Relating spatial pattern of forest cover to accessibility

1 Abstract

2 Urban planning for optimal provision of recreational forests is not only con-
3 cerned with how much space is needed, but equally with how this could be
4 arranged in the landscape in order to make these forests accessible to many
5 potential visitors. The present study sought to establish relationships between
6 the spatial pattern of forest cover and these forests' accessibility - either on
7 foot or by bike - for short walks. This question was approached in an experi-
8 mental way using landscape structure metrics.

9 A factor analysis identified the common axes of spatial pattern. The first five
10 factors explained 82.2 % of the variation of the original data set. The first
11 factor is related to forested area and number of forest patches, the second is
12 related to shape complexity. The third factor quantifies contiguity, and the
13 fourth measures the clumpiness of forests. The fifth refers to variability in

1 forest shape. Only the factors related to forested area - shape complexity
2 and clumpiness - show a significant correlation with recreational provision. A
3 higher forest coverage and more forests should thus lead to a higher provision
4 for short walking trips. However, when a small afforestation budget is available,
5 high shape complexity, low forest contiguity and a high landscape shape index
6 (LSI) should take priority. Shape indices make the most important contribution
7 to single out patterns that offer recreation possibilities to a high number of
8 people. The findings show the potential of using landscape structure metrics
9 for modelling of forest recreational provision.

10 **2 Keywords**

11 landscape configuration, recreational provision, regional scale, landscape met-
12 rics

13 **3 Introduction**

14 Over the 20th century, large parts of the world have become strongly urbanized
15 and forests are increasingly recognized as vital elements for keeping urban
16 dwellers in touch with nature (Konijnendijk et al., 2005). In various countries
17 across Europe (e.g. United Kingdom, Denmark, the Netherlands, Belgium),
18 this has prompted decision makers to adopt ambitious policies for increasing

1 the forest cover (Van Herzele et al., 2005).

2 Remarkably, these afforestation strategies - especially apparent in heavily ur-
3 banized regions of Western Europe - have shown to be particularly effective at
4 the national and regional scale (Van Herzele et al., 2005; Van Herzele, 2006).
5 To make valid projections of the outcome of such afforestation policies, their
6 effects on outdoor recreational provision should be evaluated. For this, the
7 wider scale - covering an area of several square kilometers - is being consid-
8 ered as the most appropriate (Zhang, 2004; Konijnendijk, 2004; Konijnendijk
9 and Randrup, 2004). Scaling up from a locus-based to a broader landscape
10 scale - which is further referred to as the regional scale - is likely to facilitate
11 the formulation of alternatives for recreation planning.

12 One of the few cases in which the effect of afforestation on recreational pro-
13 vision has been assessed on a regional scale is that of possible forest locations
14 near Antwerp, Belgium (Van Herzele et al., 2005). In this study, a GIS-based
15 working method was applied to evaluate seven alternative locations for the
16 creation of a new forest. Accessibility, defined as the number of people living
17 near enough to visit this future forest on a regular basis, was calculated using a
18 hierarchical system of standards, which links distance from the home to forest
19 size (Van Herzele and Wiedemann, 2003). The study used a fixed afforesta-
20 tion 'budget' of 300 ha, to be realized in one single forest unit. However, even
21 the best location could supply the demand for forest recreation only partially.
22 This observation prompted a need for further research to verify whether a well

1 considered spatial arrangement dividing the afforestation 'budget' in terms of
2 hectares over smaller units would benefit more urban dwellers. If so, a more
3 efficient solution could be obtained by creating spatial patterns that provide
4 a high number of people with short walking trips in relation to the land area
5 that is set aside for forest. The ability to quantify this pattern is a prerequisite
6 to monitor the recreational provision on a regional scale and offer alternative
7 scenarios for spatial planning.

8 In this paper, we aim to make a first step to establish relationships between
9 accessibility and measures of spatial pattern on a regional scale. Flanders
10 (northern autonomous part of Belgium - $13,522km^2$) is selected as study area,
11 as it features a very high degree of urbanization. According to UN (2004), 98
12 % of the flemish population is living in urban areas. This situation is combined
13 with a relatively low forest cover (about 11 %). Before elaborating on the case
14 study, we clarify the main concepts used, and their integration within the
15 study approach.

16 *3.1 Recreational provision assessed by accessibility*

17 Accessibility refers to the ability of using transportation facilities to reach
18 desired locations at suitable times (Geertman and Van Eck, 1995). Most mea-
19 sures of accessibility incorporate the distance between a person and his or her
20 destination, as well as the utility of this location. Some of the best known

1 measures are based on the 'potential model' (Geertman and Van Eck, 1995;
2 Horner, 2004; Liu and Zhu, 2004; Stanilov, 2003; Talen and Anselin, 1998;
3 Zhang, 2004). The concept of potential is closely related to gravity, where
4 the attraction of object a on object b is directly related with the mass of
5 object a and inversely related with the distance between these two objects.
6 Several software packages have implemented this concept, such as FlowMap
7 (<http://flowmap.geog.uu.nl>), LADSS, and LocNet (Kammeier, 1999).

8 The potential model can be applied to recreation forests and calibrated using
9 data on average travel distance derived from socioeconomic research. Numer-
10 ous recreation studies in Flanders and elsewhere have concluded that travel
11 distance from home is the single most determinant factor for the use of a
12 recreational space (for an overview, see Van Herzele and Wiedemann (2003);
13 Grahn and Stigsdotter (2003) or Roovers et al. (2002)). In addition, the max-
14 imum distance people are willing to travel differs according to the attributes
15 of the recreational space. In this respect, the size of the forest is a determinant
16 factor for recreational use in terms of frequency, duration, and travel distance
17 (Van Herzele et al., 2005).

18 3.2 *Relating spatial pattern of forest cover to accessibility*

19 Landscape monitoring, focussing on spatial pattern, also defined as landscape
20 structure, rapidly evolved during the last decades, combining remote sensing

1 and geographic information systems (GIS) (Forman and Godron, 1986; Turner
2 and Gardner, 1991; Farina, 2000; Luck and Wu, 2002; Turner et al., 2003).
3 Statistical measures to quantify composition and configuration of a landscape
4 are called landscape metrics or pattern indices (McGarigal and Marks, 1994).
5 In the field of landscape ecology, a comprehensive set of landscape indices has
6 been developed (Hulshoff, 1995; Riitters et al., 1995). These are considered as
7 useful tools to monitor the natural environment (Forman and Godron, 1986;
8 O'Neill et al., 1988; Baskent and Jordan, 1995; Trani and Giles, 1999; Farina,
9 2000; Imbernon and Branthomme, 2001). Metrics of landscape composition are
10 not spatially explicit. They measure what is present and their relative areal
11 proportions, without reference to its location in the landscape. Configuration
12 refers to the relative spatial arrangement of forests in the landscape (Turner
13 et al., 2001).

14 **4 Research questions**

15 The objective of this paper is to explore the relationship between the spatial
16 structure of a forested landscape, as assessed by pattern metrics, and the num-
17 ber of people that could use these forests for short walking trips, as determined
18 by accessibility. The following questions are answered:

- 19 (1) Which measures of spatial pattern are correlated with forest accessibility
20 on a regional scale?

- 1 (2) Which of these metrics are independent of the amount of forest ?
- 2 (3) Which pattern metrics can single out forest patterns that contribute to
- 3 efficient land use, by providing the maximum number of people with forest
- 4 recreation, combined with the minimum land area set aside for forest ?
- 5 This paper seeks to determine which metrics, if any, are most appropriate in
- 6 models assessing the provision of forest recreation on a regional scale.

7 **5 Material and Methods**

8 *5.1 Study Area*

9 The study area of Flanders (see figure 1) comprises $13,522 km^2$ and features

10 a modest forest cover (146,000 ha or ca. 11% forest cover) (Leyman and

11 Vandekerckhove, 2003). High land pressure is caused, amongst others, by high

12 population density, amounting to 443 inhabitants per km^2 (NIS, 2004).

13 [insert figure 1 here]

14 *5.2 Data and Software*

15 Artificial maps with random spatial patterns can be generated by random

16 processes (Turner et al., 2001). However, this technique is cumbersome, while

17 the existing spatial pattern of forest cover is readily available in digital format

1 and performs better in capturing all pattern characteristics of actual landscape
2 patterns (Gustafson and Parker, 1992; Baldwin et al., 2004; Li and Wu, 2004).

3 To obtain a spectrum of spatial patterns, the forest map of Flanders (with a
4 spatial accuracy of 10 m (OC GIS-Vlaanderen, 2001a) was subdivided into 135
5 coverages corresponding to the geographic extent of equally sized hexagons,
6 as shown in figure 2. These hexagonal coverages were the basis for all pattern
7 metric calculations and were chosen as calculating units because of their reg-
8 ular and compact shape. These coverages were considered as just one possible
9 sample of future and past landscape patterns in Flanders.

10 Spatial population data was available per neighborhood, defined by the digital
11 administrative boundaries of *statistical sectors* and was acquired from the
12 National Statistics Institute (NIS, 2001). Flanders counts 10,826 statistical
13 sectors. These are the size of a small number of building blocks and represent
14 a more or less homogeneous quarter in social respect (Pelfrene et al., 1998).

15 [insert figure 2 here]

16 Pattern metrics on a regional scale were determined for each hexagon, using
17 ESRI's ArcView 3.1 and Fragstats 3.3 (McGarigal and Marks, 1994).

1 5.3 *Description of the GIS-based accessibility model*

2 To assess the accessibility of forested landscapes, the greenspace monitor-
3 ing tool was applied (Van Herzele and Wiedemann, 2003; Van Herzele et al.,
4 2005) and programmed in ArcView 3.1 using AVENUE. It is a straightfor-
5 ward method that determines the recreational provision in a region, using the
6 attractiveness of each greenspace, based on its size and specific attributes for
7 recreation. In this study, the tool was used in a simplified way, because extra
8 information concerning amenity was not available. We preferred this model
9 to other models, since it has been especially developed for the evaluation of
10 outdoor recreational provision.

11 The greenspace monitoring tool is based on the concept of accessibility as
12 developed by Geertman and Van Eck (1995). Attraction of each forest site is
13 linked to its area and expressed as a maximum distance people are willing to
14 travel for a visit to this forest. This maximum distance delimits an attraction
15 zone, henceforth referred to as catchment. The recreational value of the forest
16 was expressed as the number of people living in the catchment. This relation-
17 ship (see Table 1) was based on the standards proposed by the Flemish forest
18 administration (Van Herzele et al., 2000). Mobility research in the Netherlands
19 has indicated that trips for leisure often cover short distances, and walking
20 and cycling are dominant modes of transport (Dieleman et al., 2002). To none
21 of the forests a distance larger than 5 km was allocated, which is considered

1 the maximum distance that will be covered on foot or by bike (Van Herzele
2 et al., 2000; Dieleman et al., 2002).

3 [Insert Table 1 here]

4 For each forest fragment the attraction distance was calculated and the asso-
5 ciated catchment area was delineated. Per hexagon the area proportion within
6 a catchment was calculated. Each sector was consecutively clipped using the
7 catchment lines. The population of partial sectors was calculated using the
8 area proportion of the original statistical sector surface. The sum of all per-
9 sons having access to forest recreation was expressed as a percentage of the
10 population living within the hexagonal sample unit.

11 5.4 Description of the spatial pattern

12 To quantify the spatial pattern, 19 commonly used pattern indices were calcu-
13 lated (see Table 2). Landscape *composition* is described by the total forested
14 area (TA) and the number of forest patches (NP) . Spatial *configuration* col-
15 lects different groups of metrics, referred to as *contagion*, *patch-based metrics*,
16 *connectivity* and *proximity*. The first, *contagion* of forest patches, is assessed
17 by the following metrics: PLADJ, DIVISION, MESH, SPLIT, AI.

18 [insert Table 2 here]

19 *Patch-based metrics* comprise a second group. Once area and perimeter of

1 each forest are determined, these can be summarized (as in LSI) or frequency
2 distributions can be drafted. *Shape complexity* is quantified through PARA,
3 SHAPE, FRAC, CONTIG and GYRATE. Per sample unit the mean (.MN) and
4 median value (.MD), as well as the standard deviation (.SD) and the coefficient
5 of variation (.CV) were recorded. *Connectivity* is assessed by LPI, CONNECT
6 and COHESION. Finally *proximity* - the degree to which patches are isolated -
7 is quantified using PROX and ENN.

8 Full description and calculation of these indices are provided by McGarigal
9 and Marks (1994) and Turner et al. (2001).

10 5.5 *Relating spatial pattern of forest cover to accessibility*

11 5.5.1 *Correlation between accessibility and pattern metrics*

12 Using Spearman correlation analysis the correlation between accessibility and
13 each of the pattern metrics was tested for significance.

14 5.5.2 *Assessing independent groups of pattern metrics*

15 Using principle component analysis (PCA), the pattern metrics were grouped
16 into a small number of independent components. In order to facilitate the
17 interpretation of the components, a Varimax rotation was applied. For a de-
18 tailed description of this technique, we refer to Riitters et al. (1995). The PCA
19 scores of all hexagons were then tested for correlation with the recreation ac-

1 cessibility data from the GIS model, using a simple linear least square model
2 and Spearman rank correlation coefficient. This procedure was also adopted
3 by Honnay et al. (2003) to investigate the biological meaning of landscape
4 structure metrics, and determine which indices should be used in ecological
5 monitoring.

6 5.5.3 *Efficiency in recreational provision*

7 Discriminant analysis tests whether a set of variables (pattern metrics) is
8 able to correctly classify the hexagons into groups. The discriminating power
9 of the respective variables is relative to the coefficients of these variables in
10 the discriminant function (Mather, 1976; Buys, 2003). This technique was
11 applied to determine which metrics indicate differences between groups. It
12 requires a division of the hexagons into groups, according to their effectiveness
13 in providing access to recreation.

14 To obtain these groups, the landscapes, representing the hexagons and their
15 spatial forest patterns, were ranked according to the criteria of optimization,
16 which are to maximize accessibility (Objective 2) with a minimum forest area
17 (Objective 1). According to pareto-logic, landscape x is dominated by (or
18 worse than) landscape y if landscape y scores better on both objectives. For
19 this, landscape y should have a higher accessibility, whilst containing a lower
20 - or equal - forest cover. In figure 3, a hypothetical example is given. Objective
21 2, accessibility, should be maximized and objective 1, forest cover, should

1 be minimized. Landscape b is dominated by landscape c , since landscape c
2 has both a higher accessibility and a lower forest cover. Landscape a scores
3 better on the first objective than landscape b , but scores worse on the second
4 objective. Landscapes a and b are considered not comparable, since neither
5 one dominates the other.

6 [Insert fig 3 here]

7 Dominated landscapes score worse on one of the two objectives, when com-
8 pared with at least one other landscape, while doing similar or worse for the
9 other objective. Non-dominated sample units form the so-called *pareto-front*
10 and represent land use configurations that cannot be improved for both ob-
11 jectives simultaneously. The forest patterns of these landscapes are given rank
12 "1". Rank "2" was assigned to hexagons that were dominated by only one
13 other landscape and rank "3" was given to all other sample units. The closer
14 a landscape is situated to the pareto-front, the more efficient the spatial forest
15 pattern is with respect to accessibility to recreation. These groups were used
16 to detect differences in landscape configuration, regardless of the percentage
17 of forest cover.

1 6 Results

2 6.1 *Correlation between pattern metrics and accessibility*

3 In Table 3, Spearman correlations between accessibility and pattern metrics
4 are listed. Not surprisingly, accessibility is highly correlated with forest com-
5 position, described by TA ($r = 0.91$) and NP ($r = 0.75$). Contagion and connec-
6 tivity have an intermediate influence on accessibility; the highest correlation
7 in this group is with MESH ($r = 0.66$). Regarding distribution of forest size,
8 it is the variation ($r = 0.65$ for AREA.CV and $r = 0.64$ for AREA.SD), which
9 is correlated. In the group describing the distribution of forest shape, several
10 metrics have a significant correlation with accessibility, although none of these
11 is high. The summarizing LSI is nonetheless rather well correlated ($r = 0.72$).
12 Finally, forest isolation, quantified by ENN.MN and ENN.SD, is negatively cor-
13 related with accessibility ($r = -0.79$ for ENN.MN; $r = -0.81$ for ENN.SD).

14 [Insert Table 3 here]

15 6.2 *Distinguishing configuration from composition*

16 Principal component analysis shows that the first 5 components explain 82, 2%
17 of the original data set. In Table 4, the factor loadings are listed, expressing the
18 correlation between a factor and the original variables after Varimax rotation.

- 1 Each variable is assigned to the factor for which the correlation is highest.
- 2 The pattern metrics are ranked according to decreasing correlation.

3 Clearly, the factors in landscape pattern in Flanders do not completely coincide
4 with the pattern aspects as defined by Turner et al. (2001). The first factor is
5 highly correlated with AREA.SD, PROX.SD, GYRATE.CV, MESH, PROX.MN,
6 AREA.CV, GYRATE.SD, TA, COHESION, AREA.MN, PLADJ, AI, PROX.MD and
7 SHAPE.CV. These variables are strongly determined by the total area of forest
8 cover.

9 [Insert Table 4 here]

10 Variables associated with the second factor are: SHAPE.MN, FRAC.MN, SHAPE-
11 .MD, GYRATE.MD, FRAC.MD, GYRATE.MN, AREA.MD, SHAPE.SD, FRAC.SD
12 AND ENN.CV. These are all indices that describe patch shape. As the values
13 of these indices increase, the patches become more irregular in shape.

14 The third factor can be interpreted as a supplementary factor connected with
15 forest shape, since it is correlated with CONTIG.MN, PARA.MN, CONTIG.MD,
16 PARA.MD, AI and FRAC.CV . The factor has its highest, albeit negative, cor-
17 relation (- 0.81) with CONTIG.MN. This pattern index assesses the spatial
18 connectedness of a patch, which is related to both patch size and patch shape.

19 The fourth factor can be interpreted as a component measuring the clumpiness
20 of the landscape. Variables correlated with this factor are: LSI, DIVISION, LPI,

1 NP, SPLIT, ENN.SD, ENN.MN, CONNECT, ENN.MD and PROX.CV. The number
2 of patches, their size and geographical distribution have an important influence
3 on these indices. Many indices using the distances between two neighboring
4 forest patches are linked to this factor.

5 Since the fifth factor contains solely standard deviations and coefficients of
6 variation of shape indices, it is interpreted as a factor describing variability
7 of shape complexity. Correlated indices are: CONTIG.SD, PARA.CV, PARA.SD
8 and CONTIG.CV.

9 Table 5 shows the Spearman correlations between the forest accessibility and
10 the pattern indices that are selected for their high correlation with the respec-
11 tive factors. The aspects of landscape configuration which are important for
12 accessibility, are described by AREA.SD (0.64), SHAPE.MN (0.29), CONTIG.MN
13 (0.03), LSI (0.72) and CONTIG.SD (0.16). Correlation with the first factor is
14 meaningful, as was expected. From the other factors, only the fourth one (LSI)
15 yields a correlation coefficient that can be considered important.

16 6.3 *Efficiency in recreational provision*

17 For the discriminant analysis, we use the three groups as obtained from pareto-
18 ranking. Group 1 contains non-dominated landscapes; the hexagons in group
19 2 are dominated by only 1 other landscape, and all other landscapes are in
20 group 3.

1 During a discriminant analysis, a multiple ANOVA is performed, testing for
2 the equality of means of the indicated groups. The value of Wilks Lambda
3 0.1750 ($p=0.00$) indicates that the groups are separable on the basis of the
4 values of the pattern indices. The pairwise comparison in Table 6 shows sig-
5 nificant differences in the multivariate means of all three groups.

6 [Insert Table 6]

7 A univariate ANOVA is performed. Significant univariate differences are record-
8 ed between group 1 and 3 for the following variables: GYRATE.MD, ENN.MN
9 and ENN.MD. Groups 2 and 3 are significantly different regarding FRAC.SD and
10 FRAC.CV. None of the univariate means were statistically different for groups
11 1 and 2. None of the variables, associated with the factors of forest pattern, as
12 determined in section 6.2, are significantly different for the three groups. Only
13 a few pattern indices feature a significant difference for the specified groups.
14 Hence, the results are not shown here.

15 Two discriminant functions are drawn. The canonical coefficients of these dis-
16 criminant functions can be found in Table 7. These are sorted according to
17 decreasing coefficients. For the first discrimination function, FRAC.MN, CON-
18 TIG.SD, FRAC.SD and CONTIG.MN have high coefficients. The coefficients for
19 the other pattern metrics quickly drop to zero. In the second discriminant
20 function, FRAC.SD and CONTIG.SD obtain rather high coefficient values as well.
21 CONTIG.SD and CONTIG.MN also describe main aspects of landscape pattern

1 (cfr. section 6.2) and are not directly correlated with forest accessibility. As is
2 apparent from Table 4, `FRAC.MN` is correlated (0.89) with the second factor of
3 forest pattern, and can be regarded as more or less equivalent to `SHAPE.MN`.
4 `FRAC.SD` is not very well correlated with the factors of landscape pattern (0.60
5 for the second factor).

6 When performing a cross-validation through iteration, each observation is
7 systematically dropped, the discriminant function is re-estimated, and the
8 excluded observation is classified. This leave-one-out technique reports a clas-
9 sification error of 14.93 %. Keeping in mind that the results are only used for
10 the detection of differences between groups and not for absolute prediction of
11 which group a landscape will belong to, this error is considered acceptable.

12 **7 Discussion and Conclusions**

13 Urban planning for optimal provision of recreational forests is not only con-
14 cerned with how much space is needed, but equally with how this could be
15 spatially arranged in the landscape in order to make these forests accessible to
16 many potential visitors. In this context, the present study sought to establish
17 significant relationships between the spatial pattern of forest cover and forest
18 accessibility for short walks.

19 The main originality of the study resides in the use of landscape structure
20 metrics in the context of recreation planning. Existing research into spatial

1 structure predominantly focuses on the use of pattern metrics for ecological
2 monitoring (e.g. Honnay et al. (2003)). More specifically, the goal of this paper
3 was to determine the utility of a given set of pattern metrics in planning for
4 the creation of new forests.

5 Given the experimental nature of the study, the results are valuable as prac-
6 tical knowledge for the construction of models for recreation assessment. The
7 results show that accessibility for short walks is related to the spatial pattern
8 of forest cover. First and foremost, forested area and the number of forests
9 have an effect on the provision of forests for short walks. The correlation is
10 respectively 0.91 and 0.75. Metrics describing forest connectivity and forest
11 shape have a lower influence on accessibility and a negative correlation is found
12 between accessibility and forest isolation. These correlations between accessi-
13 bility and pattern metrics indicate that nearly all aspects of spatial pattern
14 have an influence on the recreational provision under investigation. Moreover,
15 high correlation amongst pattern metrics suggest that when metrics are se-
16 lected only on the criterion of high correlation with accessibility, the selected
17 subset would provide redundant information.

18 Factor analysis, commonly performed for the selection of a subset of pattern
19 metrics, yields five factors of spatial pattern. The first factor is related to
20 forested area; the second factor indicates shape complexity of forest patches.
21 The third factor quantifies contiguity. The fourth factor measures the clumpi-
22 ness of forests. The fifth factor contains metrics referring to variability in

1 forest shape. Only the first, the second and the fourth factor have a signifi-
2 cant correlation with recreational provision. The correlation coefficient with
3 the second factor is low but still significant. Contagion, expressed by MESH,
4 seems to be a useful pattern metric based on its correlation with accessibility.
5 Factor analysis, however, indicates that this metric describes the same compo-
6 nent of spatial pattern as expressed by forested area or patch size distribution.
7 Similarly, an increasing number of forest patches entails a decreasing forest
8 isolation. Only forest contiguity, making up 2 of the 5 factors of the spatial
9 pattern, is not significantly correlated with recreational provision.

10 This leads to the logical conclusion that a higher forest coverage and more
11 forests will indeed increase recreational provision. However, when a small af-
12 forestation budget is available, high shape complexity, low forest contiguity
13 and a high landscape shape index (LSI) warrant special attention.

14 To corroborate these conclusions, the forest patterns available were divided
15 into groups. To ensure that the groups were not dependent on the quantity of
16 forested area, pareto logic was used. Univariate ANOVA showed that metrics
17 having different means for the defined groups are variables related to for-
18 est shape (GYRATE.MN, FRAC.SD and FRAC.CV) and isolation (ENN.MN and
19 ENN.MD). These variables show a significant Pearson correlation with accessi-
20 bility. They are allotted to the first, second and fourth factor in the PCA, but
21 do not show a very high correlation with their respective factor.

1 Consequently, a discriminant analysis was performed on these groups. The
2 results show that the pattern metrics are able to classify the forest configu-
3 rations into the given groups with an accuracy of 85.07 %, based on shape
4 indices alone (FRAC.MN, FRAC.SD, CONTIG.MN and CONTIG.SD). These vari-
5 ables are not correlated with accessibility, but show high correlations with the
6 factors two, three and five. Despite the small divergence in outcome between
7 the factor analysis and discriminant analysis, this analysis confirms the impor-
8 tance of shape and contiguity when a higher recreational provision is sought
9 without a substantial enlargement of the forested area.

10 The findings of this study confirm that possibilities exist for the use of pattern
11 metrics in the modelling of forest recreation. At the same time it indicates is-
12 sues for further investigation. First and foremost, the relationships between
13 spatial pattern and recreational provision should be verified in other geograph-
14 ical regions. Secondly, it should be tested whether these relations equally apply
15 to longer forest recreation (e.g. hiking, ..), where accessibility by car is more
16 important.

17 Finally, models for recreational provision, based on pattern metrics, should
18 be developed. The following variables are assumed to yield good results for
19 short forest recreation : forested area, number of forest features, shape metrics
20 such as fractal dimension (FRAC) or contiguity (CONTIG) and nearest neighbor
21 distances (ENN). Since the relationships between pattern metrics and species
22 richness have been studied intensively, other objectives - such as maximizing

1 biodiversity - and ancillary data - such as road networks - can be included in
2 the model.

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1 9 Tables

Table 1

Relation between the minimum area of forest and the maximum distance that will be covered for a recreation experience (after Van Herzele et al., 2000)

Maximum distance (m)	Minimal area (ha)
150	—
400	1
800	10
1600	30
3200	60
5000	200

Table 2
Acronyms of the pattern metrics

Abbreviation	Full name (units)
.MN	mean value of the preceding pattern index
.MD	median value of the preceding pattern index
.SD	standard deviation of the preceding pattern index
.CV	coefficient of variation of the preceding pattern index
TA	Total Area (ha)
NP	Number of Patches (-)
PLADJ	Percentage of Like Adjacencies (%)
DIVISION	Landscape Division Index (Proportion)
MESH	Effective Mesh Size (ha)
SPLIT	Splitting Index (-)
AI	Aggregation Index (%)
LSI	Landscape Shape Index (-)
AREA	Area (ha)
PARA	Perimeter-Area Ratio (-)
SHAPE	Shape Index (-)
FRAC	Fractal Dimension Index (-)
CONTIG	Contiguity Index (-)
GYRATE	Radius of Gyration (m)
LPI	Largest Patch Index (%)
CONNECT	Connectance Index (%)
COHESION	Patch Cohesion Index (-)
PROX	Proximity Index (-)
ENN	Euclidean Nearest-Neighbor Distance (m)

Table 3

Spearman correlations between accessibility and the pattern metrics

* $0.01 < P \leq 0.05$; ** $P \leq 0.01$

Aspect	Metric	r	
composition	TA	0.91	**
composition	NP	0.75	**
contagion	DIVISION	0.17	
contagion	MESH	0.66	**
contagion	SPLIT	0.17	
contagion	AI	0.43	**
contagion	PLADJ	0.51	**
connectivity	LPI	-0.15	
connectivity	CONNECT	-0.45	**
connectivity	COHESION	0.47	**
patch size distribution	AREA.MN	0.54	**
patch size distribution	AREA.MD	0.10	
patch size distribution	AREA.SD	0.64	**
patch size distribution	AREA.CV	0.65	**
patch based configuration	LSI	0.72	**
patch shape	SHAPE.MN	0.29	**
patch shape	SHAPE.MD	0.08	
patch shape	SHAPE.SD	0.37	**
patch shape	SHAPE.CV	0.38	**
patch shape	FRAC.MN	0.14	
patch shape	FRAC.MD	0.19	
patch shape	FRAC.SD	0.20	
patch shape	FRAC.CV	0.21	*
patch shape	PARA.MN	-0.04	
patch shape	PARA.MD	-0.06	
patch shape	PARA.SD	0.16	
patch shape	PARA.CV	0.21	*
patch shape	CONTIG.MN	0.03	
patch shape	CONTIG.MD	0.18	
patch shape	CONTIG.SD	0.16	
patch shape	CONTIG.CV	0.15	
patch shape	GYRATE.MN	0.32	**
patch shape	GYRATE.MD	0.11	
patch shape	GYRATE.SD	0.48	**
patch shape	GYRATE.CV	0.52	**
patch isolation	PROX.MN	0.67	**
patch isolation	PROX.MD	0.80	**
patch isolation	PROX.SD	0.66	**
patch isolation	PROX.CV	0.01	
patch isolation	ENN.MN	-0.79	**
patch isolation	ENN.MD	-0.63	**
patch isolation	ENN.SD	-0.81	**
patch isolation	ENN.CV	-0.33	**

Table 4

Factor loadings for the factors after VARIMAX rotation

The first 5 factors explain 82% of the variance of the original data set

Factor	Pattern metrics	r
1	AREA.SD	0.94
1	PROX.SD	0.90
1	GYRATE.CV	0.90
1	MESH	0.90
1	PROX.MN	0.87
1	AREA.CV	0.87
1	GYRATE.SD	0.86
1	TA	0.83
1	COHESION	0.76
1	AREA.MN	0.74
1	PLADJ	0.68
1	PROX.MN	0.62
1	SHAPE.CV	0.57
2	SHAPE.MN	0.93
2	FRAC.MN	0.89
2	SHAPE.MD	0.88
2	GYRATE.MD	0.82
2	FRAC.MD	0.80
2	GYRATE.MN	0.78
2	AREA.MD	0.65
2	SHAPE.SD	0.61
2	FRAC.SD	0.60
2	ENN.CV	0.31
3	CONTIG.MN	-0.81
3	PARA.MN	0.78
3	CONTIG.MD	-0.74
3	PARA.MD	0.73
3	AI	-0.67
3	FRAC.CV	0.59
4	LSI	0.91
4	DIVISION	0.84
4	LPI	-0.82
4	NP	0.81
4	SPLIT	0.66
4	ENN.SD	-0.65
4	ENN.MN	-0.60
4	CONNECT	-0.56
4	ENN.MD	-0.37
4	PROX.CV	0.29
5	CONTIG.SD	0.95
5	PARA.CV	0.95
5	PARA.SD	0.95
5	CONTIG.CV	0.93

Table 5

Spearman correlation coefficients between the selected variable representing a factor and forest accessibility

Factor	Variable	r
F1	AREA.SD	0.64 **
F2	SHAPE.MN	0.29 **
F3	CONTIG.MN	0.03
F4	LSI	0.72 **
F5	CONTIG.SD	0.16

Table 6
Multiple ANOVA for the three groups

	F	df1	df2	p
Wilks lambda				
0.175	2.721	88	176	0.00 *
Hotelling's T pairwise comparison				
1-2	3.142	44	88	0.00 *
1-3	2.612	44	88	0.00 *
2-3	2.926	44	88	0.00 *

Table 7

Canonic coefficients for the two discriminant functions

Pattern metric	First discriminant function	Second discriminant function
FRAC.SD	326.07	-2171.81
CONTIG.SD	369.88	1154.52
FRAC.MN	-592.17	-103.27
CONTIG.MN	300.09	-223.58
FRAC.MD	90.36	-67.19
SHAPE.MN	45.86	27.37
SHAPE.SD	-38.76	5.22
FRAC.CV	-2.70	22.59
CONTIG.MD	-17.19	2.98
PLADJ	-5.83	8.99
AI	3.45	-9.86
CONTIG.CV	-1.92	-9.06
SHAPE.MD	-4.54	5.39
DIVISION	-2.01	0.90
COHESION	1.65	-0.05
AREA.MD	0.75	0.94
PARA.CV	-0.39	-0.45
SHAPE.CV	0.42	-0.25
CONNECT	-0.17	0.17
PD	-0.21	-0.05
LSI	-0.10	-0.12
AREA.SD	0.16	0.05
AREA.MN	-0.15	0.04
GYRATE.MN	0.08	-0.05
PARA.MN	0.08	-0.05
GYRATE.MD	-0.08	0.01
PARA.SD	0.02	0.06
GYRATE.SD	-0.02	-0.03
GYRATE.CV	0.00	0.05
LPI	0.00	0.04
SPLIT	-0.01	-0.03
AREA.CV	-0.01	-0.01
ENN.CV	0.02	0.00
ENN.MD	-0.01	0.01
ENN.SD	0.00	0.01
NP	0.00	0.01
MESH	0.00	-0.01
PROX.MD	0.00	-0.01
PARA.MD	0.00	0.00
ENN.MN	0.00	0.00
PROX.CV	0.00	0.00
PROX.MN	0.00	0.00
PROX.SD	0.00	0.00
TA	0.00	0.00

10 Figure captions

Figure 1 : Location of the study area in Belgium

Figure 2 : The Flanders region of Belgium overlayed with the hexagons used as sample units

The grey shades are forests.

Figure 3: Illustration of the pareto-rank logic

Landscape b is dominated by landscape c , since landscape c has both a lower value for objective one (that should be minimized) and a higher value for objective two (that should be maximized).

Landscape a scores better on the first objective than landscape b , but scores worse on the second objective. Landscapes a and b are considered not comparable, since neither one dominates the other.

11 Figures

Fig. 1.

Fig. 2.

Fig. 3.