested whether there are significant and relevant differences between scenic qualities (as perceived by people) in different seasons, respectively, different vegetation foliage

states. 35 sites were photographed at multiple times, producing landscape scenes from identical viewpoints with identical ranges of vision. 676 persons evaluated this season subsample and produced 3511 landscape assessments according to set of five criteria. This dataset was analysed on three levels: individual person, data aggregated for each site, whole dataset. Generally speaking, high correlations and only small average differences could be observed between the respective seasons or foliage states (with/without leaves). For further details and statistical data cf. Roth and Gruehn (2011). Overall, the maximum influence of the season on the landscape quality assessment was 2.6 % (scenic beauty). With eta-squared values between 0.004 and 0.026 for all criteria investigated, the practical influence of seasonal aspects when performing a visual quality analysis (aiming at relative values on an ordinal scale) can thus be neglected. Nevertheless, it is interesting that all criteria had their maximum values in autumn, but perceived naturalness had its maximum in summer, when the green colour prevails.

- All the socio-empirical factors (sex, age, school and professional qualification, importance of nature and environment, frequency of outdoor trips) determined the variance of scenic quality ratings to a degree of less than 1% (eta-squared < 0.01). Therefore, there was no necessity to draw stratified random sub-samples as there was no bias introduced by those factors.

Whereas the selected photographs represent a three dimensional view of the landscape, for the virtual viewer, the amount of landscape components in the two dimensional projection of the viewshed, not the three dimensional virtual image was analysed. This was necessary for different reasons:

1. When the statistical model for visual quality mapping was developed, it was essential to assess the scenic quality of a certain surface area according to its impact on a potential viewer, which might not be identical with the scenic quality the viewer perceives when standing on this area. Therefore, the content of the viewshed area, not the content of the view itself were considered as relevant parameters for the scenic quality models.
2. From a technical point of view, it was quite a huge effort to calculate the statistical model for scenic quality based on a grid with more than 4000 raster cells (with a size of 2500 m × 2500 m). It would have been impractical to calculate viewshed analyses for thousands of viewpoints. Also in terms of the theoretical concept, the 2500 m × 2500 m raster cell represents an average viewshed size (as demonstrated by Roth and Gruehn, 2005; 2010). Whereas the scenic quality model based on specific viewpoints might change drastically when moving the viewpoint only a few meters, moving the raster grid a few meters produces relatively stable models.
3. It was one goal of the project described to deduce planning objectives and measures. As the scenic quality of a particular area (represented by a grid cell) was assessed according to the method described above, it was easy to identify whether a certain region should be conserved, maintained, or (re-)developed according to the land uses and landscape elements in their specific composition in a certain area.

Finally, visual quality models were developed for visual diversity, uniqueness/distinctiveness, scenic beauty, perceived naturalness and an overall landscape preference. Figure 4 shows the map of scenic beauty as one example of these models. This model incorporates land use variety and small scale segmentation, relief, the area of agricultural

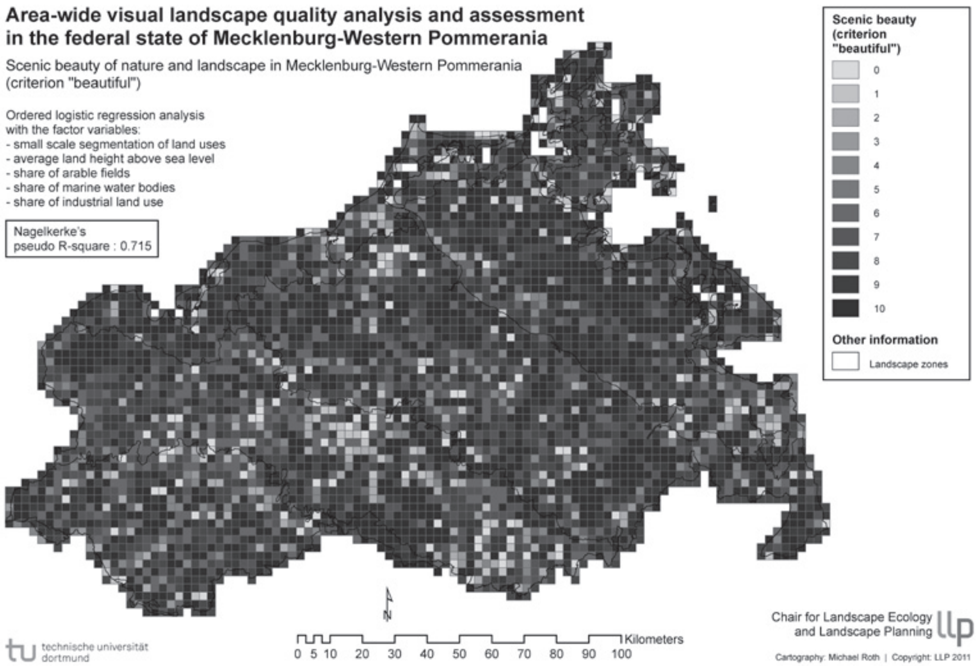

Fig. 4. Area-wide map of scenic beauty as an example of the ordinal regression analysis models developed. Darker grid cells represent higher scenic beauty.

fields, the area of marine water bodies and the area of industrial land use. The statistical quality of this model is measured using Nagelkerke's pseudo R-square which corresponds to R-square in linear regression analysis. For scenic beauty a pseudo R-square of 0.715 was achieved, this means that 71.5 % of the variance of scenic beauty can be explained by the factors mentioned. For visual diversity pseudo R-square reached 0.624, for uniqueness pseudo R-square reached 0.547, and for perceived naturalness 0.782.

Discussion

The statistical methodology of ordered logistic regression allows overcoming restrictions that traditional approaches (using linear regressions) faced. It has thus various advantages compared to the linear regression analysis that has been used in similar studies (e.g. Shafer *et al.*, 1969; Shafer and Brush, 1977; Patsfall *et al*., 1984; Kaplan *et al*., 1989; Gobster and Chenoweth, 1989; Steinitz, 1990; Bishop and Hulse, 1994; Bishop *et al*., 2000; Arriaza *et al*., 2004) during the last decades:

- The ordinal regression analysis, which does not rely on the interval scale or normal distribution requirement, is a more appropriate and efficient tool from a mathematical point of view.
- Linear regression analysis implies that there is a linear, monotonous relationship between in our case — landscape components and visual quality. This is obviously doubtful, as Bishop (1996) criticises. Ordinal regression analysis also allows including non-linear relationships in the model. One example of such non-

linear relationship is the influence of the percentage of forested area on scenic variety: Variety rises with an increasing portion of forests, but at a certain stage, a further increment of forested area leads to decreasing visual variety. Due to the better representation of these interrelationships, ordinal regression analysis delivered statistically more valid models than linear regression analysis. Cohen and Cohen (1975, p. 243, as referenced in Buhyoff and Wellmann, 1980, 261) state: "… it is a fundamental law of psychophysics that constant increases in the size of a physical stimulus are not associated with constant increases in subjective sensation." Buhyoff and Wellmann (1980) declare the logistic relation as generally suitable for modelling landscape qualities and refer to the Weber–Fechner law, which attempts to describe the relationship between the physical magnitudes of stimuli and the perceived intensity of the stimuli in a quantitative, logarithmic fashion.

The central point in visual quality modelling, as with all other models, is validity (Palmer and Hoffmann, 2000; Palmer, 2003). The scenic quality models developed in the study described can be judged concerning their validity by using the measure illustrated above (Nagelkerke's pseudo R-square). The models explain between 54.7% and 78.2% of the scenic quality components that were acquired in the broadly empirically based online visual quality survey. Looking at the explained variance of other scenic quality models found in literature (36% with Hunziker and Kienast (1999) based on image diversity/contrast; 54% with Palmer and Lankhorst (1998) calculating spaciousness based on landscape objects; 57% with Bishop *et al.* (2000) based on land-cover; 80% with Bishop and Hulse (1994) based on land-use and relief/slope), the results of the study presented confirm the amount of explained variance by using models based on area-wide accessible digital geodata. One aspect that distinguishes the study described in this paper from nearly all other models listed above is the size of the study area: The federal state of Mecklenburg-Western Pomerania has an area of more than 23 000 km² whereas Bishop and Hulse (1994) mapped scenic beauty within an area of about 10 km². Considering this huge scale difference, the large dataset and the fact that all calculations could be performed on a standard PC, the explained variance of the model developed seems quite satisfying.

As no polygon boundaries suitable for visual quality modelling were available, the scenic quality map(s) had to use a grid as spatial basis. Regarding the grid cell size, there are two opposed demands: To derive specific planning measures, a small cell size seems desirable whereas a larger cell size seems to better represent the average viewshed area in Mecklenburg-Western Pomerania. Different authors recommend to limit the "middleground" (where landscape components still can be clearly distinguished) at up to 5 km distance from the viewer (cf. e.g. Nohl, 2001, p. 81). To balance those two requirements, a correlation analysis between different cell sizes' (5000 m, 2500 m, 1250 m) amounts of landscape components was carried out in a previous study (Roth and Gruehn, 2005). An average correlation of about 0.75 could be observed between the 5 km grid and the 2.5 km grid, whereas the correlation between the 5 km grid and the 1.25 km grid were considerably lower. For these reasons, the 2500 m grid was used for all the analyses described. At first sight, one might think that this is a relatively coarse resolution for scenic landscape quality analyses. Compared to other approaches that were used in the past on the planning level of the landscape programme for a whole federal state, this resolution with more than 4000 grid cells is actually very fine opposed to the few dozens of scenic units that are used in traditional expert assessments.

Different scenic quality estimation methods used in German planning practice sum up different components of visual quality in an overall aesthetic value (e.g. Adam *et al*., 1986; Wöbse, 2002; Hoisl *et al*., 1989). A different way of generating such overall values was used in this approach: A simple allocation of the maximum value of variety, uniqueness/distinctiveness and beauty into the overall aesthetic value was performed. This fulfilled the requirements of the precautionary principle in the Federal Nature Conservation Act to conserve the diversity, characteristic features and beauty of nature and landscapes, as a high value for one component cannot be averaged to a lower overall value by the other components.

By using relatively simple landscape metrics (areas, relative shares, numbers, line lengths etc.), the transparency and comprehensibility of the assessment and modelling is guaranteed even for lay people. The latter is the target group of visual landscape assessment (CoE, 2000). Thus, a method for analysis and assessment of visual landscape qualities, that is based on empirically validated preferences among the general public, reflects the “open-minded average landscape viewer” that is used as a benchmark in German jurisprudence (Augenstein, 2002, 55; cf. also Gruehn, 2001).

Conclusions and outlook

Online surveys, combined with GIS tools and statistical software allow including objectively measurable landscape elements and landscape preferences in scenic quality assessment and participatory landscape planning, even when dealing with large areas, as the study presented has demonstrated. Thus, modern technology can help to base planning measures on the strategically very important federal state planning level on a valid empirical basis. The depth of participation and width of outreach of such participatory planning procedure with up-to-date data on internet accessibility and usage (Eurostat, 2011), can be judged far higher than traditional ways of laying completed plans open to public inspection, restricted to opening hours of administrative buildings and physical presence of participating people. Thus, from a practical perspective, information and communication technologies (ICT, in this case GIS, the Internet, statistical software etc.) can facilitate public participation and therefore can help to implement SEA-directive requirements in the landscape planning process.

The degree of explained variance in scenic landscape qualities (roughly speaking 50 to 75% in the respective models) is absolutely satisfying, bearing in mind, that there are several layers influencing landscape preferences (cf. Hunziker, 2000), including a subjective individual layer. Thus, reaching a model that explains 100% of the variance in preference is even theoretically impossible. Nevertheless, the authors of this study have thought of various ways to further improve the method presented:

- If the catalogue of landscape metrics incorporated in future studies will be enlarged, further metrics with low complexity and theoretical validation should be used instead of more complex landscape metrics which are often less comprehensible to the stakeholders involved in landscape planning processes (cf. Scherner, 1995). Based on an investigation of theoretical and empirical literature (cf. Kiemstedt, 1967; Ruddell and Hammitt, 1987; Kaplan and Kaplan, 1989; Appleton, 1996), the authors of this paper suggest investigating border and fringe effects such as forest fringes, water shore lines, and land use changes first.
- The ordered logistic regression analysis allowed incorporating relationships that reflect the way humans perceive landscapes, instead of performing pure math-

ematical data fitting. Neural networks could provide similar qualities to visual landscape quality modelling, as has been shown in initial studies (Bishop, 1996).

Software packages such as FRAGSTATS (McGarigal *et al*., 2002) or SPAN (Turner, 1990) might tempt less experienced users to tick all boxes of available metrics to be calculated and then see which indicator complies with their personal landscape preferences. Instead of this, it should be emphasized again, that especially in times when the availability of hardware, software, digital geodata and processing power are no longer main restrictions to even very complex modelling studies, "the point has been reached where theoretically based model development should become a primary goal" (Buhyoff and Wellmann, 1980). According to the point of view of the authors of this paper, ICT can facilitate this process in many ways, from empirical ground research to participatory approaches in practical landscape planning scenarios.

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