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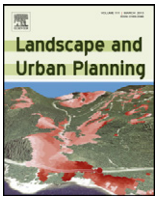

Research paper

Predicting scenic beauty of mountain regions

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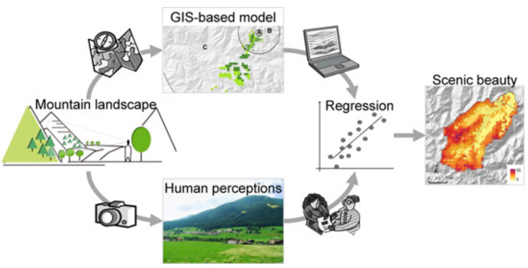
HIGHLIGHTS

- Developed method allows predicting scenic beauty of mountain regions.
- Good prediction of scenic beauty ($R^2 = 0.72$).
- Near zone contributes to scenic beauty by 48%.
- Method can be used for decision making and landscape planning.

GRAPHICAL ABSTRACT



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ABSTRACT

Scenic beauty of mountain landscapes contributes to human well-being. Valuation of natural scenery and specific landscape properties by perception studies is complex and time-consuming. Sophisticated spatial analysis tools can support the assessment of scenic beauty by quantitative methods. We implemented an innovative GIS-based modeling approach for mountain regions which combines objective methods with perception-based methods. Based on viewpoints, spatial patterns of visible landscape were analyzed by means of landscape metrics. A set of 60 landscape metrics were reduced by principal component analysis (PCA) to 11 components explaining 93% of the variance. The components were related to perceived scenic beauty values found through a perception study via stepwise regression analysis. We found that two components, shape complexity and landscape diversity, are positively related to visual quality ($R^2 = 0.72$). In the Central Alps, especially areas above the tree line are characterized by high scenic beauty. Abandonment of agriculturally used areas implies a loss of scenic beauty, mainly in the valley bottom and in the subalpine forest belt, as a result of urban sprawl and natural reforestation. The GIS-based model offers a valid instrument for scenic beauty assessments of mountain regions as a basis for policy making and landscape planning.

1. Introduction

Humans find great opportunities for recreation and leisure in natural ecosystems (de Groot, Alkemade, Braat, Hein, & Willemen, 2010). The demand for outdoor recreation has been growing continuously, and especially mountain environments are highly appreciated by tourists (Raitz & Dakhil, 1988) because of scenic beauty, fresh air, varied topography, and forests (Beza, 2010; Scarpa, Chilton, Hutchinson, & Buongiorno, 2000). The cultural landscape of mountain regions has been shaped by hundreds of years of agricultural activities (Fischer, Rudmann-Maurer, Weyand, & Stöcklin, 2008) leading to a mosaic of agricultural land, natural grassland and forests. During the last decade, many European mountain regions have become affected by land abandonment (Rutherford, Bebi, Edwards, & Zimmermann, 2008; Schneeberger, Bürgi, & Kienast, 2007), and non-agricultural sources of income, in particular tourism, have become more important for the local population. Particularly the abandonment of alpine pastures and meadows results in natural forest re-growth (Sitzia, Semenzato,

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& Trentanovi, 2010; Tasser, Schermer, Siegl, & Tappeiner, 2012) which, however, humans perceive a loss in scenic beauty (Hunziker & Kienast, 1999). As the recreational quality of a region is to a great extent linked to its scenic beauty (Chhetri & Arrowsmith, 2008), it constitutes a competitive advantage in respect to other tourist destinations. Therefore, scenic beauty assessments are an important aid for planners and stakeholders (Ribe, 2009; Tasser et al., 2012).

The scenic beauty of a landscape comes from the interaction between its biophysical features and the human observer which has led to perception-based and expert-based methods for scenic beauty assessments (Daniel, 2001). Perception-based methods assess community perceptions and analyze perceived scenic beauty on-site or by presenting photographs (Arriaza, Cañas-Ortega, Cañas-Madueño, & Ruiz-Aviles, 2004; Grêt-Regamey, Bishop, & Bebi, 2007). Although some perception studies found differences between groups by age, gender, social stratum (Hunziker et al., 2008; Tveit, 2009) or cultural background (Zube & Pitt, 1981), many studies suggest substantial agreement across different groups (e.g. Cañas, Ayuga, & Ayuga, 2009; Kearney et al., 2008; Ode, Fry, Tveit, Messager, & Miller, 2009). Perception-based assessments have a high level of reliability (Daniel, 2001), but they are relatively expensive, time-consuming and difficult to organize on site (Lothian, 1999). Assessments of large complex landscapes are often limited to locations along linear features such as roads, trails, and rivers (Meitner, 2004; Beza, 2010). In contrast, expert-based approaches examine defined visual properties and biophysical features of the landscape by quantitative methods (Daniel, 2001). Germino, Reiners, Blasko, McLeod, and Bastian (2001) estimated visual properties of Rocky Mountains landscapes quantifying dimensions of views, e.g. areal extent, depth, relief, and composition of views in terms of diversity and edge of land cover. de la Fuente de Val, Atauri, and de Lucio (2006) correlated different variables describing scenic beauty, e.g. coherence, legibility, complexity, mystery and diversity, to landscape metrics. The major advantage of an expert-based assessment is its efficiency (Lothian, 1999), which allows the application for whole regions by using automated procedures. However, expert-based assessments have not reached the high reliability of perception-based methods because they are extremely dependent on the professional knowledge of the assessor (Daniel, 2001).

To benefit from the advantages of each assessment method, several authors linked perception-based approaches to expert-based approaches by examining the relationship between landscape preferences and landscape patterns by landscape metrics. They found that diversity indices in particular are positively correlated to landscape preferences (Dramstad, Tveit, Fjellstad, & Fry, 2006; Franco, Franco, Mannino, & Zanetto, 2003; Hunziker & Kienast, 1999). Palmer (2004) identified a better relation of scenic beauty to composition metrics than to configuration metrics. Only few studies examined the scenic beauty of mountain landscapes using a combination of perception-based and expert-based methods. Whereas Hunziker and Kienast (1999) examined landscape metrics based on photographs, Grêt-Regamey et al. (2007) included a three-dimensional view analysis but concentrated on only three land-use types. In contrast to flat landscapes, where only artificial features like wind turbines are visible at greater distances (Shang & Bishop, 2000), in mountain areas topographic characteristics like slope and aspect have to be considered in addition to distance. Especially places of higher elevation than their surrounding area, such as mountain peaks, have long vistas (Germino et al., 2001) and visual properties as size and perceived landscape color change with distance (Bishop, 2003). While in flat landscapes artificial elements or vegetation can block the view, in mountain regions vistas in lower regions such as valley bottoms can be limited by mountains.

To estimate scenic beauty for any viewpoint within mountain landscapes, an efficient spatially explicit assessment method that accounts for the implications of topography on view properties, and, at the same time, ensures the high reliability of perception-based assessments is still lacking. To fill this gap, we aimed at developing a modeling approach to predict scenic beauty of mountain regions and divided our research into the following steps: (1) explore relief-dependent visual properties by using a geographical information system (GIS), (2) examine composition and configuration of landscape by landscape metrics, (3) test if perceived scenic beauty can be related to landscape pattern, and (4) estimate scenic beauty for the Central Alps, aiming to investigate relationships of land use and scenic beauty.

2. Methods

The methodology followed in this paper can be divided into six distinct parts. First, we selected representative study sites for the Central Alps. Second, we introduced distance zones to explore visual properties of mountain regions. Third, we determined the necessary input data for the different distance zones. Fourth, we conducted a visibility analysis to determine the visible area seen from an observer point by using GIS. The visible area was then intersected with the land-cover maps of each distance zone and land cover mosaics were created. Fifth, we calculated landscape metrics based on the land cover mosaics. Finally, to assess human perceptions, we carried out a perception survey to obtain perceived scenic beauty values. We related the perceived scenic beauty values to landscape metrics by a regression analysis to predict scenic beauty for any viewpoint.

2.1. *Study sites*

We developed our model for the greater region of the Central Alps. To cover geographical variations of relief and land cover, we selected four minor study sites (Fig. 1): (1) Lech Valley, Austria (municipalities of Gramais, Hinterhornbach, Pfafflar and Stanzach); (2) Stubai Valley, Austria (municipalities of Neustift im Stubai and Fulpmes); (3) Pustertal, Italy (municipalities of Gsies, Rasen-Antholz, Sand in Taufers, Prettau) and (4) Vinschgau, Italy (municipalities of Glurns, Graun im Vinschgau, Mals, Schluderns). Their landscapes are mainly composed of forest and grassland with different management intensities, from intensively used grassland in lower regions to alpine pastures and abandoned land, mostly in regions above the tree line, with higher areas covered by rocks and glaciers. The study sites belong to the Northern Central European climate zone except for the Vinschgau, which is part of the Central Alpine arid climate zone (Fliri, 1984). They are characterized by different relief properties and have diverse land cover distributions (Table 1).

2.2. *Distance zones*

In mountain landscapes with long vistas, object appearance, color difference, and lightness contrast of an object and its surroundings decrease with increasing distance, leading to less discernible detail (Bishop, 2003). To account for the effect of distance on the perception of size and color, several authors introduced distance zones and divided the landscape into foreground, middle ground and background (Bishop & Hulse, 1994; de la Fuente de Val et al., 2006; Germino et al., 2001). While Bishop and Hulse (1994) limited the viewshed analysis to just 2 km from the observation point, Germino et al. (2001) defined background as up to 150 km. In contrast to flat landscapes, where only elements rising from the landscape are visible, the landscape in mountain regions can be seen in top view from viewpoints at higher positions than the surrounding area. We adapted the distance zones to the high

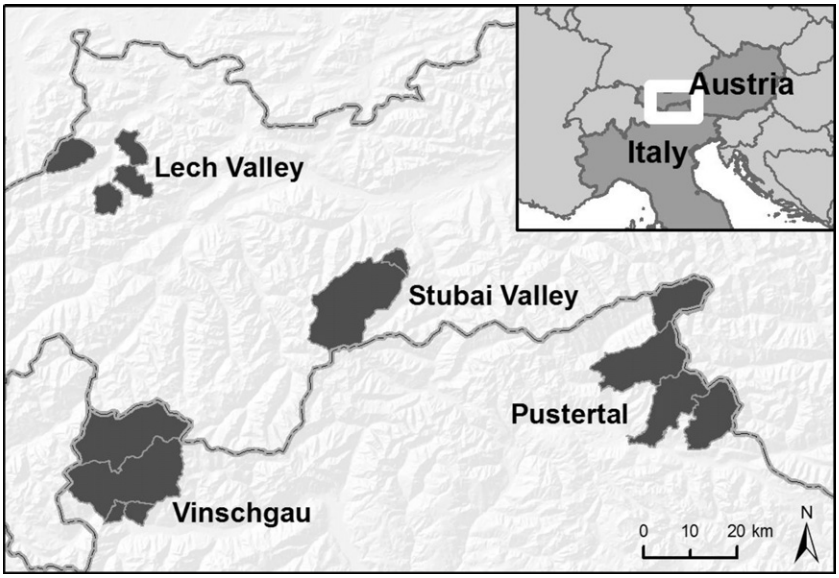

Fig. 1. Location of study sites.

Table 1
Areal extent, relief-dependent properties, and land cover distribution of the four study sites.

Study site		Area [km^2]	Elevation [m a.s.l.]			Slope [°]			Land cover distribution [%]		
			Min	Max	Mean	Min	Max	Mean	Agricultural area	Forest	Settlement
1	Lech Valley	150	905	2727	1724	0	79	31	5	51	<1
2	Stubai Valley	265	890	3488	2167	0	86	31	10	34	<1
3	Pustertal	482	833	3456	2026	0	75	28	14	41	<1
4	Vinschgau	491	882	3723	2196	0	69	26	34	29	<1

variability of landscape pattern and relief properties of the Central Alps. Based on the distinguishability of landscape elements, we defined three distance zones from a viewpoint within the study area (Fig. 2):

- near zone, up to 1.5 km. Details of single features such as trees or buildings are clearly identifiable.
- middle zone, from 1.5 to 10 km. Single elements merge, e.g. single trees form a forest or buildings make up a village.
- far zone, up to 50 km. Although views of up to 150 km are possible from mountain peaks (Germino et al., 2001), good visibility outside population centers in Europe is considered as 40–50 km, and longer vistas occur only under rare occasions (Horvath, 1995). The number of perceivable land-cover classes decreases, whereas edge and outline of the landform still play a major role for the perception of space.

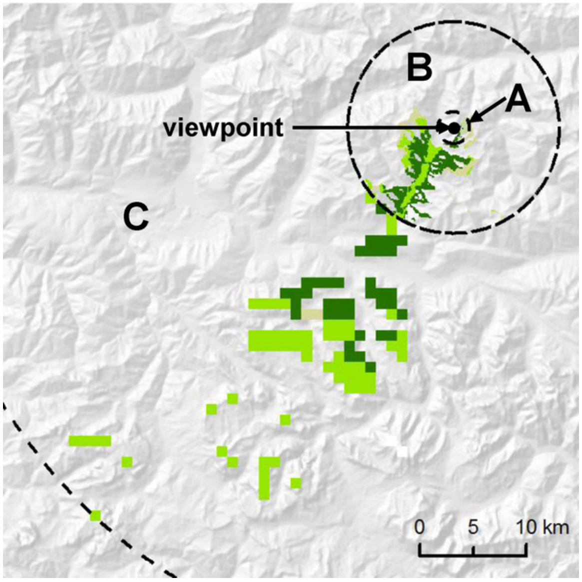

Fig. 2. Visible area intersected with land use of the three distance zones from a viewpoint (black dot). (A) Near zone (0–1.5 km), (B) middle zone (1.5–10 km) and (C) far zone (10–50 km).

The different distance zones are used to select input data with diverse spatial and thematic resolution for the GIS-based model. The visibility analysis within the model was performed taking into account scale and perceived color dependencies from a distance. The distance zones were also applied for attributing weights to the pictures of the perception survey.

2.3. Data collection

For each distance zone, spatial information was selected and/or aggregated with regard to content and spatial resolution. Digital elevation models (DEM) were applied to determine visible area and to derive relief-dependent variables. For the near zone, we used DEM with a resolution of 20 m × 20 m, provided by the Tyrolean Information System (tiris, ©Land Tirol) of the Province of Tyrol and the Autonomous Province of Bolzano-South Tyrol. For the middle and far zone, elevation was obtained from a DEM consisting of processed data from the Shuttle Radar Topography Mission (SRTM) with a resolution of 3 arc-seconds (Jarvis et al., 2008). The resolution was adapted to 100 m × 100 m for the middle zone and resampled to 1 km × 1 km for the far zone.

Habitat and land cover maps were used to calculate landscape metrics. For the near zone, the analysis was performed using habitats which are essential in the analysis of species and landscape diversity (Dudley, Baldock, Nasi, & Stolton, 2005). The habitat map as applied by Tasser, Ruffini, and Tappeiner (2009) is a register of natural, near-natural, and artificial habitats, e.g. grassland habitats in valleys are distinguished from those on the subalpine belt, or managed coniferous forests are different from mixed or deciduous forests. The variety of habitats helps to capture landscape diversity. Structural elements like point or linear landscape features (e.g. groves, hedges, single trees, banks, debris areas) explain landscape texture (Michel, Burel, Legendre, & Butet, 2007) and help to express landscape quality better (Weinstoerffer & Girardin, 2000). A landscape structure map was intersected with the habitat map, both generated for the study areas from orthophotos (scale 1:10,000) by on-screen digitizing in a GIS. Additionally, land cover was supplemented by three spatial datasets: major streams selected from the river network; plus roads, both provided by the Tyrolean Information System (tiris, ©Land Tirol) of the Province of Tyrol and the Autonomous Province of Bolzano-South Tyrol, and mapped single settlement points. All datasets were converted to raster datasets with a spatial resolution of 20 m × 20 m and merged into one dataset.

For the middle and the far zone, we used CORINE land cover 2000 (CLC2000) seamless vector database (EEA, 2009). Based on the low number of land cover classes in the Central Alps and according to the distinguishability of elements as defined for the distance zones, the 44 CLC-level-3 classes were aggregated into six classes for the middle zone: forest, grassland, settlement, rock, water and glacier. For the far zone, rock was included in the grassland because it is often covered by sparse vegetation and therefore less distinguishable from alpine grassland with increasing distance. Water, settlements and glaciers constitute important landscape elements. Presence of water has a positive influence on scenic beauty (Bishop & Hulse, 1994) and offers a wide range of recreational activities. Glaciers are also important tourist attractions (Scott, Jones, & Konopek, 2007). In contrast, large settlements have negative effects on scenic beauty in mountain regions (Grêt-Regamey et al., 2007) and perceived scenic beauty is strongly correlated with naturalness (Lamb & Purcell, 1990). Color differences, which are greater between the bright color of settlements and glaciers with vegetation than between different vegetation types, and the reflection of water surfaces also support visibility and distinguishability of these landscape elements from greater distances (Litton, 1977; García, Hernández, & Ayuga, 2003). To account for the large scale of the CORINE land cover map and to include all areas of the classes water, settlements and glaciers, these classes were treated as a priority in the conversion from polygon to raster datasets.

2.4. Visibility analysis

Visual properties of the landscape are determined by the location of a viewpoint. Rather than any specific restricted view as captured by photographs, the surroundings affect the perception of the visual environment in their entirety (Meitner, 2004). A geographic information system is a suitable tool for analyzing 360° views from a viewpoint. Due to the topography of mountain landscapes, some areas of the landscape may not be visible from the viewpoint. By using an algorithm for estimating whether or not each target cell is within the observer's line-of-sight (Kim, Rana, & Wise, 2004), viewsheds can be calculated and non-visible areas excluded. A DEM does not take into account feature height from vegetation or buildings which can narrow or completely block the view. Heights of mapped surface features were superimposed onto the DEM and a digital surface model (DSM) was generated by adding the feature heights to the ground elevation (DEM). An average height of 20 m was assigned to forest (Wallentin, Tappeiner, Strobl, & Tasser, 2008) and 2 m to shrubs (Dullinger, Dirnböck, & Grabherr, 2003), while the average height of buildings was estimated as 10 m. We created a set of 5565 viewpoints for all study sites (Lech Valley 602; Stubai Valley 1068; Pustertal 1928; Vinschgau 1967), regularly distributed over the whole study area, by placing a viewpoint every 500 m to account for the landscape variability but to maintain feasible computing time. Each viewpoint was assigned a unique ID in order to relate all non-spatial information to the specific viewpoint. Viewpoints within forest and settlement areas were excluded from viewshed analysis because of viewing restrictions. For all other viewpoints, three viewsheds, one for each distance zone, were computed, based on the DSM using an eye level of 1.6 m. To obtain the visible land cover for each distance zone, viewsheds were intersected with the corresponding land cover datasets (Fig. 2). A mosaic of the three resulting datasets was created for further analysis because the different zones are seen from the viewpoint as one scene belonging together.

To repeat the analysis for an arbitrary number of viewpoints, calculation was automated by generating a GIS-based model written in Python 2.5 (Python Software Foundation, NH, USA) and using standard routines provided with ArcGIS 9.3$^{\text{TM}}$ (ESRI, Redlands, CA, USA).

2.5. Landscape metrics

Landscape metrics were calculated for the land cover mosaic using FRAGSTATS Version 3.3. (McGarigal et al., 2002) which includes a variety of metrics describing area, patch, edge and shape properties as well as diversity on three different levels: patch, class or landscape. Selection of landscape metrics can be based on expertise or on statistical approaches (Lausch & Herzog, 2002; Riitters et al., 1995). In line with comparable studies (Dramstad et al., 2006; Franco et al., 2003; Hunziker & Kienast, 1999; Palmer, 2004), we selected 60 landscape metrics at landscape level (see Appendix A for details). The land cover mosaics of the 5565 viewpoints were all of the same size. Non-visible areas, classified as background, were assumed to be 'outside' the landscape of interest and had no influence on area-based metrics (McGarigal et al., 2002). The selected landscape metrics were subsequently reduced by principal component analysis (PCA).

2.6. Perception survey

Landscape metrics can describe landscape in terms of heterogeneity, diversity, and composition, but they do not reflect human perceptions. The areal extent of the visible landscape is positively correlated to perceived scenic beauty (Germino et al., 2001; Sander & Manson, 2007) and can be assessed by area-based metrics. Landscape metrics were related to human perceptions through a survey investigating people's perception of scenic beauty. The survey was based on a questionnaire presenting a set of photographs and containing six series related to (1) landscape structure, (2) settlement pattern, (3) forest pattern, (4) presence of water, (5) forest density, and (6) view zones. Each series was made up of four images: one real photograph and three different versions of the original photograph modified with Adobe PhotoShop$^{\text{TM}}$. A seventh series was added at the end of the questionnaire repeating the six original photographs from series 1 to 6. Additionally, we included questions related to demographical information (age, gender, origin). The questionnaire was translated in German and Italian by a professional translator. The respondents were selected in public locations in the study sites on the basis of an equal distribution of age, gender, origin (inhabitants and tourist) to represent perceptions of the whole community (Lothian, 1999). A total of 253 persons were interviewed by presenting the questionnaire. The respondents were asked to rank

Picture		Represented view zone	$\bar{x}$[a]	SD[b]
1		3 zones with foreground elements	2.25	0.886
2		2 zones (near and middle zone)	1.80	0.901
3		1 zone (near zone)	1.09	1.035
4		3 zones without foreground elements	0.86	1.054

[a] Mean preference score (N = 253)
[b] Standard deviation

Fig. 3. Mean scenic beauty values of picture series 6, representing different view zones (1 for least beautiful and 4 for most beautiful).

the four pictures of each series according to scenic beauty (from 1 = least beautiful to 4 = most beautiful). The response rate was 89%, and the respondents employed in average 5–10 min to fill out the questionnaire. The rankings of the six different picture series are not comparable with each other because each series is related to a specific theme and the pictures were ranked only within each series. To compare the different themes represented by series 1–6, we used the seventh series, which repeated the six original photographs from series 1 to 6. The seventh series consisted of six pictures which led to a ranking scale ranging from 1 = least beautiful to 6 = most beautiful. To obtain comparable scenic beauty values for the series 1–6, we calculated a modified scenic beauty value for each image by multiplying each original value with the scenic beauty value of the related photograph of series 7. The sixth series was manipulated to obtain different combinations of the view zones: Picture 1 shows all three zones, Picture 2 represents the near and middle zone, Picture 3 shows the near zone, and Picture 4 contains all three zones but has no foreground elements (Fig. 3). To quantify the influence of each view zone, we assigned a weight to each zone. First, we computed a scenic beauty value for each zone by subtracting scenic beauty value of the pictures. Subsequently, the weight of each zone was calculated by dividing each mean scenic beauty value by the scenic beauty value of all zones to obtain values between 0 and 1 (Table 2). We used these weights to calculate the total weighting factors for all images of the questionnaire. After visually identifying the number of view zones of all images according to the distinguishability of landscape elements as defined in Section 2.2, we obtained a total weighting factor for each image by summing up the weights of the contained view zones. Finally, the weighting factor was applied to the modified scenic beauty values of each picture to take into account the number of view zones present and their influence on scenic beauty.

All photograph positions were geo-referenced in the field with GPS. By setting the appropriate view angle and direction of the picture, the views were located on the land cover map (Fig. 4). Non-visible areas were excluded in calculating the viewshed based on the DSM from the position of the photograph. According to the different versions of the original photographs, also different land cover maps were created. Based on the adapted land cover maps, landscape metrics were calculated for all picture views of the survey.

3. Results

3.1. Perception survey

The survey suggests that view zones play an important role for the perception of scenic beauty. The higher the number of visible view zones, the better the picture was liked, and foreground

Table 2
Calculation of mean scenic beauty value for each view zone, based on mean scenic beauty values of picture series 6 (see Fig. 3). Weight was obtained by dividing each mean scenic beauty value by the scenic beauty value of all zones.

View zone	Calculation	Mean scenic beauty value	Weight
Near zone	Picture 3 (1.09)	1.09	0.48
Middle zone	Picture 3 (1.09) subtracted from Picture 2 (1.80)	0.71	0.32
Far zone	Picture 2 (1.80) subtracted from Picture 1 (2.25)	0.45	0.20
All zones	Picture 1 (2.25)	2.25	1

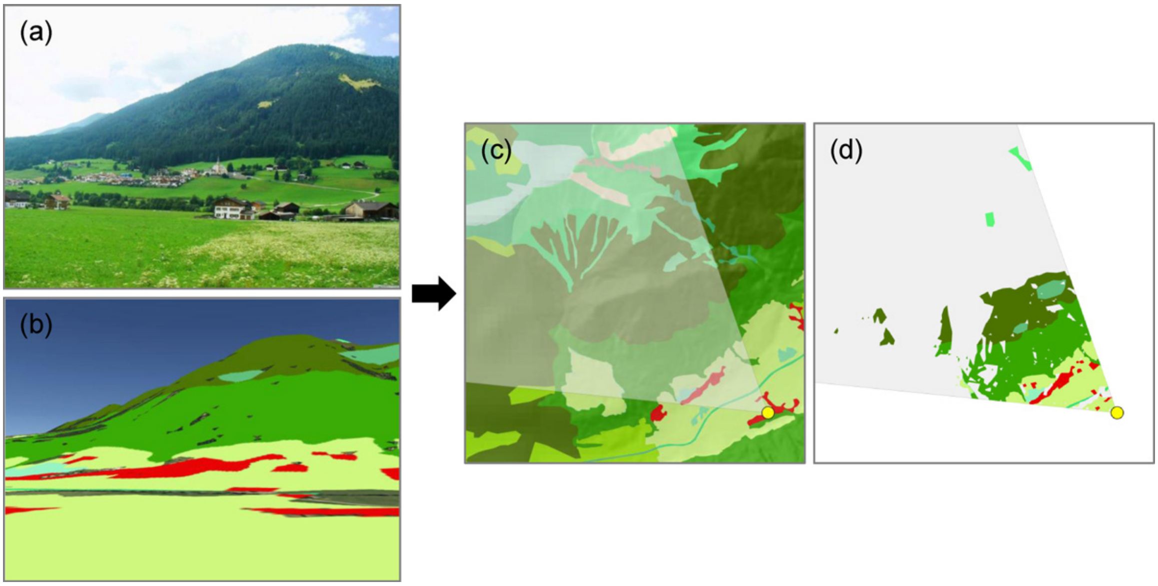

Fig. 4. (a) The original photograph and (b) the same view in Google Earth with a map overlay. (c) The position of the viewpoint (yellow circle) was placed on the land cover map and the viewshed delimitated by setting view angle and direction. (d) Non-visible areas were excluded.

elements were preferred to the middle and far zone (Fig. 3). By calculating the weights of each zone, we assessed their influence on scenic beauty. While the near zone contributes by 48% to scenic beauty, the middle zone reaches 32% and the far zone only 20% (Table 2). The distribution of the scenic beauty values for the 24 images is shown in Fig. 5.

3.2. Statistical analysis

For the 5565 viewpoints, we calculated 60 landscape metrics and selected explanatory variables by means of a principal component analysis (PCA) with varimax rotation. The rotated, standardized components are described by the covariance of the original variables and reflect the input variables in few but significant variables that are absolutely independent (Riitters et al., 1995). Eleven components with an eigenvalue above 1 were extracted and explain 93% of the total variance (Appendix B). The first and fourth components consist mainly of area metrics quantifying the area and extent of patches. Whereas the second component comprises different types of metrics expressing complexity of patches within landscape, the third component includes only diversity metrics representing richness and evenness to quantify diversity of landscape. The fourth component consists of different area metrics. Components five, seven and eight are dominated by different shape metrics describing landscape configuration by representing the complexity of patch shape, patch size and patch compaction. The sixth component contains different indices describing landscape fragmentation. Components nine and ten include shape metrics, while the eleventh component is represented by the number of patches.

Based on the scenic beauty values of the perception survey and the landscape metrics related to the pictures, we applied a stepwise linear regression analysis to build a model for estimating scenic beauty. Scenic beauty values were entered as a dependent

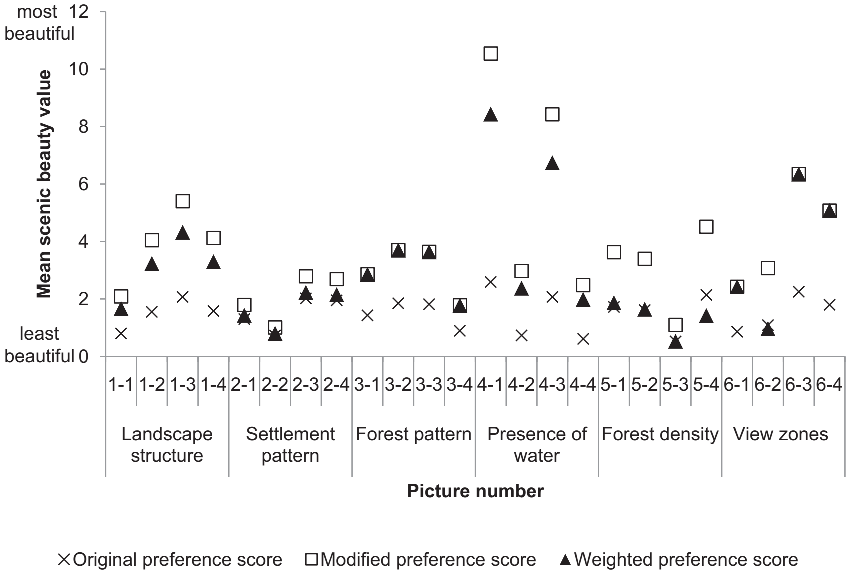

Fig. 5. Mean scenic beauty value for each image, showing original, modified (multiplied with related photograph of series 7) and weighted scenic beauty value (modified scenic beauty value weighted by the view zones).

Table 3
Linear regression result with beta-coefficients and significance of the components.

	Unstandardized coefficients		Unstandardized coefficients	*T*	Sig
Variable	B	SEB	Beta		
Component 7	0.519	0.108	0.617	4.813	0.000
Component 3	−0.579	0.129	−0.575	−4.492	0.000

variable, while the eleven selected components were used as independent variables. The model identified two predictors of scenic beauty (Table 3) and a good level of prediction was achieved ($R^2 = 0.72$, adjusted $R^2 = 0.69$). The first predictor corresponds to component 7 (Appendix B) with highest loadings for shape and fractal index distribution representing shape complexity. Component 3 was selected as second predictor expressing landscape diversity with high loadings for all six diversity metrics and negative loading for contagion.

3.3. *Scenic beauty*

Scenic beauty was estimated for all viewpoints outside forests and settlement areas by applying the regression model. Viewpoints within forests returned scenic beauty values from the survey (series 5). Viewpoints within settlement areas, which were less than 1% of all viewpoints, were set to no data because no scenic beauty values were available from the survey. Finally, area-wide maps with a raster size of 500 m × 500 m were created for all study sites (Fig. 6).

Scenic beauty of the viewpoints ranges between 0.9 and 55.4 (Table 4). To examine the spatial variations of scenic beauty, we used landscape units as applied by Tasser et al. (2009). While similar land cover does not always correspond to the same elevation range for all study sites, due to diverse climate and agricultural use, the landscape units reflect land cover related to elevation: (1) agriculturally used valley bottom, (2) agriculturally used valley slopes, (3) montane forest belt, (4) subalpine forest belt, (5) agriculturally used alpine pastures, (6) natural alpine grassland, and (7) nival belt. Based on the scenic beauty maps and the delimitation of the landscape units, we calculated mean values for each unit of all study sites (Table 4). Generally, viewpoints in the valley bottom indicate mean values of scenic beauty or below and landscape pattern is dominated by settlements and grasslands but the visible area is limited by slopes, trees, or buildings (Fig. 7a). The forest belt (montane forest and subalpine forest belt) is characterized by very low scenic beauty due to the view being impaired by trees (Fig. 7b). High scenic beauty can be found for viewpoints above the forest belt, especially within natural alpine grassland and the nival belt (Fig. 7c). The visible area of viewpoints above the tree-line increases with increasing elevation. The viewsheds are mostly characterized by complex topography, heterogeneous landscape patterns of alpine pastures in the vicinity, and more homogeneous landscape patterns in the distance.

4. Discussion and conclusions

Daniel (2001) indicated that, in contrast to just perception-based methods (e.g. Arriaza et al., 2004; Cañas et al., 2009; Hunziker et al., 2008; Zube & Pitt, 1981) or purely expert-based approaches (e.g. Bishop & Hulse, 1994; Germino et al., 2001; Herbst, Förster, & Kleinschmit, 2009), merging the two opposing approaches could result in a more effective approach that better represents landscape features and human judgments. Accordingly, our GIS-based modeling approach combined an automated assessment of the specific view properties of mountain landscapes and landscape patterns with a perception-based method, investigating human perceptions of scenic beauty. In a first step, the area seen from a viewpoint was examined and, by considering different distance zones, the model accounted for the influence of distance on perceived size, shape, and color of landscape features. The visible area was intersected with land-cover maps, and landscape patterns, expressed by landscape metrics, were related to perceived scenic beauty out of a perception survey by a regression analysis. In line with other studies (de la Fuente de Val et al., 2006; Dramstad et al., 2006; Hunziker & Kienast, 1999; Palmer, 2004), our results confirm the relationship between landscape pattern and scenic beauty. We found that scenic beauty is positively correlated to complexity of patch shape, diversity and structural richness of landscape, whereas large homogeneous areas reduce scenic beauty.

The regression model was developed and established for our study region, the Central Alps. In contrast to other studies in the European Alps (Grêt-Regamey et al., 2007; Hunziker & Kienast, 1999) our model can be applied for any viewpoint in mountain regions within Europe, which is considered a human entity, sharing common area, culture and behavior patterns (Jordan-Bychkov & Bychkova-Jordan, 2008). Thus, the scenic beauty of any viewpoint can be compared to all other points throughout Europe. The GIS-based model can also easily be transferred to other regions with similar topographic properties all over the world. It might be necessary to repeat the perception study for other cultural regions where people might perceive scenic beauty differently (Zube & Pitt, 1981). Although the perception of scenic beauty can vary between diverse social groups or different generations within one landscape region (Dramstad et al., 2006; Hunziker et al., 2008; Tveit, 2009), landscape variations are generally much greater than the variations between observer's judgments (Daniel, 2001). Input data are based on digital elevation models and land cover maps, which are usually available for most areas in Europe and comparable satellite-based data exist for many regions world-wide. There are no restrictions regarding spatial and non-spatial resolution of the data. Availability of high resolution data used for the near zone is more difficult and might necessitate new mapping. The high resolution data can be substituted e.g. by CORINE land cover (EEA, 2009) for first assessments but lower resolution of input data reduces the quality of the model and smoothes the values for scenic beauty. Another advantage of our method is that scenic beauty can be predicted for any viewpoint which allows different applications: (1) it is possible to perform area-wide mapping by distributing viewpoints over the whole area, or (2) to explore selected zones, for instance those of touristic interest, along roads or hiking trails by placing the viewpoints along defined features. The quality of assessments depends on the resolution of the input data, which determines the highest possible density of viewpoints because view properties and landscape composition are highly variable and can change within very short distances.

In comparing scenic beauty of diverse landscape units, major differences can be observed between viewpoints above the forest belt, characterized by high scenic beauty, and viewpoints within the forest belt, to which low scenic beauty was attributed. Supported by Ribe (2009), the survey indicated that structure and diversity influence the perception of scenic beauty in timber stands. Open forests are generally preferred. On the other hand, forests are highly appreciated for recreational activities and are related to spiritual, esthetic, cultural, and educational values (Scarpa et al., 2000). Close

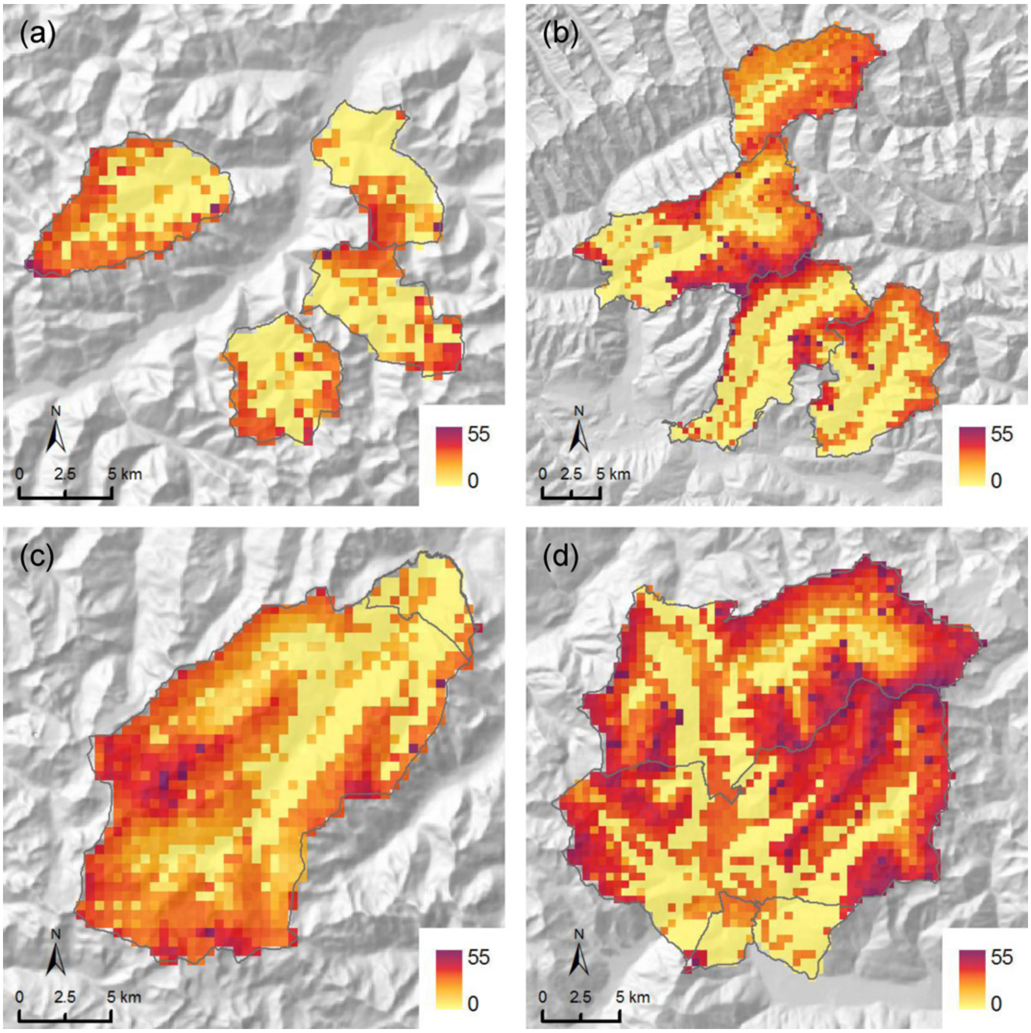

Fig. 6. Scenic beauty of (a) Lech Valley, (b) Pustertal, (c) Stubai Valley and (d) Vinschgau. High values correspond to great scenic beauty.

to average scenic beauty was found for the agriculturally used valley bottom and the natural alpine grassland belt. In these landscape units, landscape pattern and structure are strongly influenced by human activities. In many Alpine regions, considerable changes in agriculture and forestry could be observed (Rutherford et al., 2008). Land abandonment mainly affected alpine pastures, and natural forest re-growth leads to altered landscape patterns (Sitzia et al., 2010), a general shift from a patchy mosaic toward a more homogeneous scenery. The increase in forest not only means restricted view and a loss of viewpoints but affects scenic beauty of any viewpoint, because scenic beauty is conditioned by the composition and pattern of the whole visible area. As a consequence, a decrease of scenic beauty, especially along hiking tracks, might affect the attractiveness of the area. Resulting maps offer a basis for various applications, especially in landscape planning or tourism geography. The GIS-based model can support scenic beauty assessments in the decision making process for future policies or to evaluate already implemented measures, e.g. Tasser et al. (2012) emphasize that mountain farming is important to maintain the cultural landscapes of tourist destinations and abandonment of agricultural land can be avoided by payments for landscape preservation. Regarding the Europe 2020 Strategy, the Common Agricultural Policy (CAP)

Table 4
Mean values of scenic beauty for different landscape units: (1) agriculturally used valley bottom, (2) agriculturally used valley slopes, (3) montane forest belt, (4) subalpine forest belt, (5) agriculturally used alpine pastures, (6) natural alpine grassland, and (7) nival belt. High values correspond to great scenic beauty.

		Landscape unit							
		1	2	3	4	5	6	7	Total
Area [km^2]		98	45	146	261	391	372	78	1389
Mean elevation [m a.s.l.]		1272	1306	1352	1850	2129	2590	3019	2081
Scenic beauty	Mean	10.0	5.9	1.8	2.1	9.7	14.8	17.5	9.1
(N = 5565)	SD[a]	4.1	4.7	2.9	3.8	5.8	4.8	5.2	7.1
	Minimum	0.9	0.9	0.9	0.9	0.9	0.9	5.3	0.9
	Maximum	16.0	16.9	15.8	46.5	48.2	48.5	55.4	55.4

[a] Standard deviation.

Fig. 7. Typical landscape patterns seen from viewpoints in (a) the agriculturally used valley bottom, (b) the subalpine forest belt, and (c) the natural alpine grassland.

proposes to relate financial support in the future to ecosystem services (European Commission, 2010). As cultural ecosystem services like the recreational value are often expressed by scenic beauty (de Groot et al., 2010), our proposed GIS-based model allows region-wide assessments for evaluating payments for ecosystem services. By calculating scenic beauty maps based on future land-use/-cover scenarios, future impacts can be visualized and management decisions adapted. For the tourism sector in particular, our proposed model offers great potential to strengthen the competitiveness of a region by preserving the landscape or by creating the necessary infrastructure to access places of great scenic beauty.

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Appendix A. Variations of landscape metrics for the 5565 viewpoints.

Acronym	Landscape metrics	Mean	Min	Max	S.D.
TA	Total area	14212.8	255.0	756241.0	16383.4
NP	Number of patches	125.1	21.0	527.0	62.2
PD	Patch density	2.7	0.0	95.9	5.4
LPI	Largest patch index	24.3	4.0	89.3	10.8
TE	Total edge	65956.5	3220.0	1904140.0	45019.5
ED	Edge density	8.2	0.5	83.4	7.3
LSI	Landscape shape index	8.5	3.4	17.7	1.6
AREA_MN	Mean patch area distribution	136.9	1.0	3959.4	137.0
AREA_AM	Area-weighted mean patch area distribution	1434.1	7.3	222591.7	3180.3
AREA_MD	Median patch area distribution	13.2	0.1	200.0	29.5
AREA_RA	Range patch area distribution	3047.9	26.0	290400.0	4620.1
AREA_SD	Standard deviation patch area distribution	402.4	2.6	29421.9	508.7
AREA_CV	Coefficient of variation patch area distribution	344.5	117.4	1106.1	117.4
GYRATE_MN	Mean radius of gyration distribution	294.1	28.1	1097.1	182.6
GYRATE_AM	Area-weighted mean radius of gyration distribution	1694.8	116.1	24779.2	869.0
GYRATE_MD	Median radius of gyration distribution	114.6	14.1	745.9	110.6
GYRATE_RA	Range radius of gyration distribution	2930.1	204.2	32334.5	1567.1
GYRATE_SD	Standard deviation radius of gyration distribution	475.0	38.6	3318.6	245.7
GYRATE_CV	Coefficient of variation radius of gyration distribution	174.6	74.4	426.7	39.0
SHAPE_MN	Mean shape index distribution	1.4	1.2	1.8	0.1
SHAPE_AM	Area-weighted mean shape index distribution	2.0	1.2	5.7	0.3
SHAPE_MD	Median shape index distribution	1.3	1.0	1.6	0.1
SHAPE_RA	Range shape index distribution	3.2	1.1	15.1	1.4
SHAPE_SD	Standard deviation shape index distribution	0.6	0.3	1.1	0.1
SHAPE_CV	Coefficient of variation shape index distribution	39.2	22.1	67.7	5.7
FRAC_MN	Mean fractal index distribution	1.1	1.0	1.1	0.0
FRAC_AM	Area-weighted mean fractal index distribution	1.1	1.0	1.2	0.0
FRAC_MD	Median fractal index distribution	1.1	1.0	1.1	0.0
FRAC_RA	Range fractal index distribution	0.2	0.1	0.4	0.1
FRAC_SD	Standard deviation fractal index distribution	0.1	0.0	0.1	0.0

Acronym	Landscape metrics	Mean	Min	Max	S.D.
FRAC_CV	Coefficient of variation fractal index distribution	5.3	3.2	7.3	0.7
PARA_MN	Mean perimeter-area ratio distribution	677.5	84.6	1362.8	282.3
PARA_AM	Area-weighted mean perimeter-area ratio distribution	48.8	5.8	506.8	35.3
PARA_MD	Median perimeter-area ratio distribution	488.3	30.0	1500.0	362.3
PARA_RA	Range perimeter-area ratio distribution	1966.8	388.1	1995.5	109.6
PARA_SD	Standard deviation perimeter-area ratio distribution	614.1	112.5	852.7	115.7
PARA_CV	Coefficient of variation perimeter-area ratio distribution	103.3	40.9	247.0	32.9
CONTIG_MN	Mean contiguity index distribution	0.6	0.3	0.9	0.1
CONTIG_AM	Area-weighted mean contiguity index distribution	1.0	0.7	1.0	0.0
CONTIG_MD	Median contiguity index distribution	0.7	0.2	1.0	0.2
CONTIG_RA	Range contiguity index distribution	1.0	0.2	1.0	0.0
CONTIG_SD	Standard deviation contiguity index distribution	0.3	0.1	0.4	0.1
CONTIG_CV	Coefficient of variation contiguity index distribution	52.9	7.3	104.6	18.7
PAFRAC	Perimeter-area fractal dimension	1.1	1.0	1.4	0.0
CONTAG	Contagion	79.9	50.4	95.4	5.5
PLADJ	Percentage of like adjacencies	97.6	74.7	99.7	1.8
IJI	Interspersion & juxtaposition index	39.9	3.9	74.0	11.2
COHESION	Patch cohesion index	99.0	89.5	100.0	0.8
DIVISION	Landscape division index	0.9	0.2	1.0	0.1
MESH	Effective mesh size	1434.1	7.3	222591.7	3180.3
SPLIT	Splitting index	10.6	1.3	56.2	5.1
PR	Patch richness	13.7	4.0	42.0	4.9
PRD	Patch richness density	0.3	0.0	10.2	0.7
RPR	Relative patch richness	137.3	40.0	420.0	49.4
SHDI	Shannon's diversity index	1.0	0.2	2.8	0.3
SIDI	Simpson's diversity index	0.5	0.1	0.9	0.1
MSIDI	Modified Simpson's diversity index	0.8	0.1	2.6	0.3
SHEI	Shannon's evenness index	0.4	0.1	0.9	0.1
SIEI	Simpson's evenness index	0.6	0.1	1.0	0.1
MSIEI	Modified Simpson's evenness index	0.3	0.0	0.8	0.1

Appendix B. Rotated component matrix. Selection of the 60 landscape metrics by means of principal component analysis (PCA) with varimax rotation and Kaiser normalization. Rotation converged in 11 iterations. The resulting components are described by the covariance of the ingoing variables. All values above 0.5 or beyond −0.5 are displayed in bold.

	Component											Communalities
Variables[a]	1	2	3	4	5	6	7	8	9	10	11	
Cumulative % of variance explained	20.1	34.0	46.1	57.2	65.5	72.4	78.4	82.5	86.2	89.5	92.5	
TA	−0.405	−0.169	−0.179	**0.791**	−0.024	0.265	−0.133	0.033	0.025	−0.003	0.087	0.948
NP	0.460	0.173	0.040	0.018	0.356	0.304	−0.210	0.057	0.038	0.203	**0.623**	0.941
PD	0.169	**0.901**	0.157	−0.073	−0.014	−0.044	−0.094	0.014	−0.012	0.090	0.087	0.896
LPI	0.140	0.083	−0.151	0.040	0.001	**−0.910**	0.043	0.134	0.026	0.011	0.036	0.901
TE	−0.071	−0.262	0.123	**0.642**	0.218	0.390	−0.023	0.254	0.009	0.121	0.259	0.848
ED	0.275	**0.763**	0.390	−0.145	0.158	0.024	0.132	0.192	−0.033	0.077	0.022	0.918
LSI	−0.202	0.251	0.049	0.108	0.217	**0.620**	−0.160	0.271	0.053	0.138	0.485	0.906
AREA_MN	**−0.632**	−0.197	−0.272	**0.603**	−0.073	0.136	−0.104	0.028	−0.008	−0.083	−0.075	0.925
AREA_AM	−0.008	−0.050	−0.063	**0.971**	−0.028	−0.080	0.023	0.004	−0.024	−0.040	−0.030	0.961
AREA_MD	**−0.740**	0.008	−0.157	0.171	0.042	0.180	−0.250	−0.107	−0.007	−0.009	0.098	0.720
AREA_RA	−0.153	−0.112	−0.125	**0.960**	−0.025	−0.040	−0.039	0.052	0.000	−0.024	0.007	0.980
AREA_SD	−0.285	−0.146	−0.184	**0.916**	−0.052	−0.015	−0.029	0.051	−0.012	−0.059	−0.055	0.989
AREA_CV	**0.532**	0.181	−0.098	0.041	0.249	**−0.517**	−0.081	0.143	0.039	0.168	0.482	0.945
GYRATE_MN	**−0.790**	−0.297	−0.256	0.287	−0.100	0.196	−0.102	0.029	−0.003	−0.097	−0.103	0.940
GYRATE_AM	−0.350	−0.383	−0.349	**0.644**	−0.004	−0.195	−0.049	0.276	0.038	−0.016	0.007	0.923
GYRATE_MD	**−0.854**	−0.116	−0.160	0.188	−0.037	0.203	−0.172	−0.078	−0.010	−0.059	0.022	0.887
GYRATE_RA	−0.445	−0.382	−0.288	**0.569**	0.012	−0.072	−0.120	0.272	0.063	0.008	0.060	0.852
GYRATE_SD	**−0.612**	−0.400	−0.334	0.447	−0.079	0.055	−0.064	0.177	0.027	−0.073	−0.113	0.909
GYRATE_CV	**0.659**	−0.113	−0.157	0.096	0.229	−0.443	−0.057	0.262	0.037	0.145	0.304	0.916
SHAPE_MN	−0.135	−0.077	0.051	0.017	0.356	−0.053	**0.852**	0.167	−0.010	−0.055	−0.171	0.942
SHAPE_AM	−0.074	0.010	0.001	0.244	0.158	−0.203	0.093	**0.900**	−0.032	0.001	0.048	0.953
SHAPE_MD	−0.136	−0.072	0.042	−0.002	−0.054	−0.020	**0.926**	0.055	0.013	−0.001	−0.018	0.891
SHAPE_RA	0.268	0.021	0.110	−0.011	**0.808**	0.053	−0.051	0.049	−0.007	0.059	0.228	0.801
SHAPE_SD	0.139	−0.037	0.085	0.016	**0.916**	−0.025	0.223	0.190	−0.016	−0.010	−0.046	0.956
SHAPE_CV	0.202	−0.023	0.081	0.012	**0.931**	−0.010	−0.006	0.167	−0.017	0.006	0.008	0.942
FRAC_MN	0.466	0.233	0.111	−0.119	0.246	−0.166	**0.747**	0.006	0.031	0.072	−0.009	0.951
FRAC_AM	0.009	0.287	0.105	0.092	0.122	−0.183	0.189	**0.872**	−0.040	−0.001	0.039	0.949
FRAC_MD	0.298	0.180	0.118	−0.099	0.019	−0.154	**0.852**	0.057	0.017	0.061	0.058	0.906
FRAC_RA	0.486	0.127	0.054	−0.053	**0.729**	0.065	0.103	−0.106	0.062	0.144	0.133	0.859
FRAC_SD	**0.615**	0.183	0.026	−0.075	**0.624**	−0.039	0.254	−0.063	0.071	0.083	−0.034	0.889
FRAC_CV	**0.615**	0.174	0.019	−0.071	**0.636**	−0.029	0.214	−0.066	0.073	0.083	−0.037	0.882
PARA_MN	**0.830**	0.363	0.077	−0.135	0.252	−0.123	−0.054	−0.053	0.062	0.130	0.133	0.968
PARA_AM	0.249	**0.886**	0.314	−0.164	0.039	−0.010	0.058	0.098	−0.031	0.055	0.031	0.992

	Component											Communalities
Variables[a]	1	2	3	4	5	6	7	8	9	10	11	
PARA_MD	**0.732**	0.389	0.088	−0.132	0.269	−0.131	−0.080	−0.066	−0.020	0.091	0.312	0.919
PARA_RA	0.154	−0.047	−0.014	−0.008	0.007	0.000	0.024	−0.020	**0.969**	0.021	0.007	0.967
PARA_SD	**0.806**	0.030	−0.006	−0.071	0.194	0.045	−0.034	−0.032	0.334	0.122	−0.281	0.902
PARA_CV	−**0.840**	−0.305	−0.124	0.182	−0.158	0.207	−0.104	0.009	0.122	−0.109	−0.106	0.965
CONTIG_MN	−**0.831**	−0.368	−0.081	0.141	−0.238	0.135	0.053	0.052	−0.058	−0.131	−0.137	0.972
CONTIG_AM	−0.255	−**0.878**	−0.323	0.172	−0.036	0.008	−0.060	−0.101	0.032	−0.051	−0.034	0.990
CONTIG_MD	−**0.747**	−0.391	−0.089	0.137	−0.254	0.149	0.078	0.063	0.021	−0.088	−0.284	0.923
CONTIG_RA	0.142	−0.089	−0.030	0.002	0.011	0.003	0.014	−0.032	**0.967**	0.022	0.017	0.966
CONTIG_SD	**0.788**	−0.017	−0.020	−0.065	0.169	0.058	−0.038	−0.044	0.342	0.118	−0.328	0.900
CONTIG_CV	**0.841**	0.292	0.048	−0.111	0.280	−0.059	−0.124	−0.062	0.118	0.118	0.079	0.942
PAFRAC	0.293	**0.567**	0.270	−0.148	0.283	−0.244	0.154	0.312	−0.147	0.022	0.295	0.872
CONTAG	0.007	−0.358	−**0.892**	0.136	−0.057	−0.014	−0.094	−0.013	0.048	0.124	−0.006	0.973
PLADJ	−0.249	−**0.886**	−0.314	0.164	−0.039	0.010	−0.058	−0.098	0.031	−0.055	−0.031	0.992
IJI	0.285	0.461	0.086	−0.182	0.272	−0.262	0.294	−0.291	−0.014	−0.115	0.231	0.715
COHESION	−0.256	−**0.860**	−0.301	0.167	−0.011	−0.054	−0.017	0.140	0.017	−0.068	−0.071	0.957
DIVISION	−0.165	−0.079	0.165	−0.035	0.004	**0.909**	−0.070	−0.119	−0.006	−0.001	−0.017	0.908
MESH	−0.008	−0.050	−0.063	**0.971**	−0.028	−0.080	0.023	0.004	−0.024	−0.040	−0.030	0.961
SPLIT	−0.322	−0.037	0.126	0.014	0.000	**0.810**	−0.175	−0.177	0.044	0.065	0.084	0.853
PR	0.391	0.267	0.094	−0.075	0.105	0.036	0.028	0.007	0.038	**0.849**	0.072	0.979
PRD	0.084	**0.863**	0.131	−0.067	−0.070	−0.103	−0.024	0.024	−0.028	0.203	−0.116	0.846
RPR	0.391	0.267	0.094	−0.075	0.105	0.036	0.028	0.007	0.038	**0.849**	0.072	0.979
SHDI	0.221	0.426	**0.805**	−0.147	0.099	0.059	0.108	0.000	0.026	0.207	0.037	0.969
SIDI	0.215	0.168	**0.915**	−0.108	0.067	0.130	0.014	0.026	0.025	0.161	0.023	0.973
MSIDI	0.189	0.272	**0.889**	−0.114	0.074	0.136	0.048	0.030	0.021	0.184	0.001	0.974
SHEI	−0.040	0.294	**0.914**	−0.127	0.046	0.014	0.084	−0.015	−0.044	−0.131	0.006	0.968
SIEI	0.148	0.139	**0.948**	−0.102	0.053	0.121	0.001	0.023	0.003	0.093	0.016	0.976
MSIEI	−0.020	0.142	**0.960**	−0.091	0.024	0.099	0.012	0.019	−0.036	−0.088	−0.022	0.972

[a] For full names of acronyms see Appendix A.

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