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A metrics-based approach for modeling covariation of visual and ecological landscape qualities

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ABSTRACT

Landscape ecological aesthetics is a relevant conceptual framework for studying landscape multi-functionality. While the relationships between aesthetic and ecological landscape qualities have been explored and debated in landscape research they have been addressed very little in spatially explicit approaches, and never in a dynamic way. However, a set of spatial metrics can be used to characterize the visual and ecological dimensions of landscape and changes in them. In this study, we propose a framework for analyzing covariation between visual and ecological landscape qualities based on spatial metrics measured from land-cover changes. We apply this framework to the urban agglomeration of Besançon (France) and its urban-rural fringes, which have been subject to several forms of change such as urbanization and agricultural transformations. Cross-mapping of visual and ecological variations reveals both their possible convergences and divergences in space. The study area is empirically affected by much more marked convergence (16.5%) than divergence (5.3%). This contribution to landscape ecological aesthetics provides insights for integrated landscape management with an alignment of visual and ecological goals for landscape sustainability.

1. Introduction

Reconciling human well-being and biodiversity conservation is a major concern in regional planning and it calls for an integrated and multi-functional approach to landscape. Despite this multi-functionality, the study of landscape has long been subdivided into the separate domains of the natural sciences and the social sciences. Many authors (e.g. Fry, 2001; Opdam et al., 2001) have emphasized the need for researchers to move constantly back and forth between different disciplinary approaches in order to integrate the multi-functional character of landscapes (Tress et al., 2001; Tress and Tress, 2001). Following the development of the now popular concept of ecosystem services, the notion of landscape services (Termorshuizen and Opdam, 2009) emerged as a new means of interpreting the relationships between ecosystems and human well-being with the aim of a sustainable development of landscapes. In addition to its relevance for landscape planning due to its operational dimension, it offered a better spatial understanding of these relationships in human-influenced areas (Bastian et al., 2014). Among the different landscape services, and following the ecosystem services' typology of the Millennium Ecosystem Assessment (MEA, 2003), landscape is at one and the same time a medium in which species' life cycles unfold (support service) and a key element in people's living environments (cultural service).

From a theoretical point of view, the study of landscape services and, more generally of landscape multi-functionality, is part of the framework of landscape ecological aesthetics, defined as a link between the aesthetic appeal and the ecological integrity of the landscape (Thorne and Huang, 1991). Since the evolutionary theories of landscape preferences such as prospect-refuge theory (Appleton, 1975) or biophilia (Wilson, 1984), many works have suggested relationships between ecological quality and human preferences for landscape. This is the case for example of Ingram (1991), finding concordances between species diversity and visual amenities in natural protected areas, and of Gobster (1999) and Sheppard (2001), assuming that landscape of high ecological quality would be more esthetically attractive for people and vice versa. More recently, several empirical studies have identified these concordant relationships for various environments such as brownfields (Lafortezza et al., 2008), private gardens (Lindemann-Matthies and Marty, 2013), wetlands and rivers or riparian zones (Cottet et al., 2013; Junker and Buchecker, 2008; McCormick et al., 2015; Zhao et al., 2017),

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coral reefs (Tribot et al., 2016), or sandy beaches (Felix et al., 2016). However, other researchers (e.g. Nassauer, 1997; Parsons, 1995; Williams & Cary, 2001) suggest that aesthetic and ecological qualities may not be correlated, i.e. what is aesthetically pleasing for people may not reflect the ecological quality of landscapes. Managing landscape so as to achieve these two objectives simultaneously would therefore be difficult (Zhao et al., 2017) or even illusory (Kimmins, 1999). This discrepancy, termed *aesthetic-ecological conflict*, has been widely debated in landscape research (Gobster et al., 2007). An intermediate opinion is that the relationships between aesthetic and ecological qualities depend above all on the ecosystems under study (Daniel, 2001).

The issue of quantifying landscape patterns by means of indicators is important for both landscape aesthetics and landscape ecology because it is a convenient way of comparing these two dimensions (Fry et al., 2009; Tribot et al., 2018). Such indicators were first developed in landscape ecology for identifying the relationship between landscape structures (reflecting both the composition and the configuration of the landscape) and ecological processes (Haines-Young, 2000; Turner, 1989) through a wide range of metrics (McGarigal and Marks, 1995). In this way, metrics quantifying the amount and connectivity of habitat appear relevant for characterizing how landscape constrains or favors the presence and movement of animal species. For example, many studies have shown the relevance of landscape graphs for modeling ecological networks (Bunn et al., 2000; Galpern et al., 2011; Urban and Keitt, 2001), assessing habitat reachability by means of connectivity metrics (Rayfield et al., 2011; Saura and Pascual-Hortal, 2007), and providing decision support in land planning and conservation (Bergès et al., 2020; Foltête et al., 2014).

Landscape indicators are also central to assessing people's aesthetic preferences, converting their visual perception of landscapes into quantifiable criteria (Sang et al., 2008). Metrics derived from *in situ* observations are rich in information but limited to the characterization of a few specific sites (e.g. Otero Pastor et al., 2007; Vouligny et al., 2009). By contrast, visual landscape modeling using GIS tools can reconstruct the landscape potentially visible by observers from digital spatial data (Sahraoui et al., 2018). Such modeling approaches were also developed for explaining landscape preferences from visibility metrics of landscape structures (e.g. Dramstad et al., 2006; Foltête et al., 2020; Joly et al., 2009). As with any spatial modeling approach, a compromise is struck between the model's capacity to estimate a landscape's aesthetic potential over a large area and the amount of information input it requires (Sahraoui et al., 2016b).

Based on these considerations, we note two gaps in the research on landscape ecological aesthetics. First, to the best of our knowledge, there are no studies coupling aesthetic and ecological qualities while taking account of complex indicators, i.e. explicitly integrating the notions of aesthetic preference and ecological processes in the quantification. The rare spatially explicit approaches for comparing aesthetic and ecological dimensions are based only on scores attributed from digital spatial data in an expert appraisal and do not consider how people perceive their visual environment and how several animal species interact with their surroundings in the landscapes studied (Steinitz, 1990; Yang et al., 2014; Zheng et al., 2019). Although Yang et al. (2014) and Zheng et al. (2019) produce integrated maps by overlaying the aesthetic and ecological values and attributing scores ranked by importance levels, they do not investigate concordance and discrepancy between the two landscape dimensions. Secondly, while it is a major challenge to understand the impacts of landscape changes on people's living environment and on the functioning of ecosystems, no research has so far proposed to analyze the coevolution of both these landscape dimensions using a spatially explicit method applied at a landscape scale. A few approaches (e.g. Lafortezza et al., 2008) have taken an interest in the potential aesthetic and ecological impacts of prospective scenarios, but by focusing on particular environments and without a spatially explicit dimension. However, in parallel to the debates on landscape ecological aesthetics it should be noted that frameworks mobilizing human and environmental sciences with GIS have been developed to provide a better understanding of the interactions between social and environmental systems and the impacts of land-cover changes on these systems (Gutman et al., 2004; Rindfuss et al., 2004; Turner et al., 2007).

In view of (1) the contradictory outcomes of studies dealing with relationships between aesthetics and ecological landscape qualities and (2) the current lack of knowledge about the way these qualities vary together in space, this study aims to explore how they covary with changes in landscape structures by cross-mapping them. We hypothesize that for changes in landscape structures their covariation may differ in space. From the framework proposed by Fry et al. (2009) about the conceptual field between visual and ecological dimensions of landscapes (Fig. 1a), we propose a dynamic approach integrating changes in landscape structures as a way of spatializing their covariation (Fig. 1b). As those authors postulate that 'visual and ecological character share dependency on landscape structure', we seek to find out what are the main divergences and convergences between these landscape dimensions, and to locate them.

In this study, landscape structures and changes to them are apprehended from land-cover maps at two dates. This type of approach relies on a quantitative analysis based on the measurement of GIS landscape metrics for each dimension. Landscape ecological quality is evaluated from connectivity metrics based on multi-species ecological network modeling, i.e. for species of different taxa and living in various habitats (forests, aquatic areas, open areas), while landscape visual quality is assessed from visibility metrics coupled with a landscape perception survey. From a diachronic approach, this modeling is used to spatialize losses and gains of both these landscape qualities jointly making it possible to identify areas of divergence and convergence. This

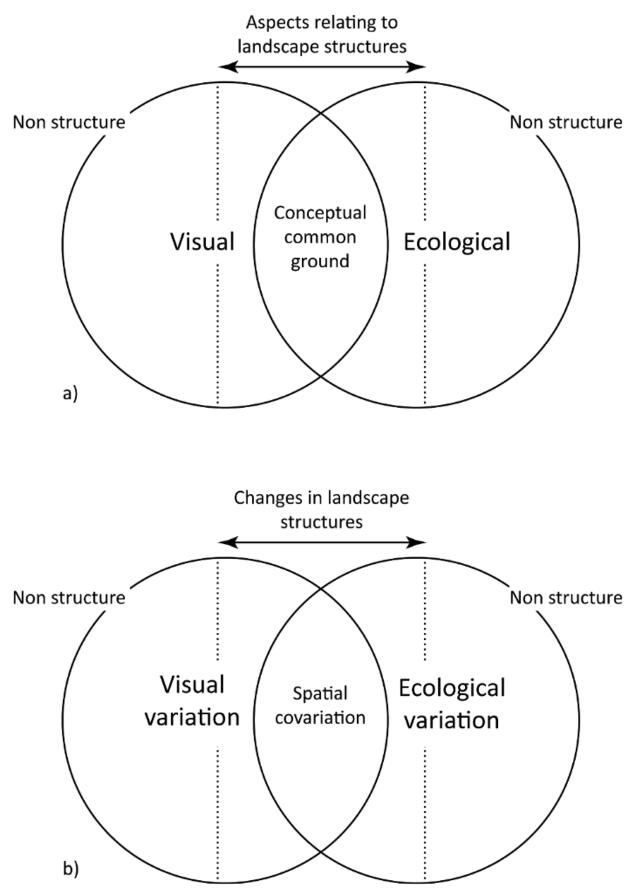

Fig. 1. Conceptual framework of the paper, with (a) the conceptual common ground between visual and ecological landscape characters proposed by Fry et al. (2009) and (b) its adaptation in a dynamic approach.

methodology can be used to consider the remote effects of land-cover changes, i.e. their potential joint effects on large areas. Land-cover changes can influence both landscape connectivity for species and visual landscapes for people over large areas. This methodological framework is applied to the northwestern part of the metropolitan area of Besançon (France) where land-cover changes are considered between 1984 and 2010. The choice of this study area allows us to reexamine the results of the spatial modeling of landscape aesthetic potential reported in Sahraoui et al. (2016).

2. Methods

2.1. Study area

The study area covers 700 km^2 including the medium-sized city of Besançon (about 117,000 inhabitants in 2010) and its northwestern urban fringes (Fig. 2). The landscape is dominated by forest and farmland (about 40% each), and it is crossed by the Ognon valley in the north and the Doubs valley in the south. Artificialized areas are less than 5% of the land cover. Like most European cities in recent decades, Besançon has been caught up in the dynamics of urban sprawl and transformations in agricultural areas. The steep hills and rugged terrain south of the city being unsuitable for urban expansion, urban sprawl has occurred mainly on its north-western fringes. This area is also crossed by several major transport infrastructures, including a motorway and a highspeed railway line.

2.2. Spatial data

Several spatial data were required for computing the landscape metrics. First, a 2010 land-cover map was obtained by combining two vectorial databases. (1) The BD Topo (2010) is provided by the French National Geographical Institute (IGN). It contains buildings, transport infrastructures, artificialized areas, and some natural elements such as forests and aquatic areas. The main transport infrastructures (highways and high-speed railway lines) were distinguished from secondary roads because of their different barrier effects on species movement, and a distinction was also made between residential and industrial buildings because people are likely to appreciate them differently. (2) The BD Agreste (2010) contains agricultural areas, separating grassland and cropland. Areas non-documented by these two data sources were classified as green spaces after a photo-interpretation step. This was particularly the case for land alongside transport infrastructures or in intra-urban areas (parks and gardens). The land-cover map of 1984 was obtained from a retrospective modification of the vectorial map for 2010, based on the photo-interpretation of historical aerial photographs. These vectorial data were combined for each date and then converted into 5 m-resolution raster layers.

Two additional analyses were conducted given the ecological requirements of several species living in forest and grassland. For species living in forests, a morphological spatial pattern analysis (MSPA, Vogt et al., 2007) was applied to the forest category in order to dissociate cores and edges (i.e. forest edges, groves, hedgerows), using a depth of 2 pixels (i.e. 10 m). For species living in grasslands, sunniest grasslands were distinguished from other grasslands by a solar radiation analysis.

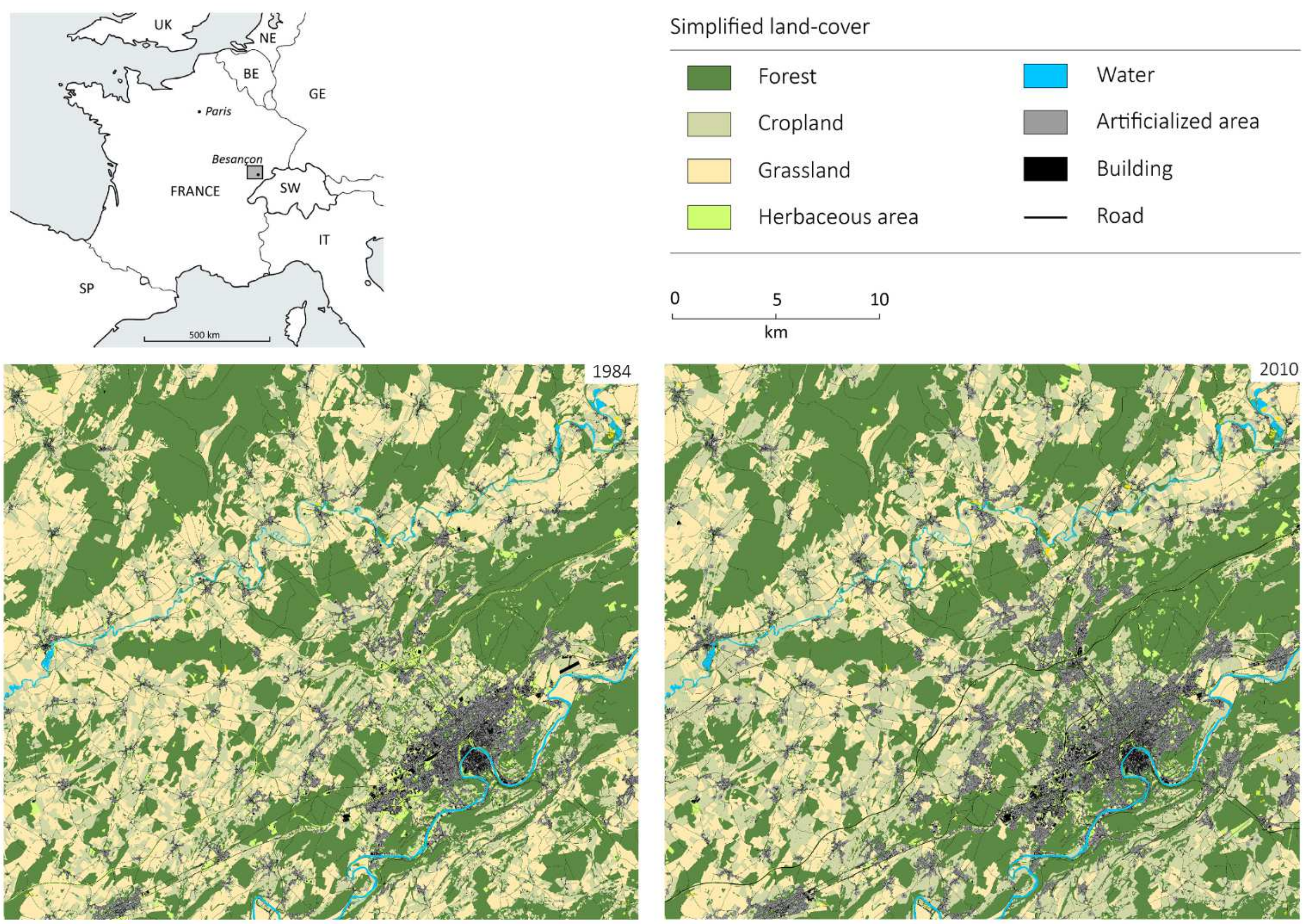

Fig. 2. Location and land-cover in 1984 and 2010 of the study area. Land-cover was simplified from to 8 classes to make the map easier to read.

This analysis was computed with ArcGis 10 from a DEM surface raster provided by the IGN.

We obtained one land-cover map by date, each of them classified into 13 categories (Appendix A). These maps were simplified by aggregating specific categories depending on whether they were used for modeling landscape visibility or landscape connectivity.

Two types of elevation data were implemented for modeling the visible landscape: (1) a 5 m-resolution digital elevation model (DEM) provided by IGN for representing the topographic relief, (2) a digital surface model (DSM) defined at the same resolution to represent the height of the elements that obstruct the view (i.e., buildings and forest elements) for each date. The DSM was constructed by combining the precise height of each building provided by BD Topo and a random height between 15 m and 25 m assigned to the forest pixels, corresponding to the range of heights of tree species in the study area. The height of elements not blocking the view was set to zero.

2.3. Spatial modeling of landscape visual quality (LVQ)

Visual landscape quality was modeled by combining a landscape perception survey with visibility metrics derived from digital data. The survey was conducted by Sahraoui et al. (2016) on the urban-rural fringes of two French urban areas, including the present study area.

2.3.1. Landscape perception survey

Landscape preferences were evaluated from the 1420 responses made to an internet survey in 2014. The survey was based on 60 pairwise comparison of 30 photographs showing landscape diversity through two roads defined as transects along an urban–rural gradient. The viewpoints were spatially sampled along the transects and by a protocol specifically designed for visibility analyses (see below). This protocol ensured an identical horizontal and vertical opening (60°/50°), a constant shot height (1.75 m), with information about geographical coordinates and orientation noted at the same time. Participants were invited to choose their favorite photograph for each pairwise comparison. We then computed a quantitative variable for each photograph as the eigenvector of a matrix comparing n by n photographs, reflecting the respondent's aesthetic judgment. Here, we focused on a subsample of respondents ($n = 727$) defined as a non-specific judgment group in Sahraoui et al. (2016), i.e. heterogeneous in its socio-demographic composition given the descriptive statistics of the respondents as a whole.

2.3.2. Computing landscape visibility metrics

The landscape visibility analysis was based on a tangential analysis, by creating a 2D image of a modeled environment from the spatial data described in Section 2.1 (land cover, DEM, and DSM) for the year 2010. Computations were launched from the geolocated points in the same direction as the photographs, and at a defined height and were limited to the horizontal and vertical angles. This made it possible to precisely quantify the landscape structures corresponding to the view in each photograph. These analyses were carried out using PixScape 1.0 software (Sahraoui et al., 2018)

(see https://sourcesup.renater.fr/www/pixscape/en.html), allowing us to compute several composition and configuration metrics from each picture (Appendix B).

2.3.3. Mapping LVQ

We used the map of the potential LVQ presented in Sahraoui et al. (2016) for the selected subsample of respondents. Quantifying LVQ from visibility metrics implied testing the capacity of the visibility metrics to explain the respondents' landscape preferences. For this we used a multiple linear regression (Appendix C) in which the photographs were the statistical individuals, the mean judgment of respondents for each photograph was the dependent variable, and the visibility metrics were the explanatory variables. For mapping LVQ, the visibility metrics selected by the regression were computed for all of the study area by applying the coefficients to these metrics from each pixel considered as a viewpoint at time t (2010).

2.4. Spatial modeling of multi-species landscape connectivity (MLC)

For modeling MLC, we applied the method based on landscape graphs proposed by Sahraoui et al. (2017) in a similar spatial context in France. It consisted in defining a set of virtual species, modeling their habitat network in 1984 and 2010, computing connectivity metrics for each of them, and mapping the multi-species landscape connectivity by their spatial combination.

2.4.1. Defining ecological requirements for a set of virtual species

The aim of this step was to create virtual species representative of the biodiversity of the area in terms of their different ecological requirements. We first focused on the list of species proposed at a national scale by the French National Museum of Natural History (MNHN, 2011) and defined by the French Ministry of Ecology given the priorities for the conservation of ecological networks. From this initial list, we focused on vertebrates (118 species) whose ecological requirements (habitat and movement capacities) can be modeled from the maps defined at 5-m resolution. Among these only species present in the study area were selected by using the *Sigogne* database (www.sigogne.org) referencing species and habitats to be found in the administrative districts of the Bourgogne-Franche-Comté region. Forty-five species were selected from the initial list: 5 amphibians, 5 reptiles, 4 mammals, and 31 birds.

Information about species' ecological requirements (i.e., habitat, movement characteristics, and dispersal capacities) were extracted from the IUCN Red List and the regional or national atlas of each taxonomic group. Values of resistance to movement were defined on a logarithmic scale: habitat or very suitable areas (1), suitable (10), neutral (100), unfavorable (1000), and barrier (10,000). To capture the movement capacity of each species, we focused on the dispersal process which is a key factor for the spread of gene flow and population viability. Maximum dispersal distances were extracted from the reviews of Smith & Green (2005) for amphibians and Sordello et al. (2013) for reptiles. For mammals and birds, median dispersal distances were computed using allometric relationships linking diet types and species body mass with dispersal capacity. Mammal body mass was extracted from Smith et al. (2003) and bird body mass from Lislevand et al. (2007). Then the equations of allometric relationships given by Sutherland et al. (2010) were used to convert the body mass M (kg) of each species to median dispersal distances (km) for birds (13.1 $M^{0.63}$), herbivorous or omnivorous mammals (1.45 $M^{0.54}$), and for carnivorous mammals (3.45 $M^{0.89}$).

The 45 selected species were arranged into 16 generic groups by their class (amphibian, reptile, mammal, or bird), their main habitat type (forest core, forest edge, open, or aquatic area), and their dispersal capacity classified as low (<4 km) or medium (>4 km). These 16 groups were defined as virtual species representing the 'true' species composing them (Appendix D). For groups containing several 'true' species, values for dispersal capacities were averaged and values for movement costs were aggregated, by taking the most frequent movement cost attributed to each land-cover category.

2.4.2. Computing landscape connectivity metrics

Connectivity metrics were computed from landscape graphs produced with Graphab 2.0 software (Foltête et al., 2012) (see https://sourcesup.renater.fr/graphab/en/home.html).

This modeling approach involves defining the habitat and the capacity of the landscape mosaic to facilitate or impede species movements from land-cover data. A minimal planar landscape graph (Fall et al., 2007) was generated for each virtual species in which the nodes constitute the habitat patches and the links the potential flux between them. The nodes were delineated from the land-cover categories corresponding to the favorable habitats whereas the links were defined as the least-cost paths between habitat patches allowing for the values of resistance to movement. Least-cost distances are the aggregate cost along the least-cost path, converted into a probability of connection between patches i and j using a decreasing exponential function as follows:

$$p_{ij} = e^{-\alpha d_{ij}}$$

where d_{ij} is the least-cost distance between i and j and α corresponds to the intensity of decreasing probability of dispersion p from the exponential function. The value of α was determined as $p_{ij} = 0.05$ when d is a maximum dispersal distance (i.e. for amphibians and reptiles) and as $p_{ij} = 0.5$ when d is a median dispersal distance (i.e. for birds and mammals).

The quantification of landscape connectivity at the local scale was based on the *Interaction Flux* (*IF* metric, Foltête et al., 2014). For a given patch *i*, IF_i is given by:

$$IF_i = \sum_{j=1}^{n} a_i^{\beta} a_j^{\beta} p_{ij}$$

where n is the total number of patches, a_i and a_j are the areas of patches i and j, and p_{ij} the maximum probability of potential paths between i and j.

2.4.3. Mapping MLC

Because each landscape graph involved a specific definition and so a different location of patches and links, the local connectivity values could not be directly combined for mapping multi-species landscape connectivity (MLC). The patch-level connectivity values (*IF)* were thus used to evaluate the potential reachability of the habitat of any point (i.e., pixel) at the scale of the overall network. For this, we shifted from a discrete to a continuous representation of landscape connectivity by spatial generalization of these patch-based values (see Appendix E for details). The 16 single-species connectivity maps were standardized to make them comparable; then they were combined by averaging connectivity values for all points of the study area to obtain MLC.

2.5. Mapping spatial covariation between LVQ and MLC

The same process was applied in 2010 for mapping LVQ_t and MLC_t and in 1984 for mapping VLQ_{t-1} and MLC_{t-1}. These maps were first spatially compared separately for LVQ and MLC at *t-1* and *t* for identifying concordances and discrepancies between both of the landscape qualities in a static dimension. For this, a discretization and cross-classification process was applied for LVQ and MLC at *t-1* and *t* respectively based on the mean $\bar{v}$ and the standard deviation σ of all the values (with $-0.25\ \sigma$ and $+0.25\ \sigma$ as class bounds). LVQ and MLC values were discretized into three classes (low, medium, high) and then intersected to cross-classify into nine categories the modalities of their spatial arrangement.

After normalizing maps of landscape qualities at *t-1* and *t* (see Sahraoui et al., 2017 for details), their local variations ΔLVQ and ΔMLC were retrospectively computed in the overall space as differences in all cell values between t_{-1} and t. The values of covariation were then mapped with a discretization into three classes (increase, decrease, stability) also based on the mean $\bar{v}$ and the standard deviation σ of all the values (with $-0.25\ \sigma$ and $+\ 0.25\ \sigma$ as class bounds). Then the spatial intersection of ΔLVQ and ΔMLC led to a cross-classification into nine categories reflecting the modalities of their spatial covariation (gain, loss, stability).

3. Results

Between 1984 and 2010, only 29% of the study area (i.e., 203 km^2) experienced land-cover changes. A large part of those changes concerned switching between cropland and grassland: 77 km^2 of cropland became grassland against 24 km^2 for the reverse switch. Some 24 km^2 of cropland and grassland became herbaceous areas (considered as abandoned land) while 11 km^2 of such abandoned land were encroached on by forest. In parallel, artificialized areas increased by 19%, mainly in open areas (17 km^2) in urban–rural fringes. The land-cover categories with small spatial footprints (water bodies and linear infrastructures) underwent very few changes in surface area.

The spatial pattern of LVQ in 1984 and 2010 (Fig. 3a) shows a contrast between artificialized areas (the least appreciated landscapes) and aquatic and forested areas (the most appreciated). In the first case, the urban agglomeration of Besançon and mainly its industrial and commercial outskirts present the lowest values, due to their low visual openness and the low visual weight of natural elements. In the second case, the preferences for forests and water areas play an important role. Natural open areas are valued more highly than croplands.

MLC values in 1984 and 2010 (Fig. 3b), i.e. the mean reachability of habitats for the 16 virtual species, show similarly low values in the urban agglomeration and in certain artificialized areas scattered across the study area. The highest values are for the aquatic areas along the Ognon River and the interface areas between forested and natural open areas, mainly in the NW part. Between 1984 and 2010, the main visible differences concern a gain of MLC on the Jura plateau, and a loss of MLC in the urban agglomeration of Besançon, due to the impacts of urban sprawl and the construction of main transportation infrastructures.

The spatial comparison of LVQ and MLC (Fig. 3c) shows that a large part of the study area presents joint medium values, with and augmentation between the two dates (28.5% in 1984 and 40.3% in 2010). Areas of medium *versus* low or high landscape qualities also have a significant proportion, here with a decrease (68.5% cumulatively in 1984 and 55.8% in 2010). Most of these areas correspond to medium LVQ values *versus* low or high MLC values. Areas of low *versus* medium values are mostly located near artificialized areas whereas high *versus* medium values are mostly located in rural areas. Areas of concordances with joint low values (1.1% in 1984 and 2.6% in 2010) mostly concern the surroundings of industrialized areas. Areas of concordances with joint high values are smaller (0.7% for both dates) and concentrated in the Ognon Valley near water courses bodies and courses. Finally, small areas of discrepancies appear on the edge of rural villages (high MLC values *versus* low LVQ values, 1.2% in 1984 and 0.3% in 2010) as well as around the Doubs River (low MLC values *versus* high LVQ values, 0.01% in 1984 and 0.3% in 2010).

The spatial covariation between MLC and LVQ resulting from the diachronic analysis was then mapped (Fig. 4). In most of the study area (78.2%), landscape qualities prove to be stable for one (49.9%) or both (28.6%) of the criteria. This mainly concerns forest areas and the dense urban area of Besançon, which changed little. In 20.1% of the study area, MLC increased while LVQ remained stable. Conversely, MLC was stable and LVQ rose in only 3.0% of the study area. By contrast, 25.1% of the study area shows lower MLC and stable LVQ, compared to 1.5% with stable MLC and lower LVQ.

Apart from these areas of relative stability, four cases of convergence or divergence are interesting to observe:

Case 1. Areas of convergence with joint gains of MLC and LVQ (10.2%) are mainly distributed on the plateau SW of Besançon and in the Ognon Valley;

Case 2. Areas of convergence with joint losses of MLC and LVQ (6.3%) are particularly visible in the urban fringes closest to Besançon;

Case 3. Areas of divergence with MLC losses and LVQ gains (3.2%) are mainly located close to large areas affected by losses *versus* stability in urban fringes closest to Besançon;

Case 4. Areas of divergence with MLC gains and LVQ losses (2.1%) are mainly inserted in large areas featuring gains *versus* stability on the plateau SW of Besançon and in the Ognon Valley.

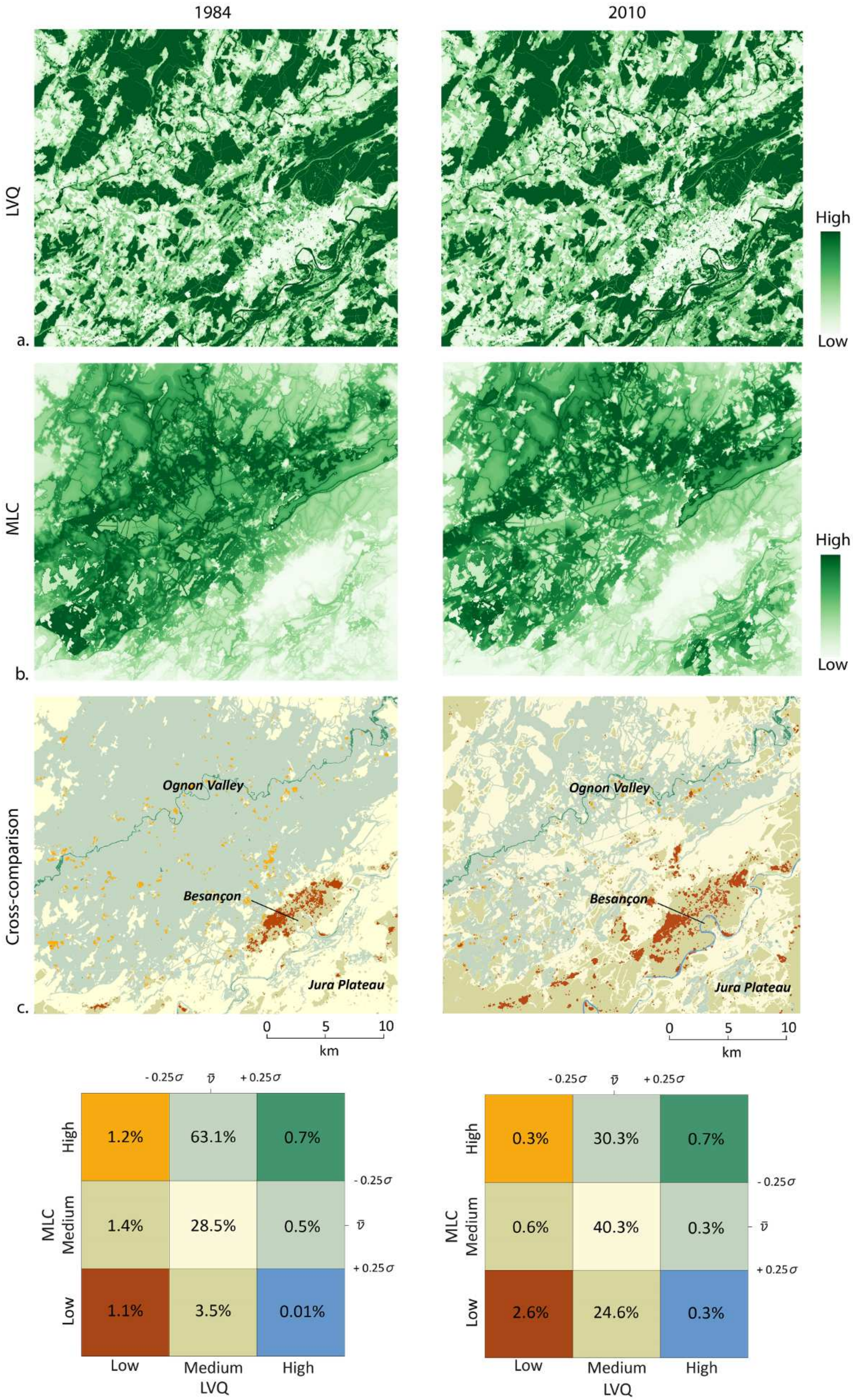

Fig. 3. Maps of landscape visual quality (LVQ), multi-species landscape connectivity (MLC) and cross-comparison for 1984 and 2010. For LVQ and MLC, higher values are in dark green, and lower values are in light green. For the cross-comparison, statistics correspond to the area concerned (%). Areas of joint high values are in green whereas areas of joint low values are in red. Areas of discrepancies with low MLC values and high LVQ values are in blue, while areas of discrepancies with high MLC values and low LVQ values are in orange. The areas of medium *versus* high or *versus* low values were not spatially distinguished. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

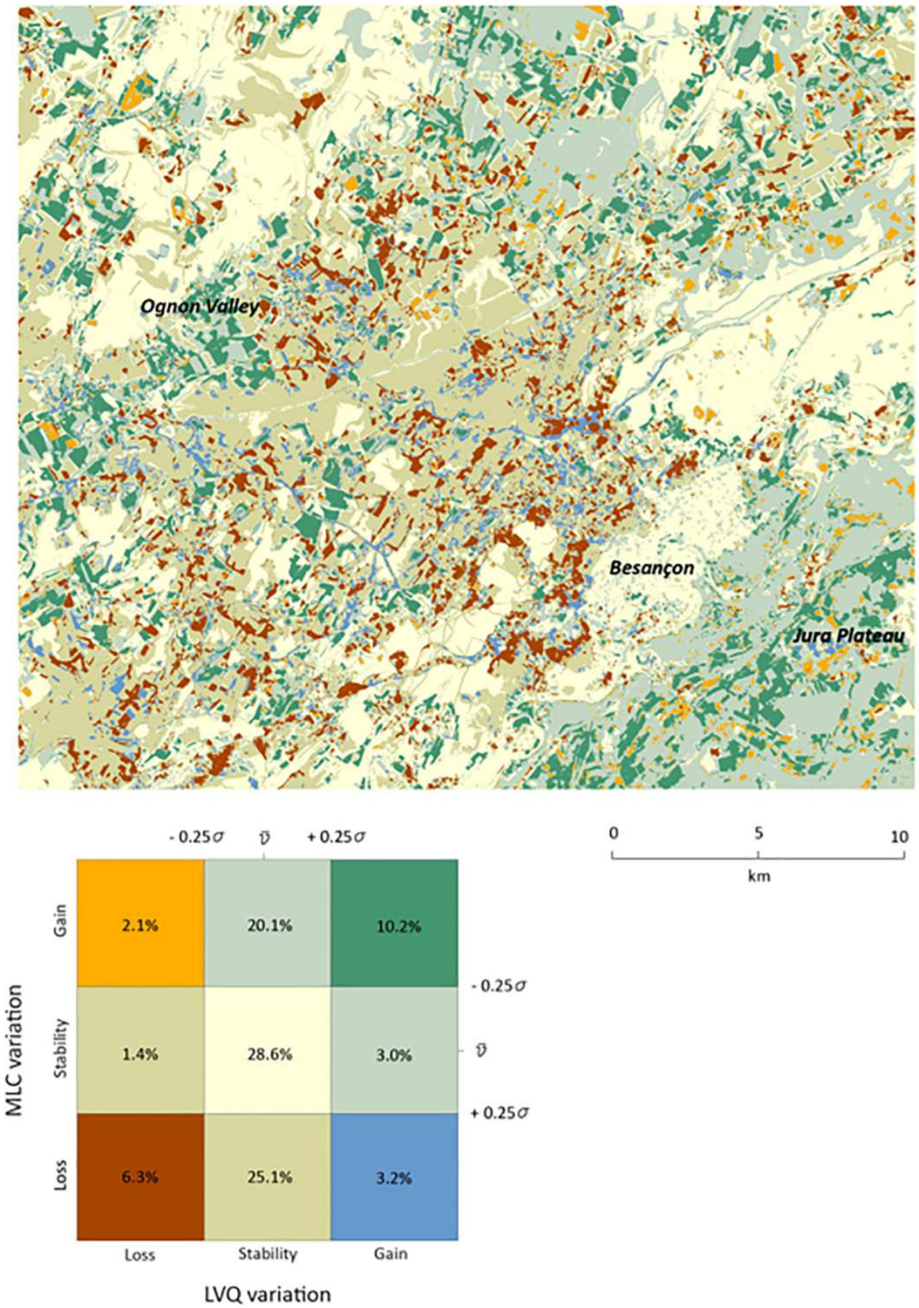

Fig. 4. Spatial covariation of *MLC* and *LVQ* between 1984 and 2010. Statistics correspond to the area concerned (%). Areas of convergence with joint gains (case 1) are in green whereas areas of convergence with joint losses (case 2) are in red. Areas of divergence with MLC losses and LVQ gains (case 3) are in blue, while areas of divergence with MLC gains and LVQ losses (case 4) in orange. The areas of stability *versus* gains or *versus* losses were not spatially distinguished because they are mainly due to *MLC* variation. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

4. Discussion

4.1. Contributions to the landscape ecological aesthetic framework

The purpose of this article was to study the covariation of the visual and ecological qualities of landscape by comparing two modeling approaches for (1) evaluating quality based on visual preferences for a sample of people, and (2) evaluating ecological quality based on habitat reachability for a set of virtual species representative of various ecosystems. To achieve this objective, the analysis consisted in mapping these two landscape dimensions in a static and then in a diachronic way with respect to land-cover changes. Our static approach differs of those of Yang et al. (2014) and Zheng et al. (2019) whose results are maps of integrated landscape values or sensitivities zones, with the aim in our case to identify areas of concordances and discrepancies between both of the landscape qualities. Beyond that, our study provides an original contribution to the joint evolution of the aesthetic and ecological qualities of landscape by focusing on their convergences and divergences. We mainly validated our hypothesis that for changes in landscape structures (represented by land-cover changes), the resulting covariation in aesthetic and ecological qualities can differ significantly in space.

The resulting spatial covariation shows that most of the study area (78.2%) is relatively stable in terms of its visual and ecological qualities due to few land-cover changes occurring in forest and dense urban areas. Elsewhere (21.8%), convergences or divergences occur in specific areas. Joint losses of aesthetic and ecological qualities occur specifically in the urban fringes closest to the city of Besançon. This can be explained by urban development affecting both ecological habitats and movements of species and people's landscape preferences. Conversely joint gains in aesthetic and ecological qualities are mainly distributed outside urban areas, involving changes from artificial to (semi-)natural areas, such as agricultural conversions from cropland to grassland or abandoned land. Areas affected by ecological losses and aesthetic gains are mainly located in urban–rural fringes, whereas ecological gains and aesthetic losses are mainly located in more (semi-)natural areas. These results provide new insights into the aesthetic-ecological debate in landscape research (Gobster et al., 2007), opposing the possible concordances or discrepancies between aesthetic and ecological landscape qualities. Even if these relations are complex, it seems that both can occur. All told, although our work reports that visual and ecological qualities are relatively stable because there is little change in land-cover, the study area is empirically affected by much more marked convergence (16.5%) than divergence (5.3%).

This work is original in that it provides a spatial representation of the impacts of land-cover changes on landscape qualities according to two different criteria involving remote effects. The evolution of the visual and ecological qualities of a given point may result from land-cover changes occurring not only at that point but at other points in its surroundings. In other words, a change in a scenic view may result from a land-cover change at a significant distance from the viewpoint. In the same way, the reachability of habitat for a species at a given location may be improved (or deteriorated) by a land-cover change elsewhere. These long-range effects show that when considering a fine spatial grain (i.e., a high spatial resolution) of land-cover changes, a strictly local analysis of their impacts is insufficient.

4.2. Limitations and avenues for improvement

One limitation of this study is the cross-mapping approach from the variation of two landscape qualities measured differently. On the one hand, MLC is estimated from the spatial generalization of a local connectivity metric, measuring habitat reachability for 16 different species, i.e. considering several animal groups with their potential movements through the calculation of connectivity metrics. On the other hand, LVQ is estimated by means of visibility analyses for a single group of human individuals, considered in an immobile manner in space. Therefore, the potential for changes in landscape structures affecting LVQ is lower, and the extent of the visual quality variation is distributed less evenly across space. Due to this difference both in measurements and in considering moving animals and fixed people, the extent of the variation values is distributed more regularly in space for MLC than for LVQ. This asymmetry affects the final results, in the relative stability between LVQ and MLC, with a much larger part of the area concerned by gains/losses of MLC and stability of LVQ than the reverse. One way of limiting this effect would be to consider people observing the landscape as mobile agents. As in Youssoufi and Foltête (2013), this would help to measure LVQ, for a point in space, as an aggregation of the perceived qualities along a path in a more or less close environment.

In addition to measuring metrics, another fundamental difference is the nature of information relating to the identification of people's landscape preferences and species' ecological requirements. For the first item, we mobilized the results of an empirical survey conducted with individuals and reported by Sahraoui et al. (2016). This approach had the advantage of taking into account the landscape preferences from landscapes captured within the study area. On the other hand, we applied the results of this survey to the year 1984, thus omitting potential changes in landscape perception between 1984 and 2010. By referring to the evolutionary theories of landscape preferences (e.g. Appleton, 1975; Kaplan and Kaplan, 1989; Wilson, 1984), we hypothesize that there is a common base in landscape preferences over time, and that they have changed very little over this short period. Concerning the identification of the ecological requirements of species, we based our analyses on the scientific literature relating to a panel of species, without reference to empirical field data. Biological data would bring more validity to landscape graphs, as sometimes achieved in this type of work (Foltête et al., 2020a, 2020b). In our case, such an approach requiring the acquisition of diachronic biological data from the 1980 s was not possible, but it would be relevant in contexts where such data are available.

A sensitive issue in this research is the level of detail of the information captured by the land-cover data for visibility analysis and for landscape connectivity modeling, especially the grain and the thematic precision. Given these two criteria, some landscape elements were omitted from the land-cover map although they may significantly affect individuals' landscape preferences and species' ecological connectivity. For example, we only distinguished grassland and cropland inside agricultural land, without taking into account the degree of intensification or the type of crops grown, while some studies emphasize the influence of these criteria on landscape preferences (Howley et al., 2012) as well as for animal species (Tscharntke et al., 2005). When analyzing land-cover changes in a systematic manner over a large study area, the challenge is thus to find spatial databases with a detailed thematic resolution, in particular for the earliest date. Outside the limit inherent in data accuracy, it should also be noted that the land-cover concept is limited to expressing certain aspects of landscape. For instance, concerning the aesthetic value of landscape specifically, the visible aspects of maintenance may impact the perception of a same land-cover category (Sahraoui et al., 2016b). Likewise, the type of landscape management (e.g., forest management) may alter the ecological potential of a given land-cover category (Mikoláš et al., 2017). Here again, access to data is a key element determining the capacity of landscape modeling to reproduce the actual landscape preferences for people and the actual habitat reachability for animal species.

4.3. Implications for integrated landscape management

Many researchers who have highlighted the idea that aesthetic and ecological quality may not be correlated (e.g. Kimmins, 1999; Parsons, 1995; Zhao et al., 2017) speak from an operational perspective. They argue that actors involved in landscape management could not reconcile the two without being confronted with dilemmas. However, the challenge of integrated landscape management is to take into account the interrelations between the preservation of landscape amenities' for people and the conservation of biodiversity. The final aim is to better integrate ecological and social objectives, particularly in human-dominated areas (Corney et al., 2015). The development of the concept of landscape services is in line with this objective, with the idea that a single landscape can provide different services thanks to its multifunctionality (Frank et al., 2012). This nevertheless requires a better understanding of how landscape patterns influence landscape services (Mitchell et al., 2015), both in natural habitats than under strong anthropic pressure. In our study, in which the urban–rural fringes are subject to such pressure, joint gains in aesthetic and ecological qualities were possible in more than 10% of the study area as a whole, but outside of these fringes. So the issue of implementing policies to reconcile visual and ecological landscape qualities would benefit from focusing on areas of urban sprawl. To achieve such integrated landscape management, the development of relevant indicators is essential for assessing how the aesthetic and ecological dimensions of landscape fit together (Fry et al., 2009). Such indicators could guide public policies in the search for compromises in preserving the different qualities of the landscape.

As an extension of the work of Steinitz (1990), there are several possible options of policies or actions in integrated landscape management (Fig. 5). It is important to note that for all options, a policy should only be considered if it potentially improves one landscape quality without deteriorating the other. In addition we believe that areas already rich in aesthetic and ecological qualities can be primarily concerned with conservation policies leading to their stability, so as to direct the search for gains elsewhere.

While our work has contributed to spatializing the impacts of land-cover changes, it would be interesting in a decision-support perspective to know their causes. To guide landscape management policies more effectively, this work should therefore explore the different impacts on

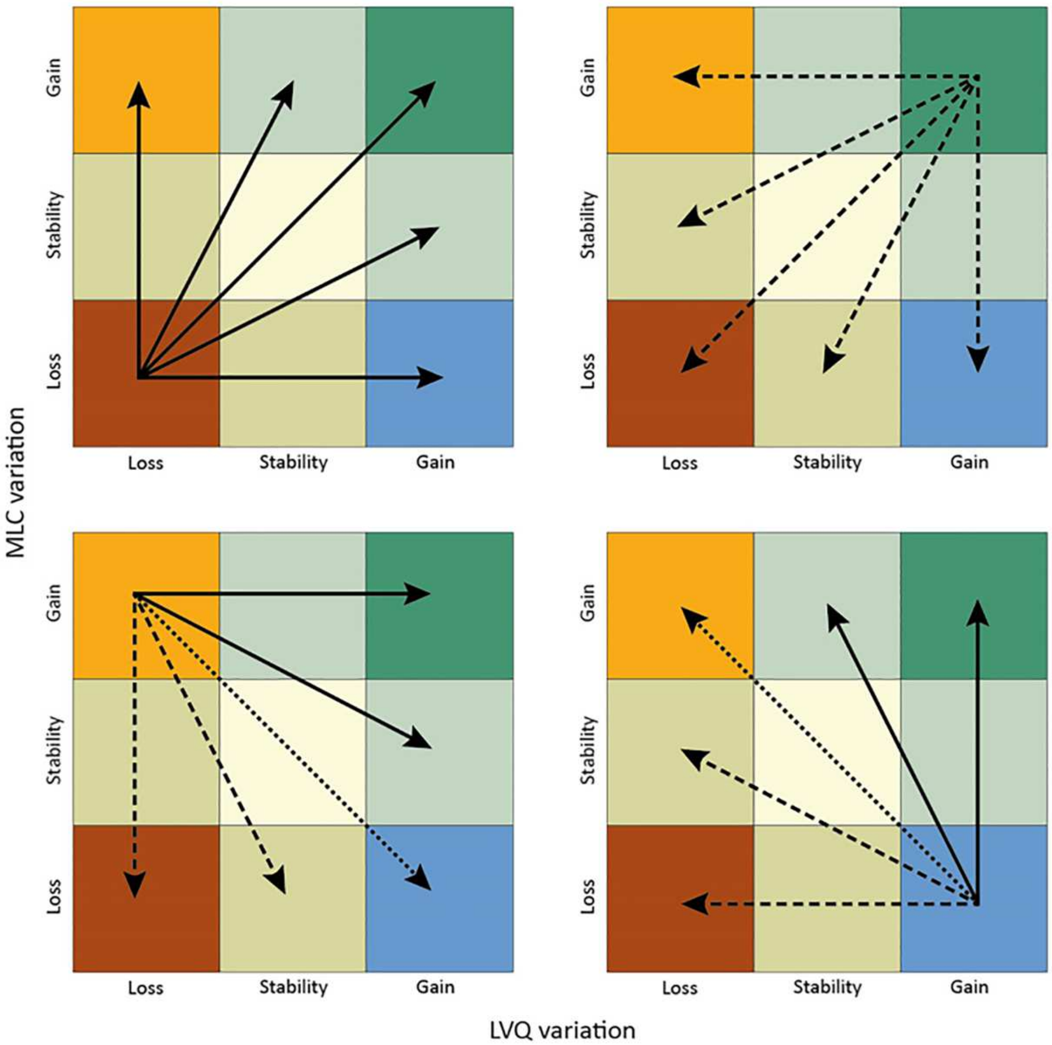

Fig. 5. Policy or action direction options for synergies in visual and ecological landscape qualities. The solid arrows show the directions to be considered. The dashed arrows indicate the directions to be rejected. The dotted arrows (antagonistic gains *versus* losses) indicate conflicting directions between the two landscape dimensions. Each of these direction options also concerns all the squares crossed by the arrows.

visual and ecological qualities according to the types of land-cover change (e.g., artificialization of grasslands, replacement of forests by croplands). Such an approach has already been developed by Sahraoui et al. (2017) to understand the impacts of the land-cover change types on MLC. Comparing the impacts of each type of change on LVQ and MLC could provide a more detailed understanding of the origin of the impacts for guiding planning decisions. In addition, we think that our methodology could be easily transposed into a prospective dimension for estimating the potential impacts of planning actions (e.g., urban planning, ecological restoration projects) on both landscape connectivity and visual landscape. Ecological network modeling using landscape graphs has already proven its effectiveness for decision-making in planning (Foltête, 2019) and more specifically for evaluating urban development scenarios (Tannier et al., 2016; Zetterberg et al., 2010). The joint use of landscape visual preferences modeling would make it possible to identify the urbanization alternatives most respectful of people's living environment and the conservation of biodiversity.

Finally, integrated landscape management between visual aesthetics and ecology could lead to a favorable dynamic by a virtuous circle in the long term. If aesthetic pleasure from landscapes can be a response to ecologically beneficial landscape patterns (Gobster et al., 2007), aesthetic values can in turn influence the motivations of individuals (general public or planners) for conserving biodiversity at the landscape scale (Tribot et al., 2018). Thus, and in agreement with Swaffield and McWilliam (2013), understanding the relationships between visual landscape quality and biodiversity attributes is a major issue that must clearly be included in landscape management and ecological conservation programs.

5. Conclusion

Due to the heterogeneity of data types and quantitative models, integrated landscape assessment in its visual aesthetic and ecological dimensions is a fundamental issue. Although a growing number of studies analyze the relationships between the aesthetic values of landscapes and their ecological functionality, few studies have so far been interested in a dynamic approach. The modeling approach developed in this study therefore fills a gap in our knowledge of how the visual and ecological qualities of the landscape can covary in space and time. In the context of the ecological-aesthetic debates, we started from the hypothesis that changes in landscape structures over time could influence these two qualities differently depending on their location in space. The results show that convergences and divergences between these qualities may occur within the same area, with a trend toward more convergent areas. Beyond these results, our methodology could provide decision support for integrated landscape management in a prospective approach. The results show that planners can potentially align visual and ecological objectives to produce sustainable landscapes.

CRediT authorship contribution statement

Yohan Sahraoui: Conceptualization, Methodology, Formal analysis, Writing - original draft, Visualization, Project administration. **Céline Clauzel:** Conceptualization, Supervision. **Jean-Christophe Foltête:** Conceptualization, Supervision, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

Details of land-cover categories and aggregations for modeling landscape visibility or landscape connectivity.

Appendix B

Details of landscape visibility metrics.

Appendix C

Results of the multiple linear regression analysis for the subsamples of respondents.

Appendix D

Information about the 16 virtual species considered for landscape graphs modeling.

Appendix E

Details for the spatial generalization of patch-based metrics.

The spatial generalization of patch-based values is computed as in Sahraoui et al. (2017). The weighting function designed to represent the effect of distance on potential accessibility from patches was the same as was used to compute the *IF*, i.e. the negative exponential function such that $w = e^{-ad}$, where w is the weight of a patch with respect to a point located at a least-cost distance d. For a given point, connectivity levels from several patches were attributed by summing the weighted values of *IF* as follows, by taking into account least-cost distances:

$$gIF(i)_i = \sum_{j=1}^{n} \mathrm{IF}(j)^* w_{ij}$$

where $gIF(i)$ is the generalized value of *IF* for the point i, and w_{ij} is the weighting of the patch j for the point i. As a result, we obtained for each virtual species a 5-m spatial resolution map on which each pixel took on a value corresponding to its potential of connectivity to the overall network.

Appendix F. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecolind.2020.107331.

References

Alex Smith, M., Green, M., D, 2005. Dispersal and the metapopulation paradigm in amphibian ecology and conservation: are all amphibian populations metapopulations? Ecography (Cop.) 28, 110–128. https://doi.org/10.1111/j.0906-7590.2005.04042.x.

Appleton, J., 1975. The Experience of Landscape, Wiley. ed. New-York & London.

Bastian, Olaf, Grunewald, Karsten, Syrbe, Ralf-Uwe, Walz, Ulrich, Wende, Wolfgang, 2014. Landscape services: the concept and its practical relevance. Landscape Ecol. 29 (9), 1463–1479. https://doi.org/10.1007/s10980-014-0064-5.

Bergès, Laurent, Avon, Catherine, Bezombes, Lucie, Clauzel, Céline, Duflot, Rémi, Foltête, Jean-Christophe, Gaucherand, Stéphanie, Girardet, Xavier, Spiegelberger, Thomas, 2020. Environmental mitigation hierarchy and biodiversity offsets revisited through habitat connectivity modelling. J. Environ. Manage. 256, 109950. https://doi.org/10.1016/j.jenvman.2019.109950.

Bunn, A.G, Urban, D.L, Keitt, T.H, 2000. Landscape connectivity: a conservation application of graph theory. J. Environ. Manage. 59 (4), 265–278. https://doi.org/10.1006/jema.2000.0373.

Corney, Helen, Ives, Christopher D., Bekessy, Sarah, 2015. Amenity and ecological management: a framework for policy and practice. Ecol. Manage. Restor. 16 (3), 199–205. https://doi.org/10.1111/emr.12177.

Cottet, Marylise, Piégay, Hervé, Bornette, Gudrun, 2013. Does human perception of wetland aesthetics and healthiness relate to ecological functioning? J. Environ. Manage. 128, 1012–1022. https://doi.org/10.1016/j.jenvman.2013.06.056.

Daniel, Terry C, 2001. Whither scenic beauty? Visual landscape quality assessment in the 21st century. Landscape Urban Plann. 54 (1-4), 267–281. https://doi.org/10.1016/S0169-2046(01)00141-4.

Dramstad, W.E., Tveit, M. Sundli, Fjellstad, W.J., Fry, G.L.A., 2006. Relationships between visual landscape preferences and map-based indicators of landscape structure. Landscape Urban Plann. 78 (4), 465–474. https://doi.org/10.1016/j.landurbplan.2005.12.006.

Fall, Andrew, Fortin, Marie-Josée, Manseau, Micheline, O'Brien, Dan, 2007. Spatial graphs: principles and applications for habitat connectivity. Ecosystems 10 (3), 448–461. https://doi.org/10.1007/s10021-007-9038-7.

Felix, Gabriela, Marenzi, Rosemeri C., Polette, Marcos, Netto, Sérgio A., 2016. Landscape visual quality and meiofauna biodiversity on sandy beaches. Environ. Manage. 58 (4), 682–693. https://doi.org/10.1007/s00267-016-0735-x.

Foltête, Jean-Christophe, Ingensand, Jens, Blanc, Nicolas, 2020a. Coupling crowd-sourced imagery and visibility modelling to identify landscape preferences at the

panorama level. Landscape Urban Plann. 197, 103756. https://doi.org/10.1016/j.landurbplan.2020.103756.
Foltête, Jean-Christophe, 2019. How ecological networks could benefit from landscape graphs: a response to the paper by Spartaco Gippoliti and Corrado Battisti. Land Use Policy 80, 391–394. https://doi.org/10.1016/j.landusepol.2018.04.020.
Foltête, Jean-Christophe, Clauzel, Céline, Vuidel, Gilles, 2012. A software tool dedicated to the modelling of landscape networks. Environ. Modell. Software 38, 316–327. https://doi.org/10.1016/j.envsoft.2012.07.002.
Foltête, Jean-Christophe, Girardet, Xavier, Clauzel, Céline, 2014. A methodological framework for the use of landscape graphs in land-use planning. Landscape Urban Plann. 124, 140–150. https://doi.org/10.1016/j.landurbplan.2013.12.012.
Foltête, Jean-Christophe, Savary, Paul, Clauzel, Céline, Bourgeois, Marc, Girardet, Xavier, Sahraoui, Yohan, Vuidel, Gilles, Garnier, Stéphane, 2020b. Coupling landscape graph modeling and biological data: a review. Landscape Ecol. 35 (5), 1035–1052. https://doi.org/10.1007/s10980-020-00998-7.
Frank, Susanne, Fürst, Christine, Koschke, Lars, Makeschin, Franz, 2012. A contribution towards a transfer of the ecosystem service concept to landscape planning using landscape metrics. Ecol. Ind. 21, 30–38. https://doi.org/10.1016/j.ecolind.2011.04.027.
Fry, G., Tveit, M.S., Ode, Å., Velarde, M.D., 2009. The ecology of visual landscapes: exploring the conceptual common ground of visual and ecological landscape indicators. Ecol. Ind. 9 (5), 933–947. https://doi.org/10.1016/j.ecolind.2008.11.008.
Fry, Gary L.A., 2001. Multifunctional landscapes—towards transdisciplinary research. Landscape Urban Plann. 57 (3-4), 159–168. https://doi.org/10.1016/S0169-2046(01)00201-8.
Galpern, Paul, Manseau, Micheline, Fall, Andrew, 2011. Patch-based graphs of landscape connectivity: a guide to construction, analysis and application for conservation. Biol. Conserv. 144 (1), 44–55. https://doi.org/10.1016/j.biocon.2010.09.002.
Gobster, Paul H., 1999. An ecological aesthetic for forest landscape management. Landscape Jrnl. 18 (1), 54–64. https://doi.org/10.3368/lj.18.1.54.
Gobster, Paul H., Nassauer, Joan I., Daniel, Terry C., Fry, Gary, 2007. The shared landscape: what does aesthetics have to do with ecology? Landscape Ecol. 22 (7), 959–972. https://doi.org/10.1007/s10980-007-9110-x.
Gutman, G., Janetos, A.C., Justice, C.O., Moran, E.F., Mustard, J.F., Rindfuss, R.R., Skole, D., II, B.L.T., Cochrane, M.A., 2004. Land Change Science : Observing, Monitoring and Understanding Trajectories of Changes on Earth's Surface. Springer, New-York.
Haines-Young, R., 2000. Sustainable development and sustainable landscapes: defining a new paradigm for landscape ecology. Fennia 178, 7–14.
Howley, Peter, Donoghue, Cathal O., Hynes, Stephen, 2012. Exploring public preferences for traditional farming landscapes. Landscape Urban Plann. 104 (1), 66–74. https://doi.org/10.1016/j.landurbplan.2011.09.006.
Ingram, Gordon Brent, 1991. Habitat, visual and recreational values and the planning of extractive development and protected areas: a tale of three islands. Landscape Urban Plann. 21 (1-2), 109–129. https://doi.org/10.1016/0169-2046(91)90036-L.
Joly, Daniel, Brossard, Thierry, Cavailhès, Jean, Hilal, Mohamed, Tourneux, François-Pierre, Tritz, Céline, Wavresky, Pierre, 2009. A quantitative approach to the visual evaluation of landscape. Ann. Assoc. Am. Geogr. 99 (2), 292–308. https://doi.org/10.1080/00045600802708473.
Junker, Berit, Buchecker, Matthias, 2008. Aesthetic preferences versus ecological objectives in river restorations. Landscape Urban Plann. 85 (3-4), 141–154. https://doi.org/10.1016/j.landurbplan.2007.11.002.
Kaplan, R., Kaplan, S., 1989. The Experience of Nature: A Psychological Perspective. Cambridge University Press, Cambridge.
(Hamish) Kimmins, J.P., 1999. Biodiversity, Beauty and the "Beast": are beautiful forests sustainable, are sustainable forests beautiful, and is "small" always ecologically desirable? Forestry Chronicle 75 (6), 955–960. https://doi.org/10.5558/tfc75955-6.
Lafortezza, Raffaele, Corry, Robert C., Sanesi, Giovanni, Brown, Robert D., 2008. Visual preference and ecological assessments for designed alternative brownfield rehabilitations. J. Environ. Manage. 89 (3), 257–269. https://doi.org/10.1016/j.jenvman.2007.01.063.
Lindemann-Matthies, Petra, Marty, Thomas, 2013. Does ecological gardening increase species richness and aesthetic quality of a garden? Biol. Conserv. 159, 37–44. https://doi.org/10.1016/j.biocon.2012.12.011.
Lislevand, Terje, Figuerola, Jordi, Székely, Tamás, 2007. Avian body sizes in relation to fecundity, mating system, display behavior, and resource sharing: ecological Archives E088-096. Ecology 88 (6), 1605. https://doi.org/10.1890/06-2054.
McCormick, Ashlee, Fisher, Karen, Brierley, Gary, 2015. Quantitative assessment of the relationships among ecological, morphological and aesthetic values in a river rehabilitation initiative. J. Environ. Manage. 153, 60–67. https://doi.org/10.1016/j.jenvman.2014.11.025.
McGarigal, K., Marks, B.J., 1995. FRAGSTATS: spatial pattern analysis program for quantifying landscape structure.
MEA - Millennium Ecosystem Assessment, 2003. Ecosystems and human well-being. Island Press, Washington DC, Synthesis.
Mikoláš, Martin, Tejkal, Martin, Kuemmerle, Tobias, Griffiths, Patrick, Svoboda, Miroslav, Hlásny, Tomáš, Leitão, Pedro J., Morrissey, Robert C., 2017. Forest management impacts on capercaillie (Tetrao urogallus) habitat distribution and connectivity in the Carpathians. Landscape Ecol. 32 (1), 163–179. https://doi.org/10.1007/s10980-016-0433-3.
Mitchell, Matthew G.E., Suarez-Castro, Andrés F., Martinez-Harms, Maria, Maron, Martine, McAlpine, Clive, Gaston, Kevin J., Johansen, Kasper, Rhodes, Jonathan R., 2015. Reframing landscape fragmentation's effects on ecosystem services. Trends Ecol. Evol. 30 (4), 190–198. https://doi.org/10.1016/j.tree.2015.01.011.
MNHN, 2011. Trame verte et bleue. Critères nationaux de cohérence. Contribution à la définition du critèe sur les espèces.
Nassauer, J.I., 1997. Placing Nature : Culture and Landscape Ecology. Island Press, Washington DC.
Opdam, P., Foppen, R., Vos, C., 2001. Bridging the gap between ecology and spatial planning in landscape ecology. Landsc. Ecol. 16, 767–779. https://doi.org/10.1023/A:1014475908949.
Otero Pastor, Isabel, Casermeiro Martínez, Miguel A., Ezquerra Canalejoa, Alejandra, Esparcia Mariño, Penélope, 2007. Landscape evaluation: comparison of evaluation methods in a region of Spain. J. Environ. Manage. 85 (1), 204–214. https://doi.org/10.1016/j.jenvman.2006.09.018.
Parsons, Russ, 1995. Conflict between ecological sustainability and environmental aesthetics: conundrum, canärd or curiosity. Landscape Urban Plann. 32 (3), 227–244. https://doi.org/10.1016/0169-2046(95)07004-E.
Rayfield, Bronwyn, Fortin, Marie-Josée, Fall, Andrew, 2011. Connectivity for conservation: a framework to classify network measures. Ecology 92 (4), 847–858. https://doi.org/10.1890/09-2190.1.
Rindfuss, R.R., Walsh, S.J., Turner, B.L., Fox, J., Mishra, V., 2004. Developing a science of land change: challenges and methodological issues. Proc. Natl. Acad. Sci. 101 (39), 13976–13981. https://doi.org/10.1073/pnas.0401545101.
Sahraoui, Yohan, Clauzel, Céline, Foltête, Jean-Christophe, 2016a. Spatial modelling of landscape aesthetic potential in urban-rural fringes. J. Environ. Manage. 181, 623–636. https://doi.org/10.1016/j.jenvman.2016.06.031.
Sahraoui, Yohan, Foltête, Jean-Christophe, Clauzel, Céline, 2017. A multi-species approach for assessing the impact of land-cover changes on landscape connectivity. Landscape Ecol 32 (9), 1819–1835. https://doi.org/10.1007/s10980-017-0551-6.
Sahraoui, Yohan, Vuidel, Gilles, Joly, Daniel, Foltête, Jean-Christophe, 2018. Integrated GIS software for computing landscape visibility metrics: XXXX. Trans. GIS 22 (5), 1310–1323. https://doi.org/10.1111/tgis.12457.
Sahraoui, Yohan, Youssoufi, Samy, Foltête, Jean-Christophe, 2016b. A comparison of in situ and GIS landscape metrics for residential satisfaction modeling. Appl. Geogr. 74, 199–210. https://doi.org/10.1016/j.apgeog.2016.07.011.
Sang, Neil, Miller, David, Ode, Åsa, 2008. Landscape metrics and visual topology in the analysis of landscape preference. Environ. Plann. B Plann. Des. 35 (3), 504–520. https://doi.org/10.1068/b33049.
Saura, Santiago, Pascual-Hortal, Lucía, 2007. A new habitat availability index to integrate connectivity in landscape conservation planning: comparison with existing indices and application to a case study. Landscape Urban Plann. 83 (2-3), 91–103. https://doi.org/10.1016/j.landurbplan.2007.03.005.
Sheppard, S.R.J., 2001. Beyond visual resource management : emerging theories of an ecological aesthetic and visible stewardship. In: Sheppard, S.J.R., Harshaw, H.W. (Eds.), FFrests and Landscapes : Linking Ecology, Sustainability and Aesthetics. CABI Publishing, Wallingford & New-York, pp. 149–172.
Smith, Felisa A., Lyons, S. Kathleen, Ernest, S. K. Morgan, Jones, Kate E., Kaufman, Dawn M., Dayan, Tamar, Marquet, Pablo A., Brown, James H., Haskell, John P., 2003. Body mass of late quaternary mammals: ecological archives E084-094. Ecology 84 (12), 3403. https://doi.org/10.1890/02-9003.
Sordello, R., Conruyt-Rogeon, G., Merlet, F., Houard, X., Touroult, J., 2013. Synthèses bibliographiques sur les traits de vie de 39 espèces proposées pour la cohérence nationale de la Trame verte et bleue relatifs à leurs déplacements et besoins de continuité écologique.
Steinitz, Carl, 1990. Toward a sustainable landscape with high visual preference and high ecological integrity: the loop road in Acadia National Park, U.S.A. Landscape Urban Plann. 19 (3), 213–250. https://doi.org/10.1016/0169-2046(90)90023-U.
Sutherland, G., Harestad, A.S., K, K.P., Lertzman, K.P., 2000. Scaling of Natal Dispersal Distances in Terrestrial Birds and Mammals. Conserv. Ecol. 4, 16.
Swaffield, S.R., McWilliam, W.J., 2013. Landscape aesthetic experience and ecosystem services. In: Dymond, J. (Ed.), Ecosystem Services in New Zealand—Conditions and Trends. Manaaki Whenua Press, Lincoln, New Zealand, pp. 349–362.
Tannier, Cécile, Bourgeois, Marc, Houot, Hélène, Foltête, Jean-Christophe, 2016. Impact of urban developments on the functional connectivity of forested habitats: a joint contribution of advanced urban models and landscape graphs. Land Use Policy 52, 76–91. https://doi.org/10.1016/j.landusepol.2015.12.002.
Termorshuizen, Jolande W., Opdam, Paul, 2009. Landscape services as a bridge between landscape ecology and sustainable development. Landscape Ecol 24 (8), 1037–1052. https://doi.org/10.1007/s10980-008-9314-8.
Thorne, James F., Huang, Chang-Shan, 1991. Toward a landscape ecological aesthetic: methodologies for designers and planners. Landscape Urban Plann. 21 (1-2), 61–79. https://doi.org/10.1016/0169-2046(91)90033-I.
Tress, Bärbel, Tress, Gunther, 2001. Capitalising on multiplicity: a transdisciplinary systems approach to landscape research. Landscape Urban Plann. 57 (3-4), 143–157. https://doi.org/10.1016/S0169-2046(01)00200-6.
Tress, Bärbel, Tress, Gunther, Décamps, Henri, d'Hauteserre, Anne-Marie, 2001. Bridging human and natural sciences in landscape research. Landscape Urban Plann. 57 (3-4), 137–141. https://doi.org/10.1016/S0169-2046(01)00199-2.
Tribot, Anne-Sophie, Deter, Julie, Mouquet, Nicolas, 2018. Integrating the aesthetic value of landscapes and biological diversity. Proc. R. Soc. B. 285 (1886), 20180971. https://doi.org/10.1098/rspb.2018.0971.
Tribot, A.S., Mouquet, N., Villéger, S., Raymond, M., Hoff, F., Boissery, P., Holon, F., Deter, J., 2016. Taxonomic and functional diversity increase the aesthetic value of coralligenous reefs. Sci. Rep. 6, 1–12. https://doi.org/10.1038/srep34229.
Tscharntke, T., Klein, A.M., Kruess, A., Steffan-Dewenter, I., Thies, C., 2005. Landscape perspectives on agricultural intensification and biodiversity â&# ecosystem service management. Ecol. Lett. 8, 857–874. https://doi.org/10.1111/j.1461-0248.2005.00782.x.

Turner, B.L., Lambin, E.F., Reenberg, A., 2007. The emergence of land change science for global environmental change and sustainability. Proc. Natl. Acad. Sci. 104 (52), 20666–20671. https://doi.org/10.1073/pnas.0704119104.

Turner, M G, 1989. Landscape Ecology: The Effect of Pattern on Process. Annu. Rev. Ecol. Syst. 20 (1), 171–197. https://doi.org/10.1146/annurev.es.20.110189.001131.

Urban, Dean, Keitt, Timothy, 2001. Landscape connectivity: a graph-theoretic perspective. Ecology 82 (5), 1205–1218. https://doi.org/10.1890/0012-9658(2001)082[1205:LCAGTP]2.0.CO;2.

Vogt, Peter, Riitters, Kurt H., Estreguil, Christine, Kozak, Jacek, Wade, Timothy G., Wickham, James D., 2007. Mapping spatial patterns with morphological image processing. Landscape Ecol. 22 (2), 171–177. https://doi.org/10.1007/s10980-006-9013-2.

Vouligny, Évelyne, Domon, Gérald, Ruiz, Julie, 2009. An assessment of ordinary landscapes by an expert and by its residents: landscape values in areas of intensive agricultural use. Land Use Policy 26 (4), 890–900. https://doi.org/10.1016/j.landusepol.2008.10.016.

Williams, Kathryn, Cary, John, 2001. Perception of native grassland in southeastern Australia. Ecol. Manage Restor. 2 (2), 139–144. https://doi.org/10.1046/j.1442-8903.2001.00077.x.

Wilson, E.O., 1984. Biophilia, Harvard Un. ed. Cambridge.

Yang, D., Luo, T., Lin, T., Qiu, Q., Luo, Y., 2014. Combining aesthetic with ecological values for landscape sustainability. PLoS One 9. https://doi.org/10.1371/journal.pone.0102437.

Youssoufi, Samy, Foltête, Jean-Christophe, 2013. Determining appropriate neighborhood shapes and sizes for modeling landscape satisfaction. Landscape Urban Plann. 110, 12–24. https://doi.org/10.1016/j.landurbplan.2012.09.005.

Zetterberg, Andreas, Mörtberg, Ulla M., Balfors, Berit, 2010. Making graph theory operational for landscape ecological assessments, planning, and design. Landscape Urban Plann. 95 (4), 181–191. https://doi.org/10.1016/j.landurbplan.2010.01.002.

Zhao, Jingwei, Wang, Ronghua, Luo, Pingjia, Xing, Lu, Sun, Tong, 2017. Visual ecology: exploring the relationships between ecological quality and aesthetic preference. Landscape Ecol. Eng. 13 (1), 107–118. https://doi.org/10.1007/s11355-016-0306-6.

Zheng, Yu, Lan, Siren, Chen, Wendy Y., Chen, Xiaoyan, Xu, Xixi, Chen, Yannan, Dong, Jianwen, 2019. Visual sensitivity versus ecological sensitivity: an application of GIS in urban forest park planning. Urban For. Urban Greening 41, 139–149. https://doi.org/10.1016/j.ufug.2019.03.010.