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Using forest history and spatial patterns to identify potential high conservation value forests in Romania

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Abstract Naturally dynamic forests have a high proportion of biotopes with old large trees, diverse vertical and horizontal structure at multiple scales, and much dead wood. As such, they provide habitat to species and ecosystem processes that forests managed for wood production cannot provide to the same degree. Whether termed old-growth, ancient, virgin, intact, primeval or continuity forests, a major challenge and need is to map such potential high conservation value forest for subsequent inclusion in functional habitat networks for biodiversity conservation in forest landscapes. Given that the delivery time of natural forest properties is much longer than of industry wood, we explore the usefulness of using historical maps to identify forests that have been continuously present for 220 years (potential old-growth) versus 140 years (potential aging forest) in a case study in the Romanian Carpathian Mountains (see Online Resource 1). While the total forest cover increased by 35 % over the past two centuries, the area of potential aging and potential old-growth forest declined by 56 and 34 %, respectively. Spatial modelling of edge effects and patch size for virtual species with different requirements indicated an even greater decrease in the area of functional habitat networks of old-growth and ageing forest. Our analyses show that compared to simple mapping of potential high conservation forests, the area of

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functional habitat patches is severely overestimated, and caution is needed when estimating the area of potential high conservation value forests that form functional habitat networks, i.e. a green infrastructure. In addition, the landscape and regional scale connectivity of patches needs to be considered. We argue that the use of historical maps combined with assessment of spatial patterns is an effective tool for identifying and analyzing potential high conservation value forests in a landscape context.

Keywords Forest continuity · Green infrastructure · Multi-temporal spatial analysis · Trajectories of change · Romanian Carpathians

Introduction

The loss and alteration of naturally dynamic forest ecosystems are the main reasons behind the loss of biodiversity and dysfunctional ecosystem services. These services include the provision of wood and non-wood goods, regulation of carbon sequestration, or habitat services for nutrient cycling and species, as well as cultural services such as recreation (Franklin and Forman 1987; Millennium Ecosystem Assessment 2005; Kumar 2010). As a consequence, there have been numerous attempts to define the level of naturalness of forest ecosystems (Peterken 1996) in the contexts of habitat mapping (Wirth et al. 2009; Burrascano 2010), biodiversity monitoring (Winter 2012), forest certification (Ioras et al. 2009; FSC 2012) and conservation planning (Kurlavicius et al. 2004). According to Peterken (1996), the degree of naturalness describes the gradual loss of composition, structure and function of forest ecosystems with increasing human alteration. The development of naturalness is linked to the type of forest ecosystem and its disturbance regime, and is about composition, structure and function across multiple spatial scales (Larsson et al. 2001; Angelstam and Dönz-Breuss 2004; Saudyte et al. 2005). It takes a much longer time for forest naturalness to develop than the duration of typical forest rotation times for wood production (Sundberg and Silversides 1996). Mapping the locations of natural and near-natural forest ecosystems on the ground has been performed mostly by non-governmental organizations (Aksenov et al. 2002; Kurlavicius et al. 2004; BirdLife European Forest Task Force 2009). Researchers have developed integrated analyses of spatial patterns using landscape metrics concerning the remnants of natural forest (e.g., Lundquist et al. 2001; D'eon and Glenn 2005; Nonaka and Spies 2005; Wulder et al. 2009). Finally, quantitative indicators have been developed at the Pan-European forest policy level (EEA 2010; Forests Europe 2011; PSFM 2011; MCPFE 2002). Finally, both evidence-based and negotiated performance targets have been published (e.g., Angelstam et al. 2013).

In the late 1990s, the policy-level emphasis moved from definitions of particular types of forest (e.g., old-growth, virgin) toward the environmental and social values that make a forest particularly important (Jennings et al. 2003). The unifying concept of High Conservation Value Forest (HCVF) emerged in 1999, and the maintenance of HCVFs was then explicitly included in the Forest Stewardship Council (FSC) Principles and Criteria (FSC 2000). High Conservation Values may refer to the diversity of species, landscape-level ecosystems and mosaics, ecosystems and habitats, critical ecosystem services, community needs and cultural values (FSC 2012). In this study, the terms used for designating 'natural' forests (e.g., old-growth, ancient, virgin) refer to complementary characteristics and values such as structure and functionality, temporal continuity and relationship to man,

thus emphasizing the different perspectives of HCVFs (Online Resource 2). A general toolkit for defining, identifying and managing HCVF was developed in 2003 (see Jennings et al. 2003). Subsequently, the concept of HCVF was interpreted at the regional and local level by national initiatives, which developed regional FSC standards. For example, in Romania, the first interpretation of the HCVF toolkit at the national level was proposed in 2005 (Stanciu et al. 2005), and the draft of a second version was recently publicly debated (Grigore et al. 2012). The category '*Ecosystems and habitats. Rare, threatened, or endangered ecosystems*' (HCV 3) also included the 'virgin' and 'quasi-virgin' forests. The term 'virgin forest' (see Biriş et al. 2000; Giurgiu et al. 2001; Biriş and Veen 2005; Veen et al. 2010) refers to the original forests, in their structure and dynamics, which evolve independently from human interference (Biriş and Veen 2005). The term 'quasi-virgin forest' refers to former virgin forests where sporadic extraction was practiced but without affecting the typical uneven-aged structure (Borlea 1999).

Europe has a very long history of loss and alteration of forest ecosystems (Darby 1956) and also hosts steep gradients among regions with different economic histories (Angelstam et al. 2011a). Today's natural temperate forest biotopes are remnants of forests once covering large parts of the European continent (Kozak et al. 2007). Among the EU Member States, Bulgaria and Romania have most of these forests (WWF-DCP 2011). However, according to BirdLife European Forest Task Force (2009), only 15 % of Bulgarian and 8 % of Romanian biologically important forest are strictly protected, and approximately 75 % of such forests do not have any protection measures.

Analysis of historical maps can be used to delimit forest patches that have a long temporal continuity and that might constitute, at least potentially, HCVFs. We use the term 'potential' to acknowledge that historical continuity does not equate to, but may at least potentially indicate, high conservation value. In addition, it is also important to assess the functionality of such patches by considering edge effects (e.g., Aune et al. 2005), patch size (Angelstam et al. 2004), and connectivity for focal species (e.g., Angelstam et al. 2011b; Elbakidze et al. 2011).

The aim of this study is to combine analyses of historical maps as a means of identifying forests with a relatively temporal continuity that are identified in this study as potential HCVFs with analyses of forest patch properties such as size and edge effects as a base for estimating the functionality of HCVF networks. We use the 'Transylvanian Alps' in Romania's Southern Carpathians as a test area. Most of Romania's natural forests (Biriş and Veen 2005) are situated in this region. In the western part of this region, near-natural forests cover significant unfragmented areas, whereas in the eastern part, the forests are fragmented and subject to numerous threats derived from increasing human pressure (Angelstam et al. 2011a). By combining analyses of historical maps with spatial analyses, we develop a methodology with the specific goals of (1) mapping and quantifying the change of forest cover, (2) identify patches of a long temporal continuity, and (3) assessing the functionality of core areas by considering edge effects and patch size. Finally, we discuss the challenges in mapping HCVFs that contribute to functional habitat networks, or green infrastructure.

Materials and methodology

Study area

The case study area covers 101 km^2 and is situated in the Bucegi Mountains in the southern part of the Romanian Carpathians, in the upper sector of the Prahova Valley

(Fig. 1). The area is currently one of the most important mountain resorts in Romania, representative of the Southern Carpathians with important ecological, economic and cultural values, forming part of the heritage of many traditional local village communities. The forest vegetation is dominated by mixed beech (*Fagus sylvatica*), fir (*Abies alba*) and spruce (*Picea abies*) forests. The sub-alpine level is composed of larch (*Larix decidua*) and mountain pine (*Pinus mugo*) forests.

The Bucegi Natural Park was established in 2000 to preserve rare and endemic species (Iojă et al. 2010) such as European yew (*Taxus baccata*) and edelweiss (*Leontopodium alpinum*). Several virgin forest patches totaling 11.45 km² have been identified in the region (Giurgiu et al. 2001; Biriş and Veen 2005) and were included as part of the area of the Bucegi Natural Park. The Management Plan of Bucegi Natural Park (Romanian Government 2011) certifies the existence of virgin forests in this area.

Data sets

Historical (Online Resource 3) and contemporary maps were used to produce land cover maps (Online Resource 4) for seven points in time: 1790, 1867, 1940, 1970, 1989, 1995, and 2010. The oldest map used in the study was produced in 1790 by an Austrian general, Specht, with a scale of 1:28,000. The second, Szathmary's map, was produced in 1867 at the scale of 1:57,600. Topographic maps were used for the years 1940 (scale 1:20,000), 1970 (scale 1:100,000), 1989 (scale 1:100,000) and 1995 (scale 1:50,000). The current
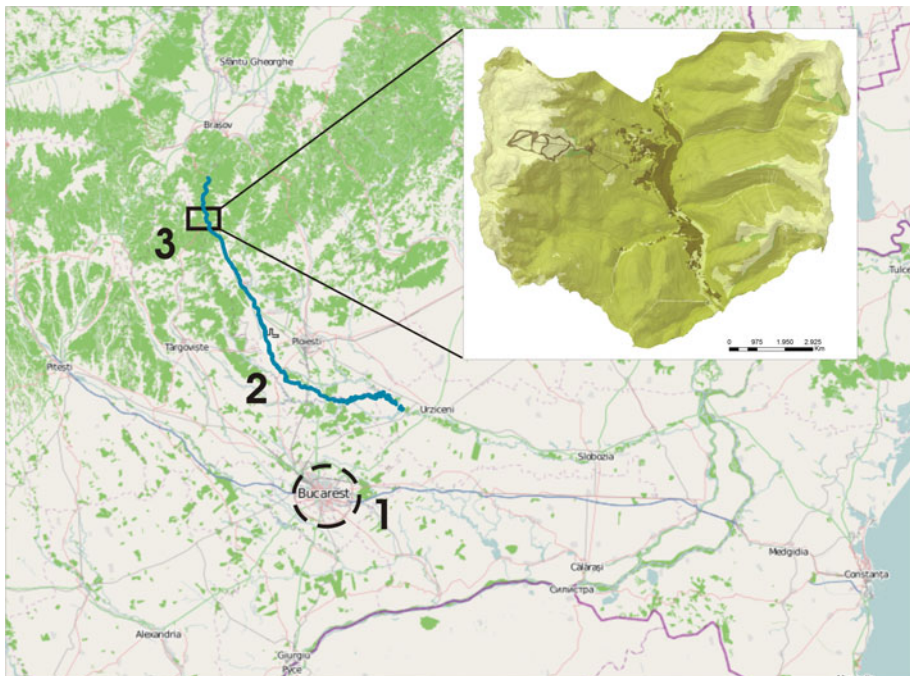
1. Bucharest; 2. Prahova Valley; 3. Sinaia

Fig. 1 Location of the study area

forest map, with a scale of 1:10,000, was produced by using orthophotomaps made by the Romanian National Agency for Cadastre and Land Registration in 2010.

Methodology

Our approach was based on processing cartographic resources (both historical and recent maps) and to carry out spatial analyses based on ecological knowledge. The findings of the cartographic and spatial analyses were validated by comparisons with (i) ecological and forest information (sites of 'virgin' forests identified by previous studies in the study area) and (ii) historical information (ancillary sources, documents, and other studies).

Bi-temporal and multi-temporal analysis

Bi-temporal (e.g., Shoyama and Braimoh 2011) and multi-temporal methods (e.g., van Ee-tvelde and Antrop 2009) are widely used to analyse remote sensing images (e.g., Coppin et al. 2004) and for forest monitoring (e.g., Estreguil and Mouton 2009). We used these methods for long-term landscape analysis based on historical and recent maps. Bi-temporal analysis is useful in producing land cover change maps (e.g., Petit and Lambin 2002). The bi-temporal method input requires two maps corresponding to successive moments t and t', and the output is a new map, corresponding to the $[t, t']$ time period, which depicts the transitions of land cover classes. The multi-temporal analysis yields landscape time-depth (van Eetvelde and Antrop 2009) and requires input from several maps. The output of the analysis is a new map, generated by overlaying all the input maps. If there at least three input maps, the succession of land cover types produce trajectories of change (Mertens and Lambin 2000). On a multi-temporal scale, one can highlight, in the same image, phenomena manifested during the entire analysis period (Marsik et al. 2011). Our analysis of forest cover change included four steps that combined the bi- and multi-temporal methods. We used the bi-temporal method for quantifying the forest cover changes and the multi-temporal method for identifying patches of forest continuity.

Step 1 Choose a common projection coordinate system for all analyzed historical and recent maps and conversion of all features into raster format   This step was performed using ArcGIS software and the 1st Order Polynomial transformation type. Several ground control points were selected to associate the maps to the specific location of Sinaia using the Stereo'70 projection and Dealul Piscului 1970 Geographic Coordinate System. Spe-cifically, we used four ground control points for the maps from 1790 and 1867, along with nine such links for maps from 1970, 1989, 1995 and the 2010 orthophotomap. The ground control points were selected from those constructions and road intersections that were constantly represented and located throughout time. Due to the fact that the 1790 and 1867 maps have very few cartographic elements comparable with the reference cartographic support, we only identified four ground control points, which were placed at the corners of the image. The accuracy of a geo-referenced map was measured through the RMS (Root Mean Square) error. In the case of the data sets between 1790 and 1867, this error had a mean value of 11.4, being determined by the low number of possible links to the reference map. Moreover, the 1790 map had no projection set, but geometrical levelling was used. In comparison, the georeferencing process of the 1970–2010 maps had a better precision, the average RMS error being 4.72. Through a manual digitization of the cartographic elements in thematic polygons, the data sets were transformed into vector format and then converted to raster format for spatial analyses.

Step 2 Differentiation of representation of the forests existing in 2010 within the newly produced map   Each of the forest patches in the 2010 map was delineated according to its appearance on previous maps. Forest loss, i.e., forest patches that during a certain period of time were covered by forest but in 2010 belonged to other land cover types, such as pastures, built-up, or leisure, was also represented on the same map. This step was achieved through multi-temporal analysis, whereby all the maps from the database were overlaid.

Step 3 Spatial delimitation of patches with a 'stable nucleus' during the time period, or potential HCVFs, in the sequence   Potential HCVFs were defined as forest patches with long historical continuity that were present in successive maps until the present time. These forests have only a certain historical continuity, and some of them were intensively managed or subject to grazing or selective felling, followed by reforestation between two subsequent maps. We use the term 'potential' to acknowledge that historical continuity does not equate to, but may possibly indicate, high conservation value. The delimitation of potential HCVF was accompanied by the spatial representation of the deforestation, reforestation and successive deforestation phenomena.

Step 4 Mapping the forest transitions   This step was based on the bi-temporal method. The maps were created by overlaying two successive maps and following the changes that involved forests: unchanged forest, transition of forest into other land cover types, and other land cover types into forest. The aim of this step was to identify forest the cover changes that occurred in different periods of time (e.g., periods of massive forestation of pastures).

Quantification of spatial patterns of potential HCFVs

The quantitative spatial analyses were performed to quantify (i) the spatial patterns of potential HCVF for the whole study area and (ii) the spatial patterns of patches of HCVF located close to 'virgin' forests sites, as well to assess (iii) the forest cover change.

The forest cover maps of the study area allowed for the identification of forests that had remained in the same place since 1790 (i.e., potential old-growth with ca. 220 years of continuous forest cover), and since 1867 (i.e., potential aging forest ca. 140 years of continuous forest cover). To estimate the loss of potential old-growth and potential aging forest, we overlaid the 1790 and 1867 maps, respectively, with the subsequent map layer themes representing non-forest land covers (e.g., agriculture, roads and built-up).

However, the functionality of a certain amount of land cover is affected by the shape, size, juxtaposition and distance between constituent patches (e.g., Groom et al. 2006; Ostapowicz et al. 2008). This is linked to edge effects such as wind-throw (Esseen 1994), drier microclimate (Chen et al. 1995) and the patch-size requirements and dispersal ability of individual species (e.g., Angelstam et al. 2004). To estimate the functional area of potential old-growth and potential aging forest patches, we considered the shape by removing inward edges of 50 and 100 m (e.g., Aune et al. 2005) and including a range of patch sizes required by focal species with different life histories (>10 and >100 ha) (e.g., Elbakidze et al. 2011).

The quantification of the spatial patterns of potential HCVF patches was performed by using landscape metrics (Haines-Young and Chopping 1996). The metrics are usually computed on the basis of land cover maps quantifying the landscape state at a given

moment in time. However, for measuring spatial patterns for patches of potential HCVFs, it was appropriate to compute landscape metrics on the basis of the maps produced by using multi-temporal analysis. All the metrics were computed by using the FRAGSTATS software (McGarigal et al. 2002). Our metrics of interest in particular were as follows:

1. *Patch area* (*AREA*) The metric *AREA* was used for computing the areas of patches of potential HCVFs (Table 1).
2. *Core area* (*CORE*) Core area is the area within a patch beyond a specified depth-of-edge (McGarigal et al. 2002). Specifically, we considered two values for the depth-of-edge: 50 and 100 m (cf., Aune et al. 2005).
3. *Fractal dimension index* (*FRAC*) The *fractal dimension index* is an index that describes the shape and the complexity of a patch. The value ranges between 1 and 2. Its definition formula is

$$FRAC = 2\ln(0.25PERIM)/\ln(AREA),$$

where *PERIM* and *AREA* are the patch perimeter (expressed in m) and patch area (expressed in m²), respectively (e.g., McGarigal et al. 2002). The advantage of *FRAC* is that it reflects shape complexity across a range of spatial scales, thus overcoming a major limitation of the simple perimeter-area ratio (McGarigal et al. 2002).

The metric *AREA* was used for quantifying forest cover changes (see Online Resource 5). It was computed on the basis of the maps produced by using the bi-temporal analysis (e.g., Marsik et al. 2011), which means that it quantifies phenomena instead of states.

Results

Forest cover changes

We produced six maps representing the land cover changes that corresponded to the intervals 1790–1867, 1867–1940, 1940–1970, 1970–1989, 1989–1995 and 1995–2010 (Fig. 2). We defined the following types of classes indicating forest cover change: (i) unchanged forest (no forest cover change); (ii) reforestation (increasing forest cover due to converting built-up—construction sites located at the urban periphery and abandoned, cf., Huzui et al. (2011), industrial units and mineral extraction sites, leisure areas and pastures to forests); (iii) deforestation (decreasing forest cover as a result of converting forest areas to built-up, industrial areas, mineral extraction sites, leisure areas, pastures and roads); (iv) other transitions (types of land cover change that did not concern the forest, e.g., transition of pastures into built-up areas; see Pătru-Stupariu et al. 2011). The forest

Table 1 Patches of potential HCVF in the neighbourhood of virgin forest sites and associated landscape metrics

Patch ID	Site	Age	AREA (ha)	CORE (ha) (ED 50 m)	% of AREA	CORE (ha) (ED100 m)	% of AREA	FRAC
1	1	Before 1790	17.83	9.22	51.71	3.14	17.61	1.0788
2	1	Before 1790	20.44	8.11	39.68	1.05	5.14	1.1180
3	1	1790–1867	119.13	97.09	81.49	77.69	65.21	1.0497
4	1	1790–1867	203.37	156.35	76.87	115.07	56.58	1.1096
5	2	Before 1790	14.52	6.59	45.38	1.85	12.74	1.0975
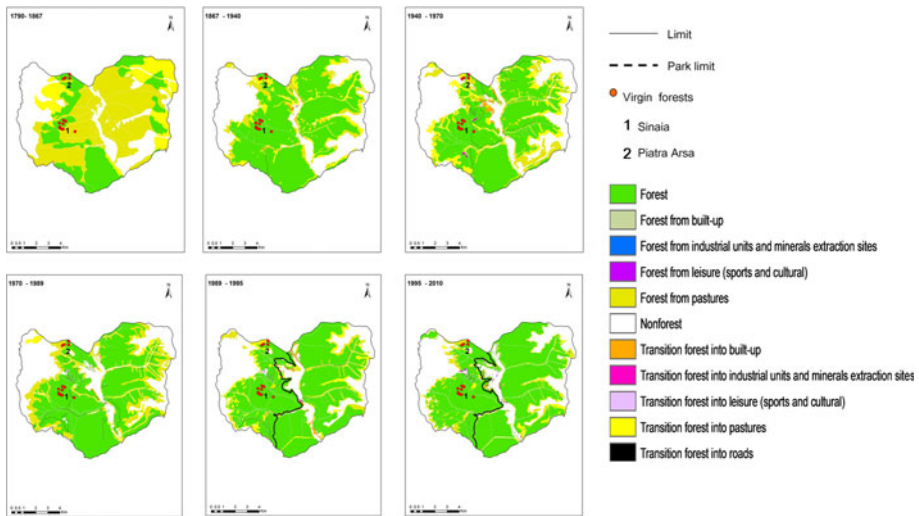
Fig. 2 Maps of forest transitions (1790–1867; 1867–1940; 1940–1970; 1970–1989; 1989–1995; 1995–2010)

gain corresponded to reforestation, whereas forest loss corresponded to deforestation (more details can be found in Online Resource 5). The analysis of the relative proportion of different trajectories indicated that during the period from 1790 to 1867, much land was reforested. From 1867 to 1940, the forest occupied over 60 % of the study area (see also Online Resource 6). Finally, the period from 1970 to 1989 was also characterized by a larger share of reforestation than deforestation, due to the efforts of the Romanian Academy since 1962 (Giurescu 1980), and to the measures stipulated in the 'National Program for the Conservation and the Development of the Forest Fund in the Period 1976–2010' (Romanian Government 1976). The other periods displayed a relative equilibrium between reforestation and deforestation. The largest changes in land cover were between forest and pastures. For instance, in the time period 1790–1867, forest gain at the expense of pastures represented 4,186 ha (more than 40 % of the site's area), whereas forest loss in favour of pastures was 1,376 ha (more than 10 % of the site's area).

Identification of forest patches with a long temporal continuity

First, the forest patches existing on the 2010 map were divided into five classes based on the origin of patches with different temporal continuity (Fig. 3). The first class represents forests present on the 1790 map and on all subsequent maps. The second class represents forest first present on the 1867 map and then on all subsequent maps, thus originating between 1790 and 1867. The other three classes were analogously defined for the years 1940, 1970 and 1989, respectively. The forest loss included patches that were converted to other land cover types in 2010. The sites of near-natural ('virgin') forests, represented in the Management Plan of Bucegi Natural Park (Romanian Government 2011) were mapped. In addition, the built-up and leisure areas were mapped (Fig. 3).

   We estimated that 15 % of the forest areas in the region present in 2010 appeared before 1790, and 27 % appeared during the 1790–1867 period. The presence of forested areas in the
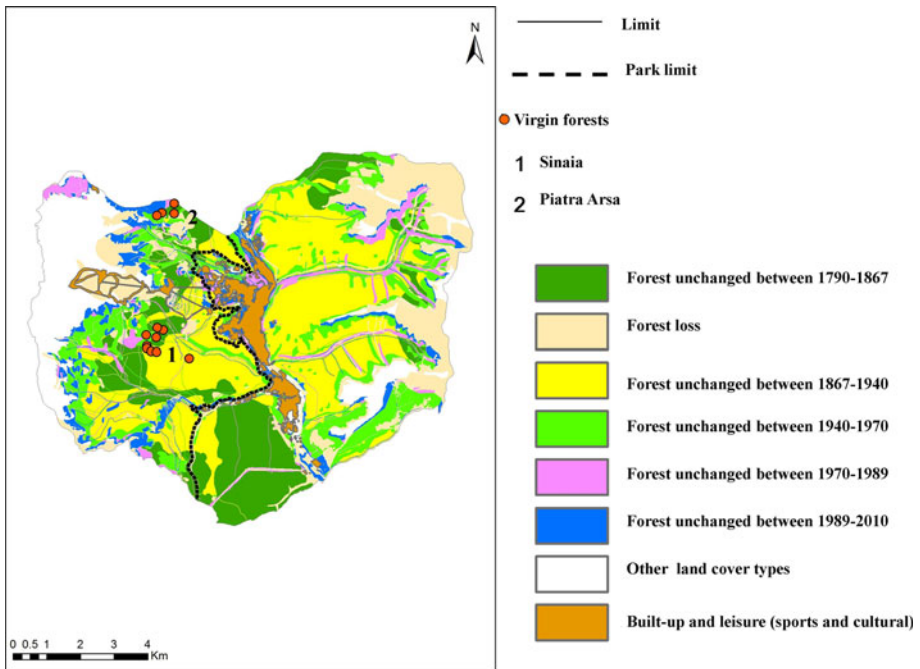
Fig. 3 Map of forest age and forest loss

study site was confirmed by a map from 1700 created by Cantacuzino. This map is descriptive, but it lacks a clear projection system. Therefore, it was not considered in our study due to the challenges of georeferencing and digitizing the map. The existence of old forests before 1790 in the study area was also confirmed by other sources. F. Mack, manager of the Royal Estate of Sinaia, noticed that before the Sinaia Monastery was founded, the surrounding forests were considered to be 'virgin forests' (Mack 1906) or 'secular (in the sense of several 100 years old) forests' (Brătescu and Moruzzi 1897). To produce a map delineating patches with a long temporal continuity, we included (1) forests existing before 1790 and (2) forest that appeared between 1790 and 1867. This separation corresponds to potential old-growth and potential aging forests or potential HCVFs (Fig. 4).

Using the location of 1790 and 1867 forests (Fig. 4), we estimated the loss of potential old-growth (i.e., forest in 1790) and potential aging forest (i.e., forest in 1867 minus forest in 1790) (Fig. 5a). Our results suggest that while the total forest cover has increased from 35 to 70 % over the past 230 years (see also Online Resource 4), forests from 1790 and 1867 that were still present today declined by 56 and 34 %, respectively (see also Online Resource 1). In addition, we assessed the core area proportion of all potential HCVFs, i.e. old-growth and potential ageing forests, in 2010 (Fig. 4). The analyses indicated that, in spite of increasing forest cover in general, the effective area for conservation of biodiversity and ecosystem services linked to continuous forest cover has been reduced. In 1790, the core area with an edge depth of 50 and 100 m represented 85 and 71 %, respectively, of the total forest cover. By 2010, the area of potential old-growth cores with an edge depth of 100 m represented 53 % of the potential old-growth forest area and 15 % of the total forest
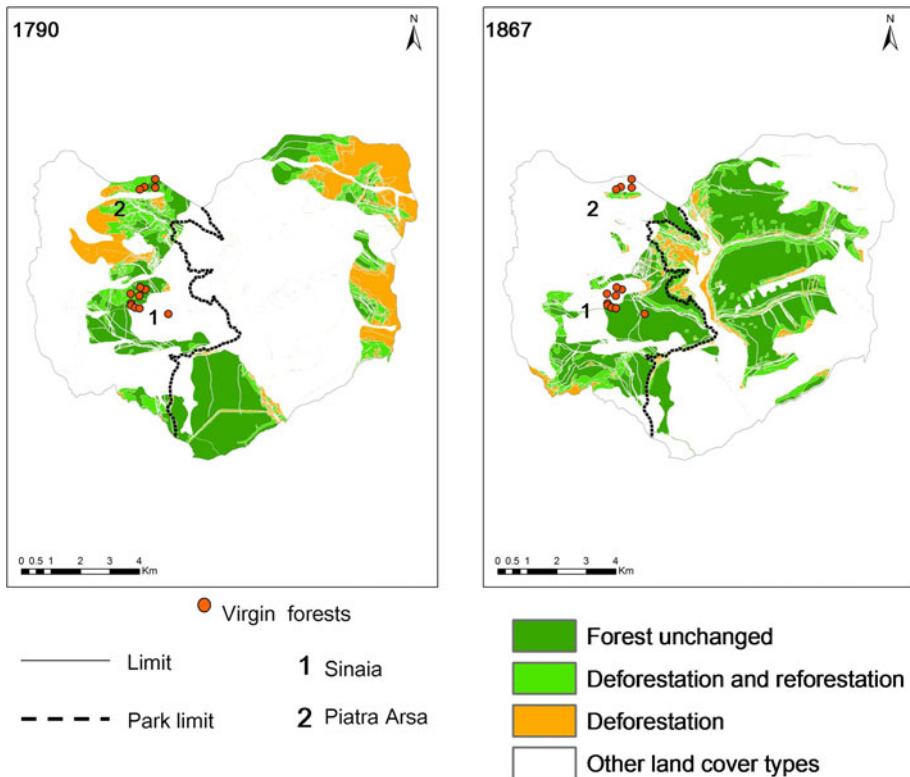
Fig. 4 Fate of forests existing in 1790 and 1867

cover in the study site. The area of cores with an edge depth of 50 m represented 73 % of the potential old-growth forest area and 20 % of the total forest cover (Fig. 5b).

To validate these results special attention was paid to two specific sites within the study area: (1) Sinaia and (2) Piatra Arsă (Fig. 4). These sites were represented in the Management Plan of Bucegi Natural Park (Romanian Government 2011) as virgin forests. Our analysis showed that these stands were actually located inside patches of HCVFs, including potential old-growth and aging forests as defined in this study. A selected set of landscape metrics (Table 1) provide additional information on the spatial patterns of these patches. The cartographic approach provided the opportunity for spatial analyses in the vicinity of these sites. In the case of site 1 (Sinaia), the development of access roads in the site perimeter was correlated to the expansion of built-up area and to the emerging tourism infrastructure. Furthermore, the larger value for the fractal dimension index *FRAC* (patches 2 and 4 of site 1) could be due to sporadic deforestations, which provided more complex borders. Along the western border of site 2 (Piatra Arsă), deforestations in favour of pasture expansion (having diverse uses, e.g., grazing, timbering) were recorded during the intervals 1940–1970 (intensive forest logging after 1947) and 1989–1995 (forest property reinvestment following incoherent legislation after the collapse of communism, see also Knorn et al. 2012a). Thus, we suggest that both sites are exposed to changes that could threaten the existing stands of virgin forests.

Fig. 5 Area and core area for
forests present in 1790 (i.e.
potential old-growth in 2010) and
in 1867 (i.e. potential ageing
forest in 2010). **a** *Graph* showing
the gradual loss of potential old-
growth and potential ageing.
b Estimates of the proportion of
all potential old-growth and
potential ageing forests in 2010
that form core areas with
different edges and patch sizes
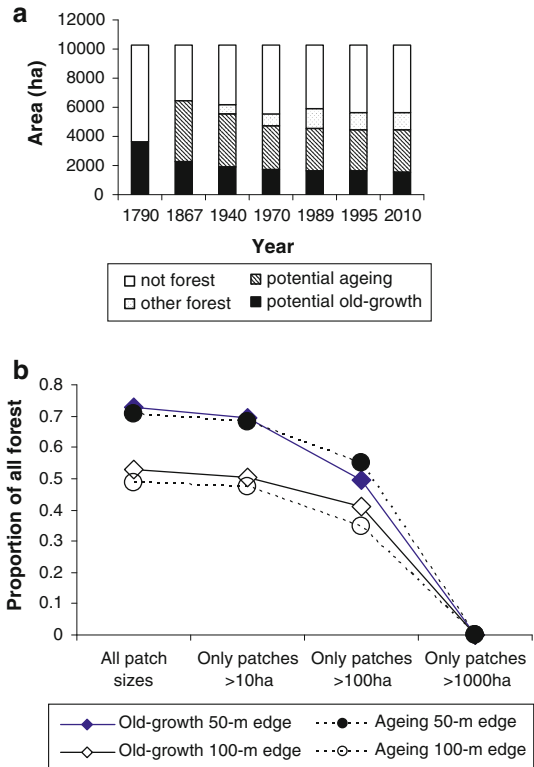
Discussion

Linking landscape dynamics and potential HCVFs

The results show that although the total forest cover increased in the study area, the area of
forests with a long temporal continuity (potential aging and potential old-growth forest) or
potential HCVFs, declined. Analysis of the forest cover changes indicates that large values
for the metric *AREA* were recorded for the period from 1790 to 1867, both in the case of
transitions from forests into pastures and vice versa. These transitions occurred in large
areas outside the case study, and were a result of a significant human forest intervention.
Historic documents confirm that the forests in the sub-alpine zone were subject to
extensive clearing to enlarge pastures (National State Forest Administration 2004). The
massive forestation recorded between 1790 and 1867 was potentially linked to the fores-
tation policies promoted in the region during the second half of the nineteenth century
(Giurescu 1980). It is worth noting that similar phenomena occurred in other regions of the
Carpathians (Kozak 2003). During the period 1867–1940, deforestation again occurred,
induced by the construction of the Royal Castle, and was compensated for by massive
reforestation, as a consequence of the requirements of forest policy issues during that
period (Mack 1906). Hence, a large area was deforested in the proximity of the forests that
are now considered natural forests. In addition to forest patch characteristics, the landscape
and regional scale connectivity of patches to satisfy the requirements of viable populations
need to be considered (Elbakidze et al. 2011). This applies in particular to species with
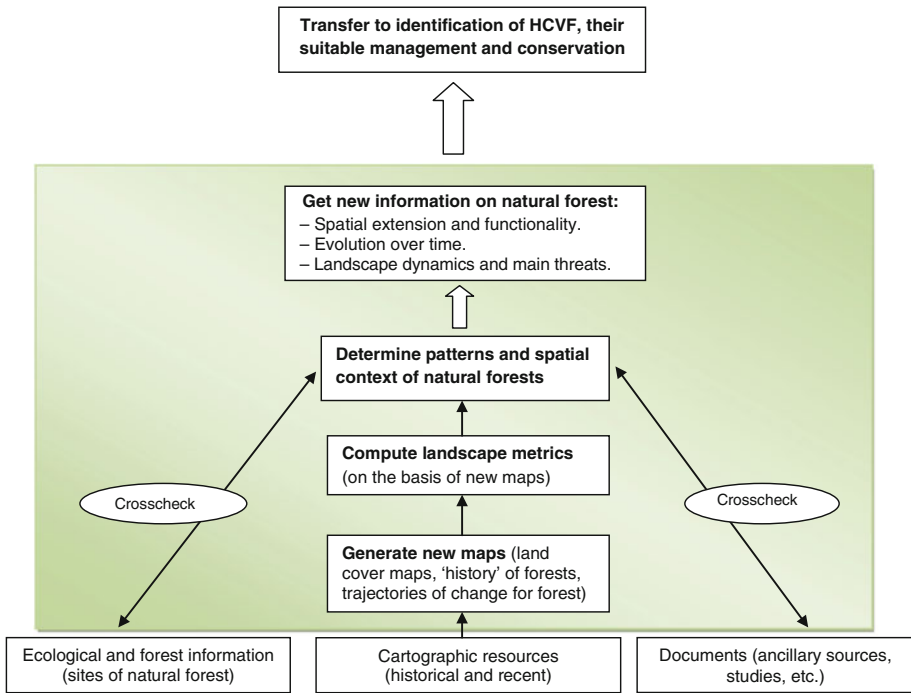
Fig. 6 Context of the research methodology

large home-ranges, such as woodpeckers and other species dependent on forest naturalness, raptors and large mammals (Edman et al. 2011, Knorn et al. 2012b, Rozylowicz et al. 2011). Considering also connectivity is a key aspect of assessing the functionality of habitat networks. For example, in a 144,877 km² large study area in Sweden, on average only 15 % (range 0–42 %) of the total area of four different forest habitats formed functional habitat networks that satisfied the requirements of the selected focal species (Angelstam et al. 2011b).

The challenge of mapping HCVFs

There are at least two types of data that need to be used to identify and assess the extent to which natural forests are functional HCVFs: ecological on different aspects of biodiversity (i.e. species, habitats and functions), and cartographic over long time (historical maps).

The methodology presented in this paper to map forests with a long temporal continuity (Fig. 6) focuses on the use of a temporal sequence of forest cover maps to quantify forest presence over time. Combined with ecological knowledge, spatial analyses allow for the identification of forest patches with temporal continuity and thus, at least potentially, aging and old-growth natural forests (Smiukse 2011). This integrated approach has at least two advantages.

(i) Maps allow the spatial visualization of potential natural forest patches in a broader spatial context that local forest stands and patches, and of the temporal dynamics of forest cover. The cartographic approach facilitates understanding natural forests using a landscape and regional perspective and strengthens their status as witnesses of landscape

history (Plieninger 2012). Multi-temporal analysis, on the basis of historical maps, facilitates understanding not only how close or far from each other the patches of natural forests are in the present, but also how these distances vary over time. Thus, the approach makes it possible to evaluate these patches not only with respect to the present configuration, but also according to their historical evolution (Kienast 1993). Furthermore, the analysis in a landscape context may reveal the factors that could affect the integrity of natural forests (Spies and Franklin 1996), by providing data on land cover dynamics and on trajectories of change involving forests.

(ii) Spatial analysis can be performed by using specific indicators such as landscape metrics or knowledge about what species require (Angelstam et al. 2013).

For instance, selected landscape metrics and ecological knowledge address the level of functionality of patches as components of green infrastructures. In addition, spatial modelling can be achieved by using evidence-based ecological knowledge about focal species (e.g., Angelstam et al. 2004) to determine the patterns and spatial context of potential natural forests patches (e.g., Kurlavicius et al. 2004). The information can be further processed in several distinct directions. By assessing the spatial extent, spatial distribution and juxtaposition of natural forest patches, one can better understand important ecological processes (e.g., Estreguil and Mouton 2009). For instance, information about the degree of forest fragmentation provides information relevant for the maintenance of old-growth characteristics (Jonsson et al. 2009). Another benefit of spatial analyses is an assessment of structural and functional landscape connectivity (Kindlmann and Burel 2008; Elbakidze et al. 2011).

The presented methodology also has some limitations. First of all, it allows the identification of forests stands having a certain historical continuity. However, this continuity does not automatically imply high conservation value because these forests might have been managed to the extent that their level of naturalness has declined. Another issue that must be treated carefully is related to the limited number of historical maps. The methodology is based on the assumption that a forest stand, which was present in two successive maps, had survived throughout the intervening period and no felling occurred. Hence, long time intervals between two successive maps decrease the precision of mapping the continuous presence of forest areas. These shortcomings can be mitigated by paying special attention to core areas or by categorizing as forest continuity only for those present stands with a substantial overlap of their area compared to the combined historical forest map (Fritz et al. 2008).

On the other hand, the use of historical maps in landscape reconstruction involves inaccuracies related both to the maps (scale and projection differences as well as thematic interpretation and resolution) and to the integration in a Geographic Information System (Rogan and Miller 2006, Stäuble et al. 2008). Thus, forest continuity should be complementarily corroborated with the use of forestry databases (e.g., Elbakidze et al. 2011) or with ecological criteria such as species continuity (Moning and Müller 2009) in the framework of multi-criteria analysis of HCVFs.

In the Romanian context, the methodology presented in the paper could contribute to enhancing the knowledge of both what high conservation values are, and localisation of HCVFs. Both academics and practitioners have pointed out that the Romanian Carpathians include significant surfaces of 'virgin' forests (e.g., Giurgiu et al. 2001). Many attempts have been made in the last several years to identify, inventory and map these forests (Biriş and Veen 2005). It is worth noting that the most recent version of the Romanian HCVF toolkit (Grigore et al. 2012) explicitly includes the 'virgin' forests as having high conservation value. The toolkit provides information about *potential* locations of HCVFs in

Romania and mentions the necessity of further investigations for the assessment of forest habitats. From this perspective, we assume that a cartographic based approach, and spatial analyses based on ecological knowledge, could also bring added value as a component of a multi-criteria analysis. Thus, our methodology might be used as the first step in the identification of potential HCVFs. It may be applied also for a region where natural forests have been found already because it can contribute to the validation of other methods, or it can provide additional information useful in spatial analyses. In this study, we focused on a site where natural forests have previously been identified and studied but not yet analyzed with respect to their functionality in a landscape context. Applying the methodology in a case study landscape confirmed its usefulness because the sites of natural forests (identified in situ) were indeed located inside patches of forest continuity. Altogether, the methodology can effectively contribute to the identification and monitoring as well as the governance and management of HCVFs as a base for providing green infrastructure for biodiversity conservation and the delivery of ecosystem services (Angelstam et al. 2011b).

Conclusions

Our approach to identifying potential HCVF stands is a response to the need to better understand the factors that threaten the integrity and the conservation of natural forest remnants (Spies and Franklin 1996). By using a sequence of historical and contemporary maps as well as ecological knowledge, both the spatial and temporal dimensions of natural forest patches as components of green infrastructures can be assessed. This case study demonstrates that without such analyses and the incorporation of ecological knowledge that negatively affect the functionality of HCVFs, the area extent of such forests is severely overestimated. An additional reduction in HCVF functionality is expected when considering connectivity as required by area-demanding species. In this case study, the forests that were already present before 1790 were revealed to be the most vulnerable. The forests that appeared between 1790 and 1867 should also be protected and conserved. In conclusion, appropriate planning strategies are necessary for sustainable management of these high conservation value forest sites.

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