Gap Analysis as a Basis for Strategic Spatial Planning of Green Infrastructure: A Case Study in the Ukrainian Carpathians

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Per Angelstam
Swedish University of Agricultural Sciences

Taras Yamelynets
Ivan Franko National University of Lviv

Marine Elbakidze
Swedish University of Agricultural Sciences

Bohdan Prots
State Museum of Natural History, National Academy of Sciences, Lviv, Ukraine

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ARTICLE

Gap analysis as a basis for strategic spatial planning of green infrastructure: a case study in the Ukrainian Carpathians

Per Angelstam[a], Taras Yamelynets[b], Marine Elbakidze[a], Bohdan Prots[c,d] and Michael Manton[e]

[a]Faculty of Forest Sciences, School for Forest Management, Forest-Landscape-Society Network, Swedish University of Agricultural Sciences, Skinnskatteberg, Sweden; [b]Faculty of Geography, Ivan Franko National University, Lviv, Ukraine; [c]WWF Danube Carpathian Programme, Lviv, Ukraine; [d]State Museum of Natural History, National Academy of Sciences of Ukraine, Lviv, Ukraine; [e]Institute of Forest Biology and Silviculture, Aleksandras Stulginskis University, Akademija, Lithuania

ABSTRACT
Increased demand for natural resources and economic transition threaten natural and biocultural capital and thus ecosystem services for human well-being. We applied an evidence-based approach to strategic planning of functional green infrastructure in a European biodiversity hotspot: the Ukrainian Carpathian Mountains. We (1) described how potential natural vegetation types have been transformed, (2) applied evidence-based critical thresholds for each potential natural vegetation land cover, (3) measured how much of the potential natural vegetation land covers are protected, and (4) estimated the area of cultural landscapes that emerged. While only 2% of lowland land cover types were left, 55% of mountain forests and 94% of alpine land covers remained. Many mountain forests were transformed to valuable cultural landscapes. Beech and oak forests covered 42% of the study area but at low levels of protection (<5%). The highest protection level (12–17%) was in mixed beech–fir–spruce and in spruce forests. However, taking connectivity into account, only alpine land covers formed a functional habitat network. More areas need to be protected and planned to build a functional green infrastructure. Traditional village systems with biocultural values need support. We discuss how strategic analyses can encourage collaborative spatial planning and international development cooperation.

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RÉSUMÉ
La demande accrue en ressources naturelles et la transition économique menacent le capital naturel et bioculturel et, par conséquent, les services écosystémiques nécessaires au bien-être humain. Nous avons appliqué une approche fondée sur des données probantes à la planification stratégique de l'infrastructure fonctionnelle verte dans un *hotspot* européen de biodiversité – les Carpates ukrainiennes. Nous avons (1) décrit comment les types de végétation potentielle naturelle ont été transformés, (2) appliqué des seuils critiques basés sur des données probantes au recouvrement de chaque type de végétation potentielle naturelle, (3) mesuré la proportion du recouvrement des types de végétation potentielle naturelle sous protection, et (4) estimé la superficie des paysages culturels. Alors qu'il ne restait que 2% des recouvrements de basses terres, il restait 55% des forêts de montagne et 94% des recouvrements alpins. Ce sont surtout les forêts de montagne qui ont été transformées en paysages culturels. Les forêts de hêtres et de chênes couvraient 42% de l'aire d'étude, mais à de faibles niveaux de protection (<5%). Le niveau de protection le plus élevé (12–17%) était pour les forêts mixtes de hêtre-sapin-épinette et pour les forêts d'épinette. Cependant, en tenant compte de la connectivité, seuls les recouvrements alpins formaient un réseau d'habitats fonctionnel. Plus de superficies doivent être protégés et faire l'objet de planification afin de mettre en place une infrastructure fonctionnelle verte, et les systèmes villageois traditionnels basés sur des valeurs bioculturelles doivent être soutenus. Nous discutons de la manière dont les analyses stratégiques peuvent encourager la planification spatiale collaborative et la coopération internationale pour le développement.

Introduction

According to the European Commission (2013), a green infrastructure (GI) is 'a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services … in both rural and urban settings'. The GI concept was developed to communicate the need to maintain natural capital by spatial planning (e.g., Thomas and Littlewood 2010). A key tool towards functional GI is to establish effectively and equitably managed, ecologically representative, well-connected systems of protected areas. With a long land use history, implementation of such policy on the ground in Europe requires systematic

CONTACT Per Angelstam per.angelstam@slu.se

analyses of the amount of different representative natural and anthropogenic land covers in a region, and comparison with evidence-based knowledge about how much area is enough to maintain functional habitat networks (Lõhmus et al. 2004; Angelstam et al. 2011a). Given globally high rates of landscape change, it is crucial to provide both policy- and decision-makers involved with governance and management with such analyses. This applies in particular to regions where landscapes still host high levels of naturalness (Peterken 1996) and biocultural authenticity (Agnoletti 2013).

The human footprint accumulated during hundreds of years of gradually intensified land use in Europe has resulted in gradients of landscape alteration from the centres of economic development to less-impacted remote regions (Mikusiński and Angelstam 2004; Konvička et al. 2006). Von Thünen (1910) noted that the type and intensity of land use were related to distance from the market. In his review of rural Europe, Whyte (1998) concluded that areas with less impact are still concentrated in northern Europe, the Atlantic periphery and mountain areas in the Mediterranean and in Central Europe. While the latter region often has a reputation of being dominated by polluted environments due to heavy industrial development during the socialism period (Szaro et al. 2002), the biodiversity status of forests and cultural landscapes is far better than in Western Europe (e.g., Puumalainen et al. 2003; Edman et al. 2011). A major reason behind this is a shorter history of economic development based on intensive use of renewable natural resources, compared to most of Western Europe (Gunst 1989). The demand for grain, timber and other primary products was satisfied by imports from the periphery of the spreading industrial revolution (Gunst 1989), reached Hungary, Romania and Ukraine in the eighteenth to nineteenth century for grain (Turner et al. 1993), and then spread into increasingly remote forests (Fröhlich 1954). The exploitation of these resources was dependent on the development of railways and roads for transportation of the bulky products (Turnock 2001). Rapid changes in traditional land use patterns due to political and socio-economic changes since World War II (e.g., Kulak and Chmielewski 2010; Munteanu et al. 2014), and after the collapse of the socialistic system in Europe in the 1990s (Baumann et al. 2011), means that the maintenance of biodiversity and cultural landscape values is no longer automatically provided as a product of traditional land use resulting from economic remoteness (von Haaren 2002; Young et al. 2007). Remnants of such landscapes are important for the conservation of natural and cultural biodiversity *in situ* and as references for biodiversity restoration elsewhere. Economic remoteness in Europe has both a West–East dimension and a lowland–mountain dimension (Angelstam 2006). In the Carpathian Mountains these two dimensions co-occur, which explains why this ecoregion is a hotspot for natural forest biodiversity and biocultural heritage (Reif et al. 2008; Angelstam et al. 2013a).

In terms of naturalness, the Carpathians host a high level of endemism, over half of the European continent's populations of large carnivores (Mosbach and Webster 2001; Salvatori et al. 2002) and large remnants of naturally dynamic forests (Commarmot et al. 2013). The Carpathian Mountains thus play a pivotal role for connectivity between Central and Western Europe. However, Carpathian ecosystems and their biodiversity are under serious threat from a number of pressures resulting from changing land use and unregulated human impact, driven in large part by increasing integration of the region into the global economy. Illegal logging, poaching, uncontrolled livestock grazing, agriculture and infrastructure development are leading to the degradation of the region's exceptional natural heritage and ecosystem services (e.g., Dubis et al. 2006; Bogdan et al. 2016). Measures to address these threats, including effective controls as well as efforts to channel socio-economic development in a sustainable manner, are limited and hampered by scarce resources, capacity and technical expertise (Prots et al. 2012).

Biocultural values in terms of high nature value farmlands are also crucial for the maintenance of processes, habitats and species in the Carpathian Mountains (Angelstam et al. 2013a). In particular, semi-natural grasslands of high conservation value were created by centuries of traditional land management. These biocultural values were created within the traditional village system, which has been the social-ecological unit for a long time in Europe and beyond. This was defined by the traditional land use of pre-industrial cultural landscapes, and a spatial structure with land use zones such as the *domus-hortus-ager-saltus-silva* system from houses and infields to outfields and forest. This system satisfied multiple needs and formed an inclusive governance arrangement (e.g., Erixon 1960; Elbakidze and Angelstam 2007). Traditional village systems also carry traditional knowledge, local culture, innovations and practices of indigenous and local communities which have been gained over many years and are adapted to the environment (Berkes et al. 2000).

Natural and cultural landscapes' biodiversity has intrinsic value, in addition to providing a wide range of ecosystem services affecting local and regional human well-being (Elbakidze and Angelstam 2007; Keeton and Crow 2009). It is thus crucial to assess the extent to which current conservation efforts by area protection are likely to be successful in the long term. Gap analysis is a method that strategically assesses the extent to which networks of areas set-aside for conservation represent the different land covers of a region (e.g., Scott et al. 1987). The original intent was 'a quick overview of the distribution and conservation status of several components of biodiversity' (Scott et al. 1993). Subsequently, empirical knowledge about what determines habitat quality and how much habitat is needed to maintain functional habitat networks for biodiversity conservation have been improved (e.g., Angelstam et al. 2004; Svancara et al. 2005; Tear et al. 2005; Villard and Jonsson 2009). Such quantitative gap analyses have been instrumental to communicate evidence-based knowledge at the science-policy interface, and have resulted in increased areas for conservation (Angelstam and Andersson 2001; Lõhmus et al. 2004; Angelstam et al. 2011a). This applies to potential natural vegetation types and takes into account the historical range of variability of semi-natural areas that result from human land management.

According to the Strategic Plan for Biodiversity 2011–2020 and the Aichi Biodiversity Targets (CBD 2010), the mission is to 'take effective and urgent action to halt the loss of biodiversity in order to ensure that by 2020 ecosystems are resilient and continue to provide essential services, thereby securing the planet's variety of life, and contributing to human well-being, and poverty eradication'. Recent work of the Convention of Biodiversity (CBD) has addressed this regarding both protected areas (Aichi target 11) and the surrounding matrix (Aichi target 7). Aichi target 11 states that at least 17% of terrestrial and inland water areas shall be protected (CBD 2010) and areas 'are conserved through effectively and equitably managed, ecologically representative and well-connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscape and seascape' (CBD 2010). Regarding the matrix surrounding protected areas, Aichi target 7 states that 'By 2020 areas under agriculture, aquaculture and forestry are managed sustainably, ensuring conservation of biodiversity'.

The aim of this study is to present and apply a simple, evidence-based systematic approach based on the landscape concepts in geography (Angelstam et al. 2013c) to strategic spatial planning towards learning for conservation, management and restoration of functional GI in a biodiversity hotspot under threat, exemplified by the Ukrainian Carpathian Mountains (e.g., Zingstra et al. 2009). First, we carry out a regional analysis of the transitions of representative types of potential natural vegetation to land covers managed to derive human benefits. Second, we compare the present amount of representative land covers with what is likely needed to maintain natural biodiversity in the long term, based on evidence-based knowledge about tipping points for how much habitat loss can be accepted without losing representative species. Third, we compare the threshold amount of protected areas to the current amount among representative land covers. Finally, we discuss how diagnoses of the amount, representativeness and area protection of representative land covers in a region can be used for collaborative learning towards natural biodiversity conservation and maintenance of biocultural values for human well-being.

Study area

The Carpathian Mountain ecoregion is divided among seven European countries and is one of the most important areas for biodiversity conservation in Europe (Kozak et al. 2013). Being in a dramatic economic and political transition, Ukraine's contribution in the central part of the Carpathian Mountains is particularly interesting. In Ukraine, the Carpathian Mountains extend over an area of 21,000 km^2 between the rivers Dnister in the north and the Tisa tributary of the Danube in the south. This represents 10.3% of the total area of the Carpathian Mountains. The altitude ranges from 95 to 2061 m above sea level (a.s.l.) but 94% of the area is at <1200 m altitude (Figure 1). The climate is temperate with a moderate continental

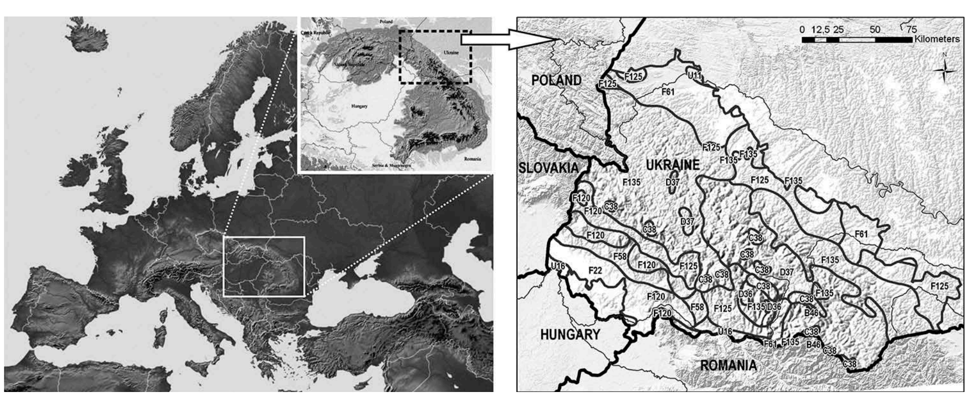


Figure 1. Location of the study region in Europe (left), and the 12 different categories of potential natural vegetation (right) found in the Ukrainian Carpathian Mountains according to Bohn et al. (2000).

influence and varies markedly with relief and aspect. Mean temperature ranges from 22 to 6°C in summer, and from −3 to −13°C in winter; annual precipitation is 900–1250 mm (Buchinskyi et al. 1971). Climate change is, however, emerging as an important factor in terms of higher temperatures, less rain and shorter winters (Gurung et al. 2009).

Below the tree-line at 1200–1600 m a.s.l. the potential natural vegetation of the Ukrainian Carpathian Mountains is forest and woodland. Wind, snow, frost, fire and flooding once resulted in wide-spread natural disturbance regimes characterised by old and large trees, diverse horizontal and vertical structure, and large amounts of dead wood in various stages of decay (Herenchuk 1968; Kalutskyi and Oliynyk 2007; Commarmot et al. 2013). Four altitudinal zones of natural vegetation have been defined for the Ukrainian Carpathians (e.g., Bohn et al. 2000): (1) Foothills and adjacent plains (<300 m a.s.l.) with broadleaved forests with pedunculate and sessile oaks (*Quercus robur* and *Q. petrea*) mixed with European beech (*Fagus sylvatica*), hornbeam (*Carpinus betulus*) and ash (*Fraxinus angustifolia*); (2) The lower mountain zone (300–1100 m) with beech, sycamore maple (*Acer pseudoplatanus*), silver fir (*Abies alba*) and Norway spruce (*Picea abies*); (3) The upper mountain zone (1100–1500 m) with coniferous species, mainly Norway spruce and Arolla pine (*Pinus cembra*); (4) Above the tree-line, large fragments of mountain pine (*Pinus mugo*), green alder (*Alnus viridis*), juniper (*Juniperus communis* subsp. *alpina*), shrub habitats and alpine grasslands dominate (Kruhlov 2008; Kuemmerle et al. 2009).

With considerable areas of near-natural mountain forests, the centrally-located Ukrainian portion of the Carpathian Mountains is crucial for maintaining ecological connectivity for forest species (Webster et al. 2001; Commarmot et al. 2013). However, after a long history of both continuous cover and even-aged forestry, forests are increasingly being subject to clear-felling (Kuemmerle et al. 2006, 2008; Potapov et al. 2015) with limited subsequent silviculture. The ecoregion is also home to several ethnographic groups of Ukrainians – Lemko, Boiko and Hutzul – who shaped mountain landscapes for centuries and created a rich biocultural heritage at different altitudinal levels (Hajda 1998). Thus, while some near-natural forests remain, in most of the Carpathian ecoregion pre-industrial cultural landscapes evolved in the valleys (Angelstam et al. 2013a). These form traditional village systems with infield houses, gardens, fields and meadows, as well as outfield meadows and pastures. This complex agroforestry, woodland and forest landscape provides multiple tangible benefits to rural areas, and forms a cultural heritage of key importance for rural development and human well-being (Elbakidze and Angelstam 2007). However, while traditional cultural landscapes are still wide-spread (Angelstam et al. 2003; Elbakidze and Angelstam 2007, 2013), they are threatened by abandonment (Baumann et al. 2011) and infrastructure development for recreation and tourism (Prots et al. 2010). Some agricultural land is gradually transforming into forest after cessation of agricultural activities and land abandonment (Kuemmerle et al. 2008).

Methodology

Overview of the approach to gap analysis for conservation planning

Quantitative gap analysis in the context of systematic territorial planning for functional GIs involves comparison of (1) the current distributions of land covers such as different vegetation types, and thus habitats and related species and ecosystem processes, with (2) their distribution and abundance in the past, (3) evidence-based knowledge about how much habitat is enough to maintain natural capital, i.e., biodiversity *sensu* (Noss 1990) and (4) the amount of current areas set-aside for conservation. Inspired by the US Gap Analysis Program (Scott et al. 1993; Scott and Jennings 1998; Jennings 2000), Angelstam and Andersson (2001) carried out gap analysis for Sweden, Lõhmus et al. (2004) for Estonia and Angelstam et al. (2005) for Latvia. This was based on a systematic approach (Table 1) to identify gaps in the area of habitat requiring restoration and re-creation of habitats (e.g., Burton and Macdonald 2011).

The results from quantitative gap analysis can then be fed into a hierarchical conservation planning processes (e.g., Angelstam et al. 2011a). This involves (1) formulation of quantitative targets of area extent where natural

Table 1. Summary of variables that need to be parameterised for quantitative regional gap analyses concerning the proportion of a land cover type that needs to be maintained by protection, management and restoration to maintain viable populations of species in an ecoregion (after Angelstam and Andersson 2001; Angelstam et al. 2011a).

Variable	Description
A	The past amount of a particular potential natural vegetation[a]
B	Today's amount of a particular potential natural vegetation
A − B	Representativeness of potential natural vegetation
C	Empirical knowledge of the proportion of a particular land cover required for retaining a viable population of a given species
A*C	Long-term target for the amount of a particular land cover
B − (A*C)	Gap (if the value is negative) or surplus (if the value is positive)

[a] natural range of variability (NRV; Cyr et al. 2009) in naturally dynamic forest landscapes (e.g., Winter 2012), or historical range of variability (HRV; Keane et al. 2009), such as in traditional cultural landscape (e.g., Erixon 1960).

and anthropogenic land covers are maintained that are not compatible with intensive forestry and agriculture (e.g., Svancara et al. 2005), (2) development of tactical spatial planning based on analyses of the functionality of different types of set-asides as GI (e.g., Elbakidze et al. 2016) and (3) operational execution of these plans by establishing set-asides with appropriate management, including allocation of required funding to carry out management, to compensate land owners for the limitations in land use that follow from area protection or to acquire land for conservation.

Potential natural vegetation

The basis for setting strategic quantitative conservation goals is a thorough understanding of the composition, structure and function of the land covers of a region in time and space. This includes knowledge about the environmental or landscape history (e.g., Östlund et al. 1997; Ranius and Kindvall 2006; Angelstam et al. 2013b; Naumov et al. 2016), including how to emulate natural disturbance regimes for conservation of natural capital (e.g., Fries et al. 1997) and the insight that cultural woodlands host bio-cultural values (e.g., Zechmeister et al. 2003). Contrary to what may be suggested by overly simplistic indicators of biodiversity such as forest cover in general (EEA 2007), there are many different representative natural and anthropogenic land cover types in any region, all involving a diversity of species, habitats and processes at different spatial scales.

We analysed land covers using the map of potential natural vegetation for Eastern Europe at the scale of 1:2,500,000 (Gribova et al. 1974, adopted by Bohn et al. 2000). The map includes a descriptive legend and a detailed explanatory text with a phytogeographical overview of the European part of the ex-USSR as well as short descriptions of all mapped units.

Critical habitat loss

A population's persistence in a landscape or region depends on how much habitat there is, whether individuals or propagules can move between different patches of suitable habitat and how the habitat network is maintained over time (Hanski 1999, 2005; Nordén et al. 2014). Additionally, the role of the matrix among habitat patches needs to be understood. While the term biotope refers to an environmentally uniform area, i.e., a natural or anthropogenic land cover with fine thematic resolution, a habitat is defined by the requirements of a species or population and often includes several biotopes (Udvardy 1959). Thus, a habitat often consists of a number of biotopes (i.e., land covers), such as for feeding, cover and breeding (e.g., Tendeng et al. 2016). Therefore, there is a need to identify and assess the quality, size and spatial distribution of biotopes that form habitats. However, habitats are more than just biotopes or land covers; predators, competitors or micro- and macroclimate also affect the functions of biotopes. The combination of decreasing amounts of habitat, which in turn decreases the number of individuals that can be supported, and increased fragmentation, which makes it harder for individuals to move in the landscape, are the most common reasons why species disappear locally, regionally and completely (Andrén 1999; Fahrig 2003).

There is both theoretical and empirical evidence for the existence of thresholds for extirpation of a population as the amount of available habitat is reduced (Bender et al. 1998; Andrén 1999; Fahrig 2003). The threshold refers to the fact that the risk for population extinction shifts from low to high within a limited range of further loss of habitat (Guénette and Villard 2004). That there are limits to how much of different forest habitats may disappear without threatening the viability of populations of all naturally occurring species forms the basis of the formulation of long-term evidence-based performance targets for how much of different forest habitats are needed (e.g., Angelstam et al. 2004; Svancara et al. 2005; Tear et al. 2005). There is a clear parallel to the concept of critical load, which addresses the question of how much deposition of, for example, nitrogen and sulphur ecosystems can tolerate (Nilsson and Grennfelt 1988).

There are two key thresholds or tipping points. The first is when contiguous habitat is broken up into patches, thus no longer permitting percolation of individuals or propagules of different species through an un-fragmented habitat (With and Crist 1995; Bascompte and Sole 1996). We used a threshold of 40% remaining forest land as habitat for the potential occurrence of species that need contiguous forest (Fahrig 2003; for details see Angelstam et al. 2017). The second key threshold is when inter-patch distance increases, leading to patch isolation. We used a target value of 20% as the minimum necessary habitat proportion (e.g., Angelstam et al. 2004; Betts and Villard 2009).

Protected areas

According to the International Union for Conservation of Nature (IUCN), a protected area is an area that has been identified as important for nature conservation. Some protected areas allow industry, extensive agriculture or fishing to occur within their boundaries, while others prohibit all of these activities. IUCN has identified seven different protected area categories based on management objectives (Dudley et al. 2013). According to the

Ukrainian legislation (Nature Reserve Fund of Ukraine), protected areas (PAs) are formed by land and water areas, and natural complexes, which have special environmental, scientific, aesthetic, recreational and other values (The Law of Ukraine 1992). These are protected as a national asset to conserve the biodiversity of landscapes, the gene pool of flora and fauna, maintain the overall ecological balance and ensure background monitoring of the environment. We obtained spatial data with national and regional PA borders from the GISdatabase of the international project 'Protection and Sustainable Use of Natural Resources in the Ukraine Carpathians' UA0004.5, which was implemented by the WWF-Danube-Carpathian Program (2007–2012). We also used spatial data available from the Departments of Ecology and Natural Resources in the Lviv, Zakarpathia and Ivano-Franko regions (http://www.ekologia.lviv.ua; http://ecozakarpat.gov.ua; http://www.if.gov.ua).

The Nature Reserve Fund of Ukrainian Carpathians includes almost 1500 objects (Prots et al. 2010; Baitsar 2012); over 200,000 ha of PAs have been established. At the national level there are the Carpathian Biosphere Reserve, Gorgany Strict Nature Reserve (category IUCN – Ia) and seven National Nature Parks (NNP) (category IUCN V). At the regional level there are regional landscape parks (category IUCN V), nature reserves (category IUCN – IV), natural monuments (category IUCN – III) and protected sites (category IUCN – Ib). Almost all large PAs were established during 1960–1990. Additionally, in 2009–2010 several large national PAs were established such as Zacharovanyi krai NNP, Cheremoskyi NNP, Verhovynskyi NNP as well as several protected sites of national importance. Most of these protected areas are of European importance, but some are of global importance. Fragments of beech forests in the Carpathians (Carpathian Biosphere Reserve and Uzhanskyi NNP) are included in the UNESCO World Heritage List (http://whc.unesco.org/en/list/1133).

Analytic procedure

The different types of potential natural vegetation (e.g., Herushynskyy 1996), to which species have adapted in the Carpathian Mountain region, were taken from Bohn et al. (2000). The polygon data for potential natural vegetation was extracted using the borders of the Carpathian Mountains in Ukraine. The vector data included 49 polygons with 12 types of potential natural vegetation, i.e., the area of potential natural vegetation (A) (Table 1). To estimate today's actual land covers (B) we used the CORINE land cover data base developed by Kuemmerle et al. (2009). The raster CORINE data includes 10 classes (coniferous forest, broadleaved forest, mixed forest, succession areas, grasslands, water bodies, cropland, dense settlements, open settlements, bare rocks; Table 2). We then calculated representativeness (A–B), the long-term target for the amount of a particular land cover (A*C) and the gap/surplus (B – (A*C); see Table 1). Next, we estimated how much of the potential natural vegetation land covers are under different forms of protection. Finally, to estimate the functionality of the networks of protected areas (e.g., Elbakidze et al. 2016), we applied a correction factor of 20–40% of habitat patches being sufficiently large and spatially concentrated to form a functional connected network (see Angelstam et al. 2011a, p. 1123).

Table 2. Definition of current land covers (CORINE land cover by Kuemmerle et al. 2005) and their absolute and relative covers.

Type of current land cover	Area (km^2)	%
Coniferous forest	5934	19.4
Deciduous forest	6004	19.7
Mixed forests	4763	15.6
Croplands (arable land)	2127	7.0
Succession areas	2903	9.5
Grasslands	5641	18.5
Bare rock	21	0.1
Water objects	131	0.4
Villages	2792	9.1
Cities and towns	212	0.7
TOTAL	30,528	100

Results

Potential natural vegetation (A)

The largest areas were covered by beech–fir–spruce (F135) and beech (F120) forests (38%), Norway spruce forests (D36 and D37; 19%) and beech–hornbeam–fir forests (F125; 18%) (Table 3). The rest were different types of oak forests (F22, F58 and F61; 21%), alluvial floodplain forests (U16 and U11; 2%), sub-alpine (C38; 3%) and alpine (B46; <1%) vegetation types. There were also differences in vegetation types in accordance to slope aspect ranging from warm south-facing low hills covered by oak (F22), mixed oaks (F58), beech–hornbeam–fir (F120) forests, north-facing slopes with mixed oak (F61) and beech (F125) forests (Table 4).

Today's land covers (B)

The current distribution of land cover types among different types of natural vegetation is shown in Table 5. Forests (55%) and grasslands (19%) were the most important land covers in the Ukrainian Carpathian Mountains

Table 3. Definition of potential natural vegetation types according to Bohn et al. (2000), their areas and proportions within the Ukrainian Carpathian Mountains.

Potential natural vegetation	Code	Characteristic species	Area (km^2)	Proportion (%)
Alpine	B46	Alpine meadows	18	0.1
Sub-alpine	C38	*Pinus mugo, Rhododendron myrtifolium*	769	2.5
Spruce	D37	*Picea abies, Abies alba*	5657	18.5
	D36	*Picea abies*	65	0.2
Beech–fir–spruce	F135	*Abies-Fagus, Picea-Abies-Fagus*	10,460	34.2
Beech–hornbeam–fir	F125	*Fagus, Fagus-Carpinus-Abies*	5475	17.9
Beech	F120	*Fagus*	1100	3.6
Oak mixed	F58	*Carpinus, Quercus petraea/robur, Tilia*	1060	3.5
	F61	*Carpinus, Quercus petraea/robur, Fagus sylvatica,*	3520	11.5
Oak	F22	*Quercus robur*	1906	6.2
Alluvial forest	U11	*Quercus robur, Ulmus laevis, Alnus glutinosa, Populus nigra, Salix alba, S. fragilis*	110	0.4
	U16	*Fraxinus angustifolia, Ulmus laevis, Populus alba, P. nigra, Salix alba, Carpinus, Quercus robur*	425	1.4
SUM			30,572	100

Table 4. Classification of types of potential natural vegetation (see Table 2) among altitudes and aspects in the Ukrainian Carpathian Mountains and surroundings.

		Types of potential natural vegetation								
Altitude (m)	Aspect	Floodplain	Oak	Oak mixed	Beech	Beech–hornbeam–fir	Beech–fir–spruce	Spruce	Sub-alpine	Alpine
>1600 m	-								C38	B46
500–1600 m	N			F61	F125		F135	D36, D37		
	S			F58		F120				
<500 m	N	U11								
	S	U16	F22							

Table 5. Distribution of CORINE land cover classes (Kuemmerle et al. 2005) in each type of potential natural vegetation according to Bohn et al. (2000).

Type of potential natural vegetation		CORINE land cover classes (km^2)										
Description	Code	Coniferous forest	Deciduous forest	Mixed forests	Succession areas	Grasslands	Croplands	Village	Urban	Bare rock	Water	Sum
Alpine	B46	2	0	1	1	15	0	0	0	2	0	21
Sub-alpine	C38	386	145	71	4	137	0	2	0	5	0	750
Spruce	D37	3197	399	768	102	1010	6	47	11	12	4	5556
	D36	4	39	11	0	10	0	0	0	0	0	64
Beech–fir–spruce	F135	2000	2814	1947	553	2424	136	501	26	2	31	10,434
Beech–hornbeam–fir	F125	269	1389	1050	731	909	339	736	25	0	33	5481
Beech	F120	10	594	106	94	144	49	87	5	0	3	1092
Oak mixed	F58	4	271	78	137	177	149	213	21	0	6	1056
	F61	50	132	536	922	525	574	709	44	0	19	3511
Oak	F22	8	148	147	229	220	739	326	59	0	22	1898
Alluvial forest	U11	0	2	10	35	18	19	23	1	0	0	108
	U16	4	25	38	95	52	67	109	16	0	10	416

(Table 5, Figure 2). The area of settlements and croplands was 17%. In the subalpine zone (600 km^2), the forest cover was 80%. In the typical mid-altitude forest zones (D37, F135, F125, F120), almost 20% have been transformed to grasslands. Mixed beech forests (F125, F135) were partly replaced by coniferous forests (14%), grasslands (21%) or settlements (8%). Due to the long history of land use and management, the Carpathian Mountain foothills and low mountains (<600 m), once covered with oak-dominated forests, have been transformed to croplands (23%), settlements (21%), successional areas (20%) and grasslands (14%).

Beech–fir–spruce forest (F135) was the dominating land cover (Figure 3, top). The proportions of the original forest cover that have been historically transformed to settlements and cropland ranged from 67–83% in alluvial and oak forests to 21–54% in beech forest. Settlements and croplands were almost absent (1%) at higher

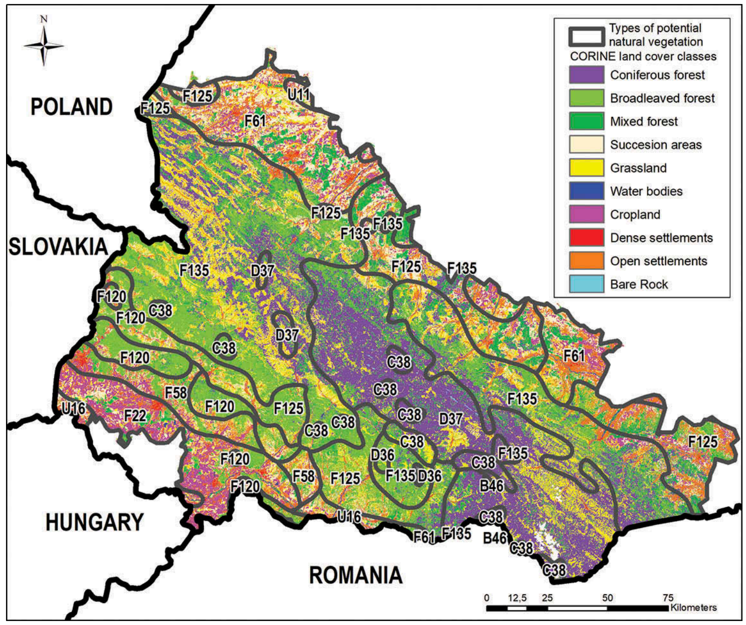


Figure 2. Distribution of 10 coarse land cover classes in the Ukrainian Carpathian Mountains according to Kuemmerle et al. (2005), consistent with the EU CORINE classification. The polygons and codes represent Bohn et al.'s (2000) potential natural vegetation types.

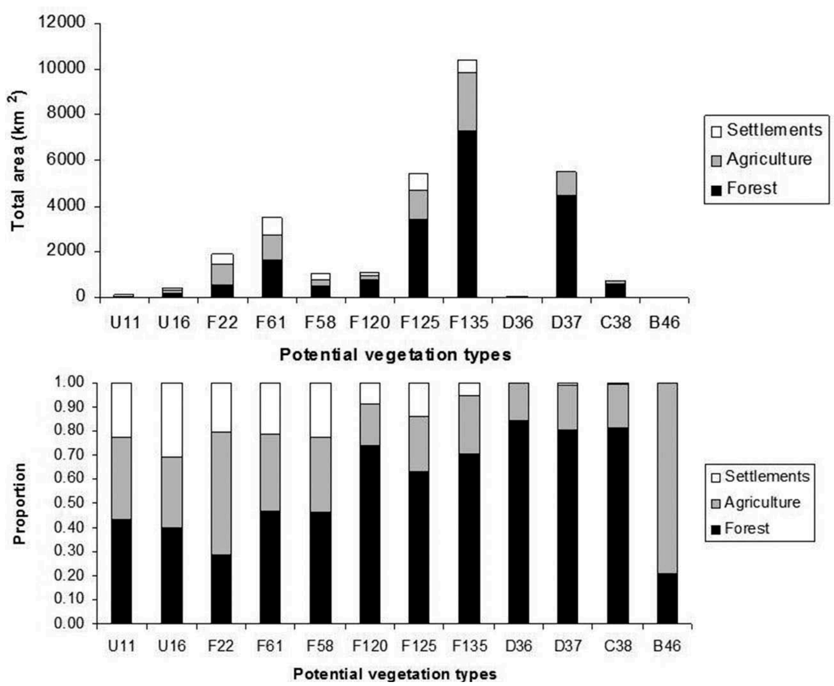


Figure 3. Amount (top) and proportion (bottom) of current coarse land covers, except bare rock and water, among different types of potential natural vegetation as defined by Bohn et al. (2000) in the Ukrainian Carpathian Mountains. Settlements is the sum of the land covers village and urban (Table 5), agriculture is the sum of the land covers grassland and cropland, and forest is the sum of coniferous, deciduous and mixed forests as well as succession areas. Definitions of vegetation type codes are provided in Table 3.

altitudes, within spruce forests (D36 and D37) and above the tree-line (Figure 3, bottom).

The two most common forest land covers today were beech–fir–spruce (F135) and spruce forest (D37) (Figure 4, top). Consistent with the altitudinal gradient in forest types (Table 4), there was a clear gradient from mixed and deciduous forests at lower altitudes to coniferous forests at higher altitudes (Figure 4, bottom). Finally, there was a steep increase in the proportion of successional forest land covers from lower to higher

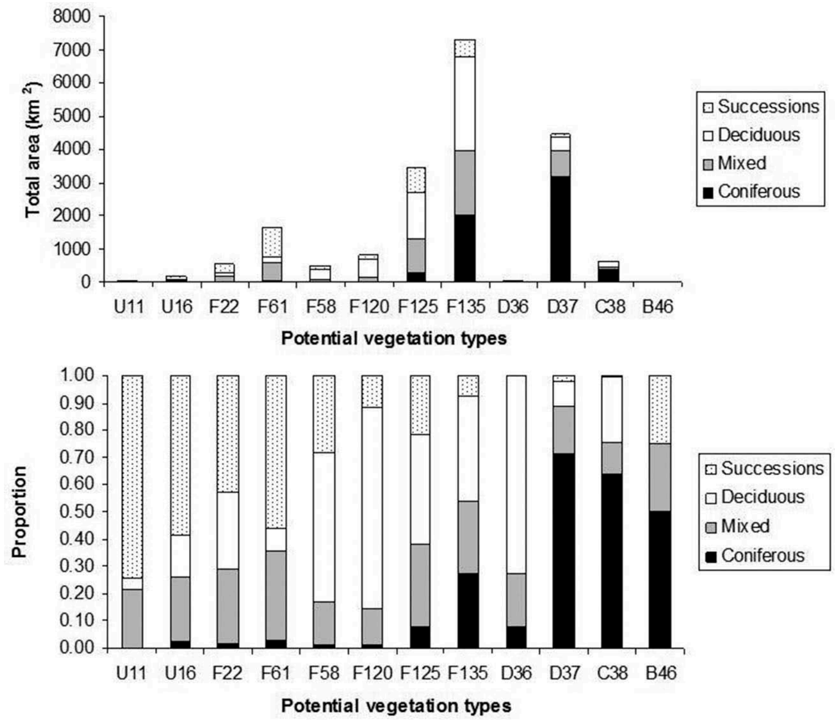


Figure 4. Amount (top) and proportion (bottom) of current coarse forest land covers among different types of potential natural vegetation as defined by Bohn et al. (2000) in the Ukrainian Carpathian Mountains. Definitions of vegetation type codes are provided in Table 3.

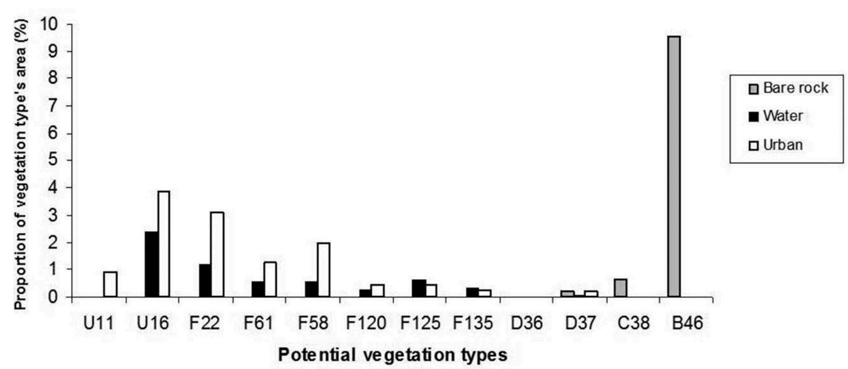


Figure 5. Proportion of bare rock, water and cities and towns among different types of potential natural vegetation as defined by Bohn et al. (2000) in the Ukrainian Carpathian Mountains. Definitions of vegetation type codes are provided in Table 3.

altitudes. The high proportion of successional forest in the alpine zone (B46) matches the abandonment of high-altitude grassland (i.e., poloniny). Figure 5 shows the proportion of bare rock, water and urban areas in the different potential natural vegetation types.

Traditional village systems are characterised by a zonation that includes houses and gardens, small patches of fields and extensive areas of grassland used as meadows and pastures (Elbakidze and Angelstam 2007). Beech–fir–spruce (F135) dominated in terms of transformation to grasslands, followed by beech–hornbeam–fir (F125) and hornbeam–oak–beech (F61) (see Figure 6, top). A high proportion of cropland indicates more intensive agriculture at low and mid altitudes (see Figure 6, bottom).

Representativeness of protected areas

Protected areas in the Ukrainian Carpathians are large and concentrated in the central parts of this mountain range (Figure 7). A total of 83% of the alpine (B46) and 33% of the sub-alpine vegetation (C38) is protected, mostly within the large PAs such as the Carpathian Biosphere Reserve, the Carpathian NNP and the Gorgany Strict Nature Reserve; 21% of beech–fir–spruce

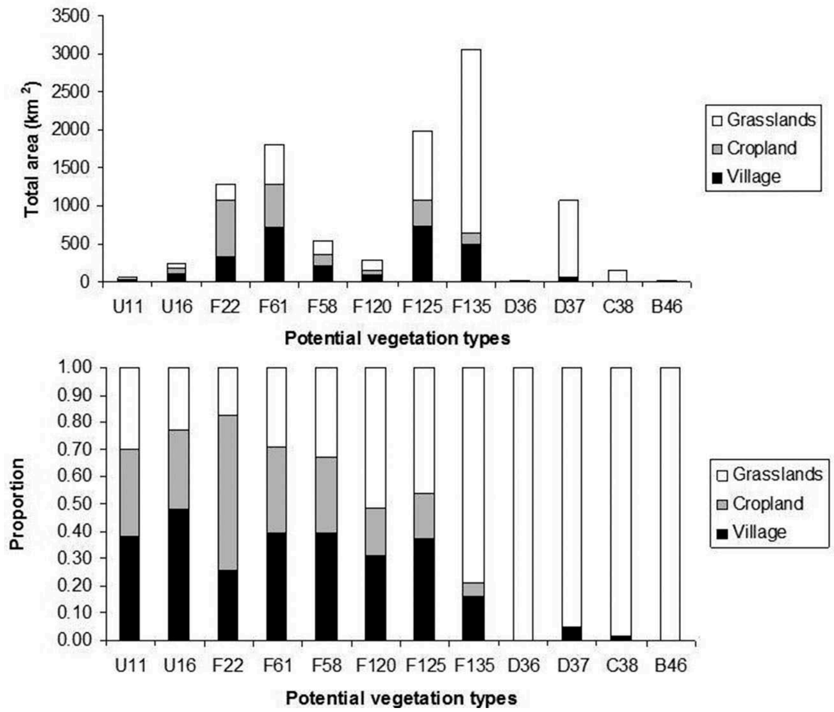
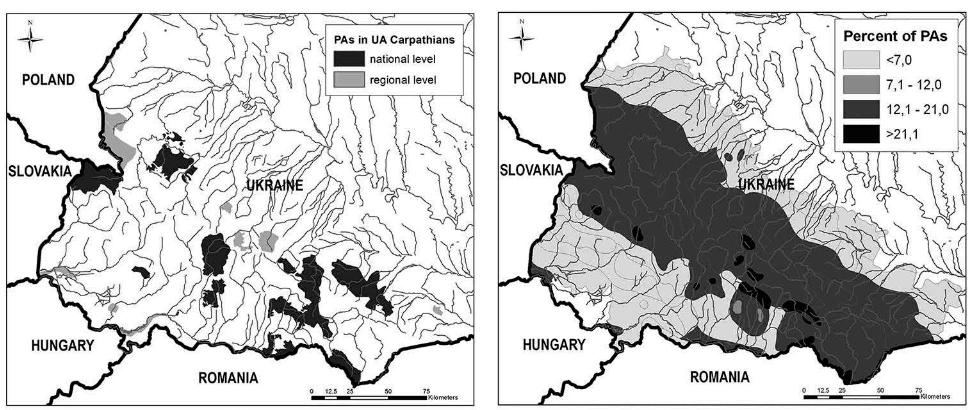


Figure 6. Amount (top) and proportion (bottom) of current typical village system land covers among different types of potential natural vegetation as defined by Bohn et al. (2000) in the Ukrainian Carpathian Mountains. Definitions of vegetation type codes are provided in Table 3.



(a) (b)

Figure 7. (a) Location and (b) proportion of protected areas in different categories of potential natural vegetation in the Ukrainian Carpathian Mountains.

forests (F135) and 12–20% of spruce–fir and spruce forests (D37, 36) are protected within the different types of PAs (Table 6). Beech and oak forests at 200–1200 m (F125, F120, F58, F61, F22) covering 42% of the area (Table 3) have a very low level of protection (0–7%). This is due to the long history of landscape transformation into cultural landscapes through the traditional village system. Alluvial forests in the southern part of the study area (U16) were protected in 2009 by the establishment of the Prytysianskyi Regional Landscape Park including almost all remaining alluvial forests in the region.

*Gaps/surpluses of natural land covers (B − (A*C))*

Using a threshold value (C) of 0.2 for what ought to remain as an absolute minimum of the potential natural vegetation, there was an average 14% surplus (range from a 18% gap to a 74% surplus). However, with a C-value of 0.4, the result changed into an average 6% gap (range from a 38% gap to a 54% surplus; Table 7). Note, however, that this estimate takes neither habitat quality nor fragmentation effects into account.

Underlining the need for strategic spatial planning, the results were also presented as maps indicating different

Table 6. Areas and proportions of national and regional protected areas distributed among Bohn's et al. (2000) categories of potential natural vegetation (the area of each of those is provided in Table 3).

Potential natural vegetation and code		National PAs		Regional PAs		Total PAs	
		Area (km^2)	Proportion (%)	Area (km^2)	Proportion (%)	Area (km^2)	Proportion (%)
Alpine	B46	15	83	0	0	15	83
Sub-alpine	C38	240	31	15	2	255	33
Spruce	D37	929	16	210	4	1139	20
	D36	8	12	0	0	8	12
Beech–fir–spruce	F135	1769	17	455	4	2224	21
Beech–hornbeam–fir	F125	228	4	26	0	254	5
Beech	F120	54	5	0	0	54	5
Oak mixed	F58	0	0	0	0	0	0
	F61	13	0	0	0	13	0
Oak	F22	3	0	134	7	137	7
Alluvial forest	U11	0	0	0	0	0	0
	U16	22	5	59	14	81	19

types of gaps to satisfy four different interpretations of how much of different land covers ought to be set aside (Figure 8(a–d)). These are areas where at least 20% of the potential natural vegetation remains, being protected or not (A); where >40% remain, i.e., allowing percolation of individuals or propagules across the landscape (B); where 17% of the potential natural vegetation polygons are protected (C); and where 17% of the potential natural vegetation polygons are protected, with sufficient connectivity (D). Thus, the last map shows where the Aichi target 11, that protected areas should form functionally connected habitat networks, is satisfied (CBD 2010), i.e., functional GI. The analyses (Table 7) and Figure 8(d) show that all land covers have gaps of 4–17%, except the alpine zone which has a surplus of 16%.

Gains of cultural landscape values

The loss of potential natural vegetation corresponds to a considerable transformation into large areas with land covers characteristic of traditional village systems (i.e., the combination of villages, croplands and grasslands; Figure 6). Hence, 29% of beech–fir–spruce forests (F135), 36% of beech–hornbeam–fir forests (F125), 71% of hornbeam–oak–beech forests (F61) and 83% of oak forests (F22) were transformed into cultural landscape land covers. The occurrence of grasslands, being the most important land cover for biocultural values, is concentrated to mid-level altitudes of 500–1600 m a.s.l.

Discussion

Are there enough protected areas to maintain naturalness?

The dynamic history of the Carpathian Mountain region, with a range of management and governance paradigms linked to being part of the Austro-Hungarian Empire until 1919, Czechoslovakia and Poland 1919–1939, USSR 1939–1991 and in Ukraine since 1991, has influenced its landscapes in many dimensions. Understanding these legacies of the past is an important starting point for maintenance of biodiversity in this ecologically and socio-culturally diverse region (Angelstam et al. 2013a; Jepsen et al. 2015). This study demonstrates significant differences in gaps among the different types of potential natural vegetation types, mainly different forest types. This loss of forest naturalness (*sensu*; Peterken 1996) raises policy concerns about the maintenance of different forest types for a functional GI.

Forests form the potential natural vegetation in 97% of the Carpathian Mountains. From the ninth to fourteenth centuries, fire was used to clear forested areas for village development, greatly increasing human's impact on forests (Hensiruk 1995). During the eighteenth and early nineteenth centuries, virgin beech forests were harvested for the production of potash used for glass, soap and paints, which were exported. Logging was concentrated along river banks and roads. It was not until the railway appeared in the late nineteenth century during the Austro-Hungarian time that the Carpathian Mountain forests were opened for commercial logging and exported as round wood (Hensiruk 1995; Adamovskyi 2006). During this period, large areas of spruce, spruce–fir–beech and beech forest were clear-cut and regenerated, often with Norway spruce seeds from foreign provenances maintained as monocultures. During the Soviet time, forests were over-exploited (Hensiruk 1995). Our analyses mirror these changes. The most accessible low mountain ranges have a low proportion of forests (74–98% loss) and a low proportion of protected areas (0–7%). Here, maintenance of viable populations of naturally occurring species requires additional protection, management and restoration of representative forest types. Since the early twentieth century, forest cover has been

Table 7. Results of gap analyses for the entire study area.

Vegetation type		Potential natural vegetation (A)		Current land cover (B)		Representativeness (A − B)	Habitat surplus or gap (B − (A*C))		Protected area cover (from Table 6)		Gap or surplus of protected areas (% units)		
		(km²)	(%)	(km²)	(%)	(%)	C = 0.2 (Figure 8 (a))	C = 0.4 (Figure 8 (b))	km²	%	Protected area proportion minus 17% target (Figure 8(c))	Connectivity correction[a]	Aichi target 11 satisfaction (Figure 8 (d))
Alpine	B46	18	100	17	94	6	+74	+54	15	83	66	0.4	16
Sub-alpine	C38	769	100	146	19	81	−1	−21	255	33	16	0.4	−4
Spruce	D37	5657	100	3197	57	43	+37	+17	1139	20	3	0.4	−9
	D36	65	100	15	23	77	+3	−17	8	12	−5	0.4	−12
Beech–fir–spruce	F135	10,460	100	6761	65	35	+45	+25	2224	21	4	0.4	−8
Beech–hornbeam–fir	F125	5475	100	2647	48	52	+28	+8	254	5	−12	0.4	−15
Beech	F120	1100	100	594	54	46	+34	+14	54	5	−12	0.4	−15
Oak mixed	F58	1060	100	271	26	74	+6	−14	0	0	−17	0.4	−17
	F61	3520	100	132	4	96	−16	−36	13	0	−17	0.4	−17
Oak	F22	1906	100	148	8	92	−12	−32	137	7	−10	0.2	−16
Alluvial forest	U11	110	100	2	2	98	−18	−38	0	0	−17	0.2	−17
	U16	425	100	25	6	94	−14	−34	81	19	2	0.2	−13
Mean		2547		1163	34	66	14	−6	348	17	0	0.35	−11

[a]Correction factor to estimate the proportion of habitat patches sufficiently large and spatially concentrated to form a functional connected network (see Angelstam et al. 2011a, p. 1123)

increasing slowly (Kozak et al. 2007; Baumann et al. 2011). Forests provide wood resources of high economic value, retain natural biodiversity and are many of Europe's last wilderness areas (Turnock 2002; Angelstam 2006; Angelstam et al. 2013a). However, after Ukraine's independence in 2001, the Ukrainian Carpathian region is under severe threat from unsustainable logging methods, past replacement of natural tree species with introduced Norway spruce, habitat loss and fragmentation due to intensified harvesting (Keeton and Crow 2009, 2013).

The CBD and its 17% target for 'well-connected systems of protected areas' is clear, and quantitative gap analysis can provide input to strategic decision making. However, key stakeholders in Ukraine, as in many other countries, neither know nor accept the role of maintaining habitat quality and connectivity for functional habitat networks. This calls for improved public and policy-level awareness of what biodiversity conservation requires at multiple levels. A gap analysis can be used as a tool to express different levels of ambition for the maintenance of habitat, species and ecological processes (Figure 8).

First, focusing on the loss of different types of potential natural vegetation during the human colonisation of the Carpathian Mountains, we chose two levels of ambition assuming that current remnants can conserve biodiversity: (1) that at least 20% of the potential natural vegetation should remain (Figure 8(a)) and (2) that 40% is needed, i.e., allowing percolation of individuals or propagules without having to enter the surrounding matrix (Figure 8(b)). With the lowest level of ambition, there are gaps only in lowland areas. However, with the higher level of ambition, areas with gaps expand slightly. Note, however, that this does not take into account changes in quality of the different land covers. Second, regarding the need for protected areas, Aichi target 11 has two key components: a target value (17% protection) and a statement about functionality as a GI (i.e., connectivity). With the first component satisfied (Figure 8 (c)), only local patches in the Carpathian Mountains clearly exceed Aichi target 11. However, with empirical estimates of the proportion of protected areas which are functional in terms of connectivity, only alpine areas clearly exceeded both components of Aichi target 11 (Table 7 and Figure 8(d)). To conclude, a sufficient forest cover needs to be maintained (Figure 8(b)) and a functionally connected network of protected areas is required (Figure 8(d)). So far, there has been no extinction of naturally occurring focal species such as large carnivores. However, little is known about the effects of industrial logging (e.g., Potapov et al. 2015; Angelstam et al. 2017) on species requiring dead wood and having large area requirements such as birds of prey.

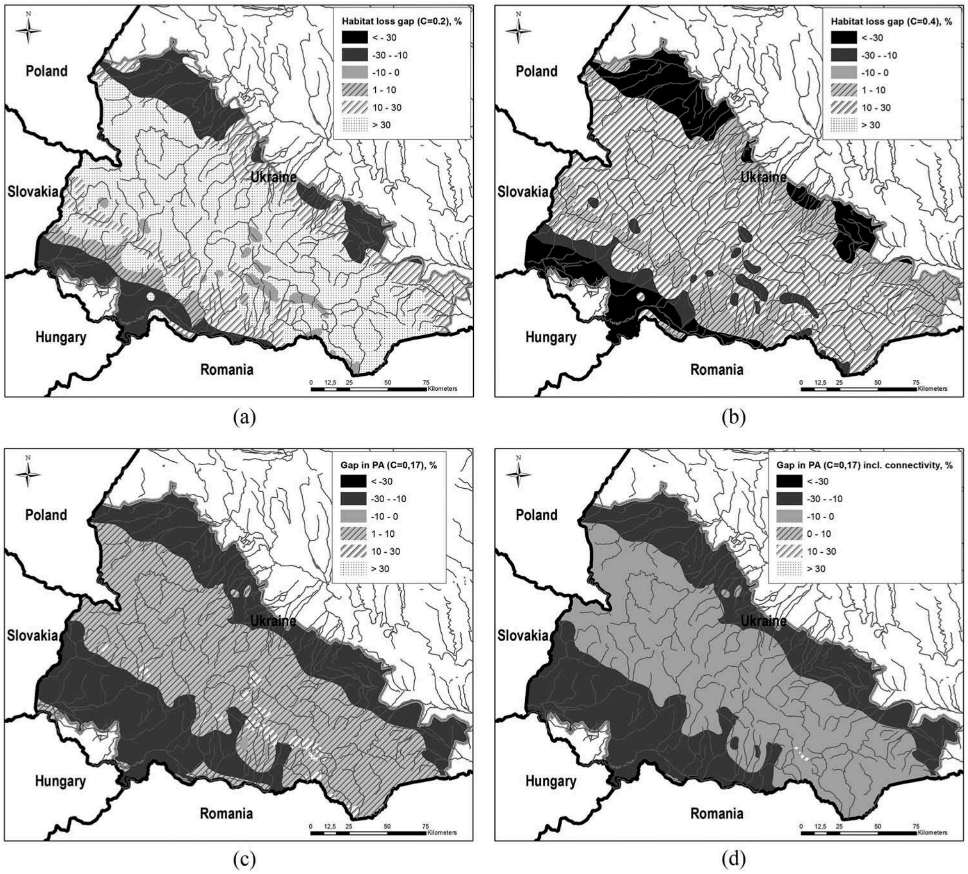


Figure 8. Results of regional gap analysis showing land cover surpluses (positive values) and gaps (negative values) based on critical habitat loss thresholds of (a) 20% and (b) 40%. Also shown are surpluses and gaps in protected areas compared to (c) 17% targets purely numerically and (d) by considering estimates of required connectivity among land cover patches that defines green infrastructure functionality.

Maintaining biocultural values in cultural landscapes

The analyses show that loss of naturalness has led to gains in cultural landscape values linked to traditional village systems, particularly at mid-level altitudes once covered by forests. Traditional land use systems were commonly practised for centuries before socialism, and played an important role for maintenance of biodiversity conservation and cultural heritage, and thus rural development, in the Ukrainian Carpathians. These systems help sustain production of multiple goods and services, providing livelihood security and quality of life, as well as contributing to characteristic natural and cultural heritage (Agnoletti 2013). Additionally, at high altitudes, mountain meadow grasslands (poloniny) (Kozak 2003; Kozak et al. 2007) have traditionally been used for grazing, which caused lowered tree-lines in some regions (Kuemmerle et al. 2009). This unique grassland was partly formed by human activity, where grazing cattle removed the *Pinus mugo* vegetation. Poloniny meadows support a wide diversity of endemic plants species, the globally threatened Corncrake (*Crex crex*) and invertebrates such as the bumblebee (*Bombus pyrenaeus*). Natural open meadows (B46 in Table 3) above the tree-line are very limited in the Ukrainian Carpathians.

After the collapse of the USSR in 1991, local people have come back to the traditional land use practices of their village system due to the need to develop local livelihoods (Elbakidze and Angelstam 2007), often supported by cash incomes from family members working abroad. The recent privatisation of farmland that began after 1991 has led to a revival of the social and cultural value of forests in Western Ukraine, which often were an unbroken part of families' cultural and natural heritage for generations. The consequences for conservation of biocultural values are nevertheless uncertain. Villages, especially those remotely located, maintain traditional practices. Human population decline and an ageing population have the opposite effect. As animal husbandry is declining, efforts to sustain anthropogenic grasslands by removing encroaching vegetation using fire in the spring and autumn have increased, favouring the expansion of *Rubus caesius* at the expense of meadow plants. Continued extensive use of mountain grasslands can only be achieved if the traditional village system as an entire socio-ecological system is maintained (e.g., Dorresteijn et al. 2015).

Barriers and bridges towards biodiversity conservation

A gap analysis is only a first strategic level step towards comprehensive analysis of the extent to which natural and cultural landscapes' different land covers form a functional GI. Based on basic conservation biology principles, this study documents severe conservation gaps, which may be closed only through changes in land or water management practices. Therefore, integrated spatial planning is needed. For example, Deodatus (2013) and Deodatus and Protsenko (2010) developed a methodology for planning functional ecological corridors to facilitate the movements of large mammals in the Carpathian region. To support operational planning, for example, GIS and satellite images have also been used to analyse forest dynamics (e.g., Commarmot et al. 2013; Hobi 2013).

Ukraine is in a transformation process to deal with threats to the environment and biodiversity since the demise of the Soviet system in 1991. Land use issues are regulated by the new Land Code from 2001, which legalised ownership of private land to Ukrainian citizens. The Land Code also addresses protected areas, wise land use and land use planning. Other relevant legal instruments and documents are the Forest Code, the Water Code and the Mineral Resources Code, the 'Strategy of Biodiversity Conservation in Ukraine' from 1997, and the 'Concept of the State Programme on Biodiversity Conservation for 2005–2025' from 2004. The development of a national ecological network has a high priority in Ukrainian conservation policy since 1995 when the European environment ministers endorsed the Pan-European Biological and Landscape Diversity Strategy. However, the existing protected areas have very low levels of financial and political support for protection and management activities, and the cooperation between existing transboundary protected areas is low.

Being involved in practice with biodiversity conservation in Ukraine, we note two barriers for ecological network development. Increased amounts of protected areas are necessary, but that is insufficient. The first barrier is the absence of participatory models for integrated spatial planning within protected areas and the surrounding matrix. The second is the dominating academic physical geography approach to ecological networks (e.g., Roosaare 1994; Kavaliauskas 1995), which does include representation of different land covers, but not the conservation biology approach based on sufficient amount of functionally connected areas of representative land covers. For biodiversity conservation in production forests, two approaches have the opportunity to bridge these barriers. The first is the High Conservation Value Forest concept used in the FSC forest certification, and the second is linked to EU directives about habitats and species which are being introduced through the association agreement between Ukraine and the EU. Regarding the conservation of biodiversity associated to cultural landscapes, the urgent need to secure social benefits of ecosystem services in rural areas is a potential driver. For example, while urban visitors to rural areas value the presence of both wildlife and cultural landscapes, the compensation for loss of domestic animals to large carnivores is linked to heavy bureaucracy, and benefits of resorts for tourists are limited for locals.

Designing governance, planning and management systems that emulate natural and cultural landscapes' disturbance regimes is a major challenge. The Carpathian Mountain ecoregion forms a quasi-experiment with new country borders that have created stark contrasts among regions regarding natural and cultural biodiversity. This ecoregion can thus be seen as a landscape-scale laboratory for systematic studies of interactions between ecological and social systems to support the development of an integrated landscape approach to biodiversity conservation and cultural heritage (Angelstam et al. 2011b, 2013c). A key dimension is about reviving local legacies of landscape stewardship. For example, Molnár et al. (2008) noted that, from the middle ages until the eighteenth century, villages in the Transylvanian part of the Carpathians had a very detailed and strict system of rules which counteracted unsustainable land use. Today, the structures and cultures of local civil society is recovering in the region; land is being returned to private hands; transport infrastructure is improving; there is growth in tourism development; and international businesses will have a strong effect on the life of the Ukrainian Carpathian Mountains. The challenge is to guide development along a sustainable route, to conserve and value the natural and cultural landscapes' biodiversity of this region for human well-being in the context of a changing world.

Conclusion

This study is the first attempt to provide a quantitative estimation of the needs to maintain GIs represented by both natural forests and biocultural landscape values in the Ukrainian Carpathian ecoregion. The results clearly indicate two trends. Regarding natural forests, loss of forest areas (especially lowland broadleaved forests) and tree species replacement (monoculture forestry) are the key problems threatening forest naturalness. Regarding cultural landscapes, they are currently maintained as a result of the need for people in rural areas to secure their livelihoods by subsistence farming. Quantitative gap analysis can be used as a base for identifying priority areas for conservation by both area protection and enhancement of biocultural values. This strategic analysis forms the basis for subsequent tactical planning about where action (protection, management, restoration) is needed, and about how traditional village systems can be maintained by rural development.

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ORCID

Michael Manton http://orcid.org/0000-0002-4812-6599

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