


Forest management and future changes to ecosystem services in the Romanian Carpathians

Žiga Malek¹  · Veronica Zumpano² · Haydar Hussin³

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Abstract This study investigates consequences of future changes to the provision of ecosystem services (ES) in the Romanian Carpathians. Two 2040 forest management scenarios were compared, using two indicators to describe the gains and losses of ES. Changes in landslide regulation potential were defined as changes to landslide susceptibility. High nature value grasslands characterized biodiversity support. The business as usual scenario results in a 8% lower loss of landslide regulation potential compared to the alternative scenario. It also results in a 29% higher regional net gain of landslide regulation potential. Both scenarios result in the loss of biodiversity support due to their prevalent transition of forest expansion. This type of information is crucial for informing decision makers on the locations of potential gains and losses of future development.

Keywords Ecosystem services · Forest management · GIS · Spatial assessment · Natural resources

1 Introduction

Mountain ecosystems provide vital services, such as forest products, protection from natural hazards and recreation-related services (Schröter et al. 2005; Grêt-Regamey et al. 2012). Moreover, they support terrestrial biodiversity, hosting significant ecosystems that are concentrated on mountains and hills (Körner et al. 2005). Ecosystems may deliver more

✉ Žiga Malek
z.malek@vu.nl

¹ Faculty of Earth and Life Sciences, VU University Amsterdam, De Boelelaan 1085-1087, 1081 HV Amsterdam, The Netherlands

² Institute of Geography, Romanian Academy, Bucharest, Romania

³ Faculty of Geo-Information Science and Earth Observation, University of Twente, Enschede, The Netherlands

than one service, and their manipulation to maximize one particular service can lead to unsustainable management of other services. A good example is timber harvesting, where unsustainable practices such as clear-cutting can lead to increases in landslide risk (Glade 2003). Mismanagement of ecosystem services (ES) can decrease their value for other uses, leading to conflicts between different stakeholders that perceive different benefits from ecosystems (Castro et al. 2011; Fisher et al. 2009; Scheffer et al. 2000).

In order to identify critical areas of changes to ecosystem services provisioning, a spatially explicit approach is needed (Verburg et al. 1999). Such an approach considers biophysical factors, such as terrain, hydrology, soil, geology, together with other spatial factors like distance to cities or population density. The changes in landscape, in terms of geographic location and spatial pattern, are reflected by changes in ES provisioning. There are several examples of spatially explicit analysis of ES provision. Burkhard et al. (2010) assigned each landscape unit a value for provision of a variety of ecosystem services. Egoh et al. (2008) used different models to identify the location of hotspots for multiple ES provisioning. Attempts have also been made to locate both the demand and supply, as in the case of regulating river flows and floods (Nedkov and Burkhard 2012). In another example, the result was a spatially explicit valuation of ES (Grêt-Regamey et al. 2008), or a spatial analysis of ES value transfers (Troy and Wilson 2006). Most of the spatially explicit approaches, however, involve a set of general models and demand abundant data. Land cover is often used as main input to spatially allocate the provision of ecosystem services; however, mostly a single time step is considered. Investigating how the provision of ES might evolve through time thus remains unknown. In order to prepare for potential negative consequences of future resource management and to plan for a desired future, it is necessary to understand how the provision of ES might develop in the future.

The Romanian Carpathians provide valuable ecosystem services on a European scale, as they are part of the biggest continuous forest ecosystems and shelters for large carnivores and herbivores in Europe (Kuemmerle et al. 2008). After the fall of socialism, the Carpathian region experienced the fall of large collective agricultural associations, changes to land use policy and to land ownership resulting in numerous new land owners (Lerman et al. 2004). As a consequence, the region witnessed land abandonment and reforestation, leading to the loss of low-intensity grasslands and cropland (Müller et al. 2009; Taff et al. 2009; Baumann et al. 2011). Simultaneously, the region witnessed an increase in timber harvesting, often leading to degradation of forest ecosystems (Griffiths et al. 2012; Knorn et al. 2013). Carpathian ecosystems are thus among the most vulnerable to anthropogenic change, also due to severe natural conditions (Kozak et al. 2007). We focus on a study area in the Buzau Subcarpathians, which is a landslide-prone area that experienced significant socioeconomic changes in the last decades. The recent socioeconomic transition leads to an increase in human influence, mostly due to the increase in forest exploitation. This has resulted in clear-cuts in an area, where a significant part of slopes is highly susceptible to landslides due to its physical–geographic characteristics (Hussin et al. 2016). The Buzau Subcarpathians, moreover, serve as a refuge for important European habitats within the Romanian Carpathians (Oszlányi et al. 2004). For example, the area has a high frequency of European large carnivores such as the wolf (*Canis lupus*) and the brown bear (*Ursus arctos*) (van Maanen et al. 2006). Increased human pressure in a previously less human-dominated landscape can, however, negatively affect these habitats and limit the area's potential for large mammal conservation and biodiversity protection in general (Boitani and Linnell 2015; Verkerk et al. 2014).

To fully understand the environmental impact of resource exploitation, we analyzed possible consequences of forest harvesting in the Romanian Carpathians. To study the

changes to ecosystem services, we adopted a geographic information system (GIS)-based approach suitable for areas with poor data. We analyzed potential changes to biodiversity support and landslide regulation by comparing future forest cover change scenarios with the existing forest cover. We used forest change scenarios for 2040, developed together with the stakeholders. Biodiversity support was analyzed by identifying the loss of high nature value grasslands due to forest expansion. These are low-intensity agricultural areas that have been identified as biologically rich and diverse and are thus ecosystems of high regional significance (MARDR 2012). Changes to landslide regulation were assessed using a statistical landslide susceptibility model. Our method resulted in a quantifiable and spatially explicit approach enabling the description of a variety of possible changes to ES that can also be applied in other study areas.

2 Study area

The area (Fig. 1) is situated in the Buzau County in southeastern Romania ($45^{\circ}27'3''N$, $26^{\circ}30'23''E$). It covers 2421 km² located between the Carpathian Mountains and the Buzau plain. The mean altitude is 429 m, with a maximum elevation of 1370 m above sea level. More than half of the area (55%) is on slopes $>10^{\circ}$. Steep slopes, with a specific geological composition, such as deposits of Neogene molasses consisting of alternating clay and sandstone formations, have caused the area to be highly predisposed to landslide occurrence (Micu and Bălteanu 2013). The annual precipitation is around 700 mm, with heavy spring and summer rainfall. In some localities, such as Patarlagele, shallow landslides cover more than two-thirds of the total slope area (Muică and Turnock 2008).

The area has around 160,000 inhabitants, with a 11% decrease in population since 1989 (INSSE 2013). Major economic activities are forest harvesting and wood processing with a

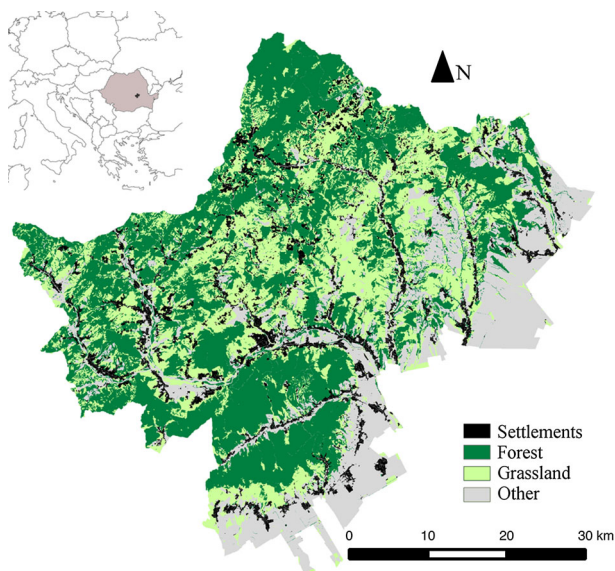


Fig. 1 Study area location and land cover. Other land cover presents intensive cropland, water bodies and bare areas

growing trend. Since 1989 the area was affected by economic collapse, abandonment of agricultural land and stagnation of urban development (INSSE 2013), while witnessing an increase in clear-cutting of forest. This could be related to numerous reasons: poor socioeconomic conditions, chaotic land ownership reforms resulting in restitution of land nationalized after the Second World War; to inefficient forest policy implementation (Malek et al. 2014). The ownership situation has changed drastically since 1989 when 100% of all forests were government property: around 35% are privately owned today (INSSE 2013). The increase in the number of owners also resulted in the dispersed ownership pattern of usually smaller forest plots, increasing the difficulty of forest management (Bălteanu and Popovici 2010).

Forests cover 40.5% (981 km²), grasslands 27.4% (663 km²), cropland 19.9% (483 km²) and built-up areas 8.2% (198 km²) of the area, with remaining areas covered by water and bare areas. More than a half of the total forest area (55.4%) is subject to timber harvesting, and 45 km² (4.6%) of forests in the area are protected. Beech is the dominant species representing 25% of the forest stock, followed by conifers (18%, mostly spruce) and oaks (12%) (INSSE 2013). The mean growing stock of the forest in the region is 217 m³/ha, with a 6 m³/ha mean net annual increment. Although most of the forest harvesting in the area is done through selective logging and clear-cuts are limited to some extent, still around 3% of all forest harvesting is done by clear-cutting (Giurgiu 2004). This practice has been observed on the field and in previous research and has also been identified by the involved stakeholders as significant, in terms of its effect on the landscape and landslide risk (Malek et al. 2014). Although on a regional scale, clear-cuts were represented as a minor land cover process, they were identified as the major process in some localities, such as side valleys of the main Buzau river valley (Muică and Turnock 2008; Micu and Bălteanu 2013).

3 Methods

3.1 Future forest cover scenarios

Two spatially explicit forest cover change scenarios for 2040 were developed in the course of the CHANGES project (Changing Hydro-meteorological Risks - as Analyzed by a New Generation of European Scientists, www.changes-itn.eu). Participatory scenario modeling involving local and regional experts on forestry was combined with Dinamica EGO, a raster-based environmental modeling software (Soares-Filho et al. 2002). The scenarios focused on two forest transitions: forest expansion and deforestation. Forest expansion was defined as a change from non-forest (e.g., grassland, agricultural areas and other types of vegetation) to forested areas. Deforestation was defined as a transition from forest to non-forested areas and described the clear-cutting forest harvesting practice (complete removal of tree cover).

The spatial part of the model simulated the pattern and location of both transitions. This was done by training the model with topographic, forest and remote sensing data between 1989 and 2010 on a 30 m spatial resolution within Dinamica EGO. The land cover map for 2010 obtained through hybrid classification of LANDSAT images served as the starting point for our scenarios (Malek et al. 2014). To train the spatial allocation part of the model, land cover maps for the years 1989 and 2000 were additionally used, also obtained by classifying LANDSAT images and by performing landscape pattern analysis. The overall

accuracies of the maps were 85.7% (1989), 87.3% (2000) and 89.2% (2010). As location factors we used maps representing slope and elevation, distance to settlements and distance to roads. Deforestation was excluded in areas, where forest harvesting in the region is legally forbidden: protected areas of the Natura 2000 network, ecologically significant forests and all slopes above 25°.

The model estimated the amount of deforested/reforested areas based on two different assumptions on future forest management in Romania. Taking into account changes to forest management (and the allowed timber harvesting and deforestation), the business as usual (BAU) and alternative (ALT) scenario was developed. The BAU scenario assumed that the current forestry legislation of Romania will be followed and sufficiently implemented. This strategy was identified as more sustainable by the stakeholders involved in the scenario development process (Malek et al. 2015a). This means that there is sufficient control on illegal logging, and that the extent of clear-cutting is limited to 3% of all timber harvesting. The alternative scenario differs in terms of a higher rate of wood harvesting, as well as an increased share of clear-cutting to enable less costly harvesting. Up to 5% of forests can be harvested by clear-cutting, which reflects the objectives of mostly foreign investors in the regional forestry sector (Schelhaas et al. 2006; Bohateret 2012). The alternative scenario projected 21.4 km² deforestation, whereas the business as usual scenario resulted in only 12.8 km² deforestation. Although on a regional scale, deforestation presents a minor process, it affected 5% of forests on slopes >15° in the ALT scenario (Malek et al. 2015a). Both scenarios have the same extent of forest expansion (99.9 km²), as this transition was based solely on the spatial and biophysical characteristics of the area, excluding protected areas. The spatial distribution of future forest cover scenarios is summarized in Fig. 2. These two scenarios served as inputs when performing the analysis of changes to ES. The methodology with technical details of the model and the scenario results are described in more detail in a previous study (Malek et al. 2015a).

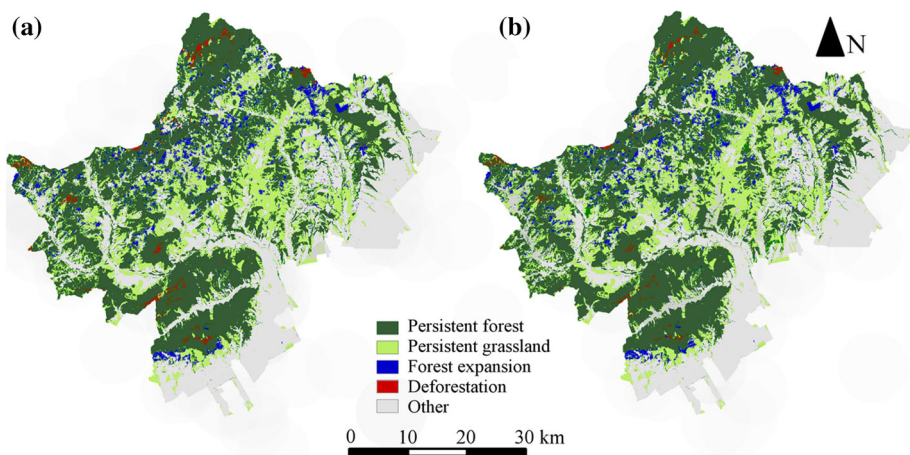


Fig. 2 Spatial distribution of the alternative scenario (a) and business as usual scenario (b) for the year 2040. Modified from Malek et al. (2015a, b)

3.2 Changes to ES provision

We analyzed changes to biodiversity support and landslide regulation, as a trade-off of forest cover change. The changes to all ES were assessed through a spatially explicit pixel-based approach, where the 2040 future forest scenarios were compared to the existing forest cover in a GIS environment (QGIS Development Team 2015). The conceptual methodology is summarized in Table 1.

3.2.1 Biodiversity support

High nature value (HNV) grasslands are low-intensity agricultural habitats that are among most biologically rich and diverse ecosystems (Bignal and McCracken 1996). The concept of HNV was developed to identify areas in Europe where agricultural land use supports high species and habitat diversity (Andersen et al. 2003). In the Romanian Subcarpathians, they host significant vascular plants and are characterized by a high butterfly, reptile and bird diversity (MARDR 2012). We used HNV grasslands as a proxy for the ES of habitat and biodiversity provision—based on the losses of HNV grasslands due to forest expansion. Land abandonment and forest overgrowth can have a negative effect on biodiversity support, as they threaten the presence of HNV grasslands.

We manually digitized HNV grasslands. The HNV region definition defines them as areas with high proportion of seminatural vegetation or grasslands without high intensity of management (MARDR 2012). Therefore, we first excluded all built-up areas, forests, bare lands and water bodies from the 2010 land cover map generated using remote sensing imagery (Malek et al. 2014). We also excluded all intensive agricultural areas. Intensive agricultural areas were identified following different criteria. Intensive cropland in the region does not occur on slopes, so only cropland on valley floors was considered. Moreover, cropland represented by large field sizes and cropland close to settlements was identified as intensive. The manual digitization of HNV grasslands among the remaining agricultural and grassland areas was done by combining field visits with high-resolution satellite images. We mapped all grasslands with notable presence of landscape elements such as hedges, old orchards and riparian vegetation and grasslands on higher altitudes and slopes without any observable presence of intensive areas (Paracchini et al. 2008).

Using the future forest cover map, we identified the extent of lost HNV grassland due to forest expansion. We performed a set of landscape metrics, to calculate how changes to land cover would result in changes to the landscape pattern and diversity of HNV grasslands. We observed changes to the number, mean and median size of HNV grassland patches and calculated the Shannon and Simpson diversity indexes. The two diversity indexes have been used widely in ecology to show the changes to the landscape pattern and disturbance effects to communities (Spatharis et al. 2011).

Table 1 Summary of gains and losses to ecosystem services provisioning

Ecosystem service	Gain	Loss
Biodiversity support	No gain analyzed	Forest expansion on HNV grasslands
Landslide regulation	Landslide susceptibility decrease	Landslide susceptibility increase

3.2.2 Landslide regulation

Regulating services allow mountain areas to be habitable and are key to the safety of numerous settlements and communication lines, maintaining access to these areas. Life conditions in mountain areas are determined by physical processes, related to gravity (natural hazards), such as erosion, landslides, avalanches and rockfall (Körner et al. 2005). In the Buzau Subcarpathians, one of the most important local ecosystem services is the regulation of landslides. A healthy vegetation cover can affect slope stability through erosion control and water regulation, especially in such a landslide-prone area (Swift et al. 2004). As the data on landslide hazard and risk of the area were relatively scarce, Hussin et al. (2016) have generated a landslide susceptibility map to identify areas with the highest landslide probability. In this study, we updated their approach, by running the landslide susceptibility model with the future forest cover scenarios. This way, we were able to identify areas, where the landslide susceptibility might increase or decrease due to the changes to the forest cover. We have extracted the areas where landslide susceptibility had increased, which means a loss in landslide regulation. Areas where landslide susceptibility decreased indicated a gain in landslide regulation.

Landslide susceptibility analysis was performed using Weights of Evidence (WoE), a statistical data-driven Bayesian probability model (Bonham-Carter 1994). It is based on the spatial association between known occurrences (observed landslide scarp points) used as training dataset, and a series of thematic maps in order to determine a predictive output represented by a post-probability map. For each class of every individual explanatory variable, positive and negative weights were calculated on the basis of the positive and negative correlation with the training dataset. This approach has been widely used in many scientific fields, and it has been proved to give good performances in predicting spatial probability of landslide occurrence in many different areas (Lee and Choi 2004; Ozdemir and Altural 2013; Regmi et al. 2010; Thiery et al. 2007; van Westen et al. 2003), but also in the observed study area (Zumpano et al. 2014; Hussin et al. 2016).

Eight explanatory variables were selected to perform the analysis: digital elevation model (DEM) derivatives such as altitude, aspect, planar curvature, profile curvature, slope and internal relief, and a soil and land use map (Zumpano et al. 2014). We chose to use the soil map to represent the characteristics of the materials involved in the failures that are mainly shallow- to medium-seated landslides. Moreover, previous studies have shown that replacing the lithological map with the soil map gives significantly better performances (Zumpano et al. 2014; Hussin et al. 2016). The DEM-derived maps were reclassified into ten classes using quantiles, except for the aspect which was reclassified into nine classes according to the main compass directions plus one class defining flat areas. The soil map (Vintila et al. 2013) was reclassified to reduce the number of classes, based on our expert judgment, combining the classes that were similar in type, which resulted in 11 soil classes. The landslide inventory composed by 1518 failures includes shallow- and medium-seated landslides. The database was derived from the archive available at Institute of Geography, Romanian Academy, mapped by means of orthophoto interpretation between 2005 and 2008 with a pixel resolution of 0.5 m. Geomorphological field mapping and local authorities database information was also incorporated. Landslide scarps were represented with centroid points, then split using a random selection into two equal subsets and used as training and a prediction set.

We compared both maps and analyzed their agreement. Specifically, we analyzed the agreement and disagreement of both maps in terms of quantity and location (Pontius and

Santacruz 2014). This way, we can observe how the maps differ in terms of location of areas subject to changes in landslide susceptibility.

4 Results

4.1 High nature value grasslands

The total agricultural land, grasslands and other vegetation types cover an area of 116,450 ha (48% of the study area). High nature value grasslands cover 54,680 ha, or 47% of the current maximum potential HNV grassland extent. The maximum potential extent is defined by all areas that are not built up, bare or covered by forests or water. Most of the grasslands in the hilly areas of the Subcarpathians are classified as HNV grassland (Fig. 3). On the valley floor and other lowland areas more intensive uses are prevalent with fewer HNV grasslands.

4.2 Landslide susceptibility

The majority of areas are in the very low and low landslide susceptibility class (Fig. 4). Most areas with low landslide susceptibility are, however, on the valley floor and on areas that are less steep. Areas with more than a 50% of landslide susceptibility (defined as medium, high and very high landslide susceptibility) are mostly present on steeper slopes that are not covered by forests. In this example, more than 90% of forests are defined with a susceptibility value below 50%.

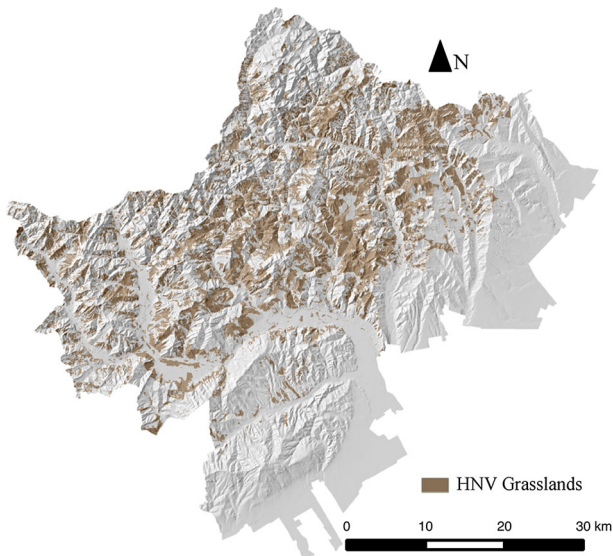


Fig. 3 High nature value (HNV) grasslands in the Buzau Subcarpathians

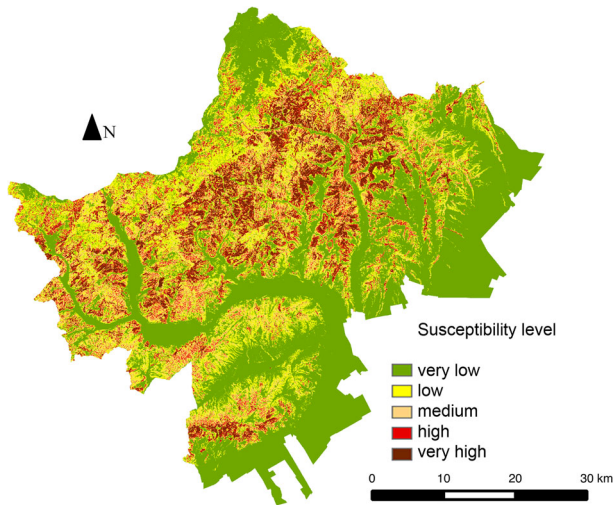


Fig. 4 Buzau Subcarpathians landslide susceptibility

4.3 Changes to ecosystem service provisioning

The results of changes to ES provisioning are summarized in a quantitative and spatially explicit way in Figs. 5, 6, and Tables 2, 3. As observed on the maps in Fig. 5, changes occur in similar locations under both scenarios. The quantities (areas) of changes to ES, however, differ between the two scenarios. Presenting numbers and locations for both gains and losses instead of net values that do not consider spatial variation is important, as some areas might experience only gains, while other experience only losses.

When looking at the changes to biodiversity support, forest expansion results in a 16.4% loss of HNV grasslands due to forest expansion. Most of the forest expansion occurred on areas at higher altitudes and steeper slopes currently classified as grasslands or low-intensity agriculture. These areas have been subject to high abandonment rates in the last 25 years (c.f. Malek et al. 2014). They also contain a considerable presence of HNV grasslands, resulting in their rather high loss. Expansion of low-intensity agriculture and seminatural grasslands was not identified in the modeled scenarios; therefore, there were no gains of biodiversity provision analyzed. Even more significant are the projected changes to the landscape pattern of HNV grasslands (Table 2). Our results suggest a strong fragmentation of HNV grasslands in the area in the future. The landscape diversity in the area decreases using both diversity indices. Due to forest expansion, the forested part of the landscape is becoming more homogeneous.

The two scenarios differ slightly in terms of gains to landslide regulation: 6.1% of the whole area in the alternative and 6.2% in the business as usual scenario are projected to experience a decrease in landslide susceptibility (at least by one class). This is on the account of forest expansion, as new forests on slopes result in a decrease in landslide susceptibility. The difference between the scenarios is more obvious when looking at the areas subjected to landslide susceptibility increase (Table 3). The ALT scenario resulted in 8.5% more landslide susceptibility increase compared to BAU. Comparing the spatial pattern and locations of changing landslide susceptibility, the differences between the two management scenarios become apparent. Here we looked at all locations that experienced

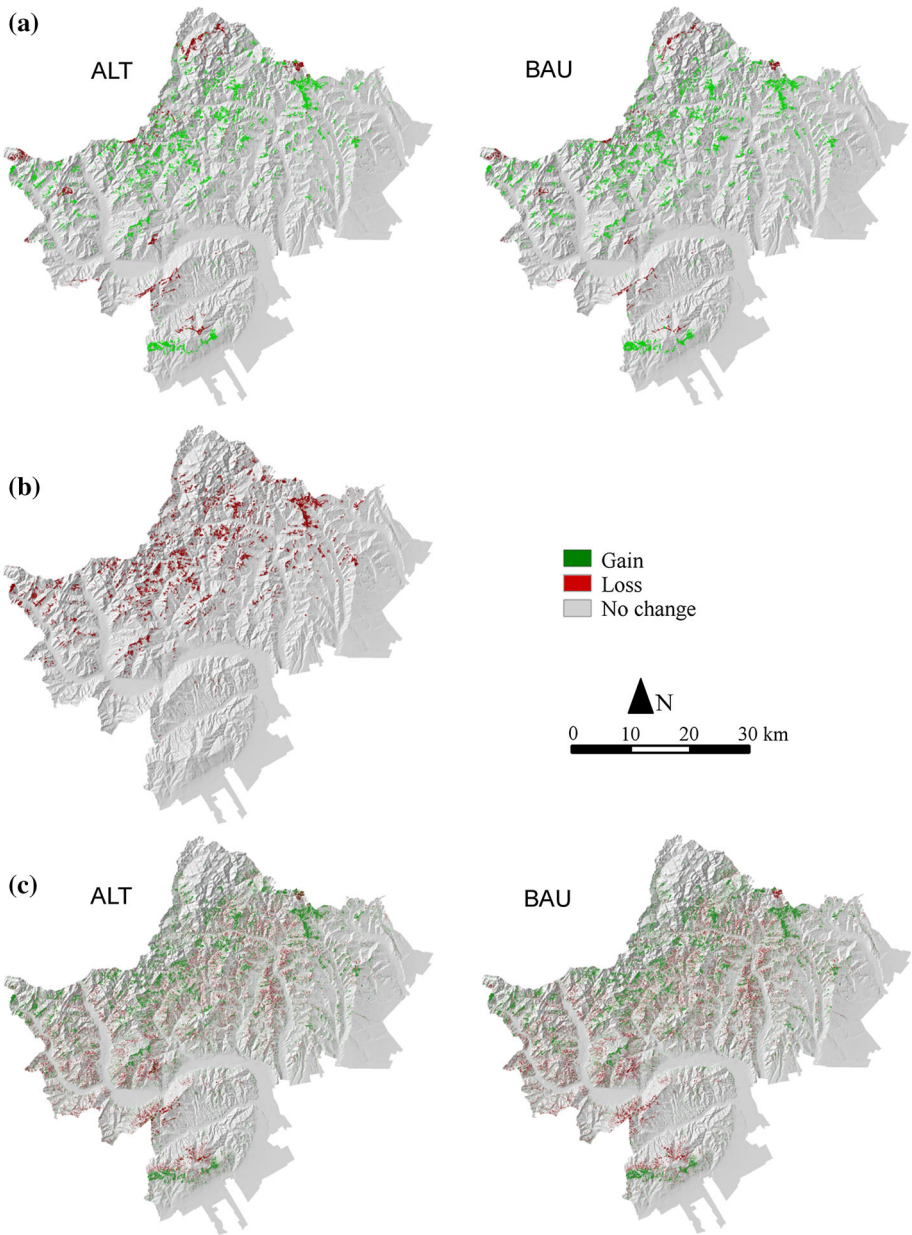


Fig. 5 Changes to the **a** forest cover for the alternative deforestation (ALT) and business as usual (BAU) scenario, and ecosystem services: **b** biodiversity support (the same for both scenarios) and **c** landslide regulation

persistence, increase or decrease in landslide susceptibility. This way we accounted for areas where both models agree and disagree. The alternative scenario resulted in 73.4% more areas with an increase in landslide susceptibility, compared to the BAU scenario (Table 3). Moreover, when looking at the agreement and disagreement of both maps in

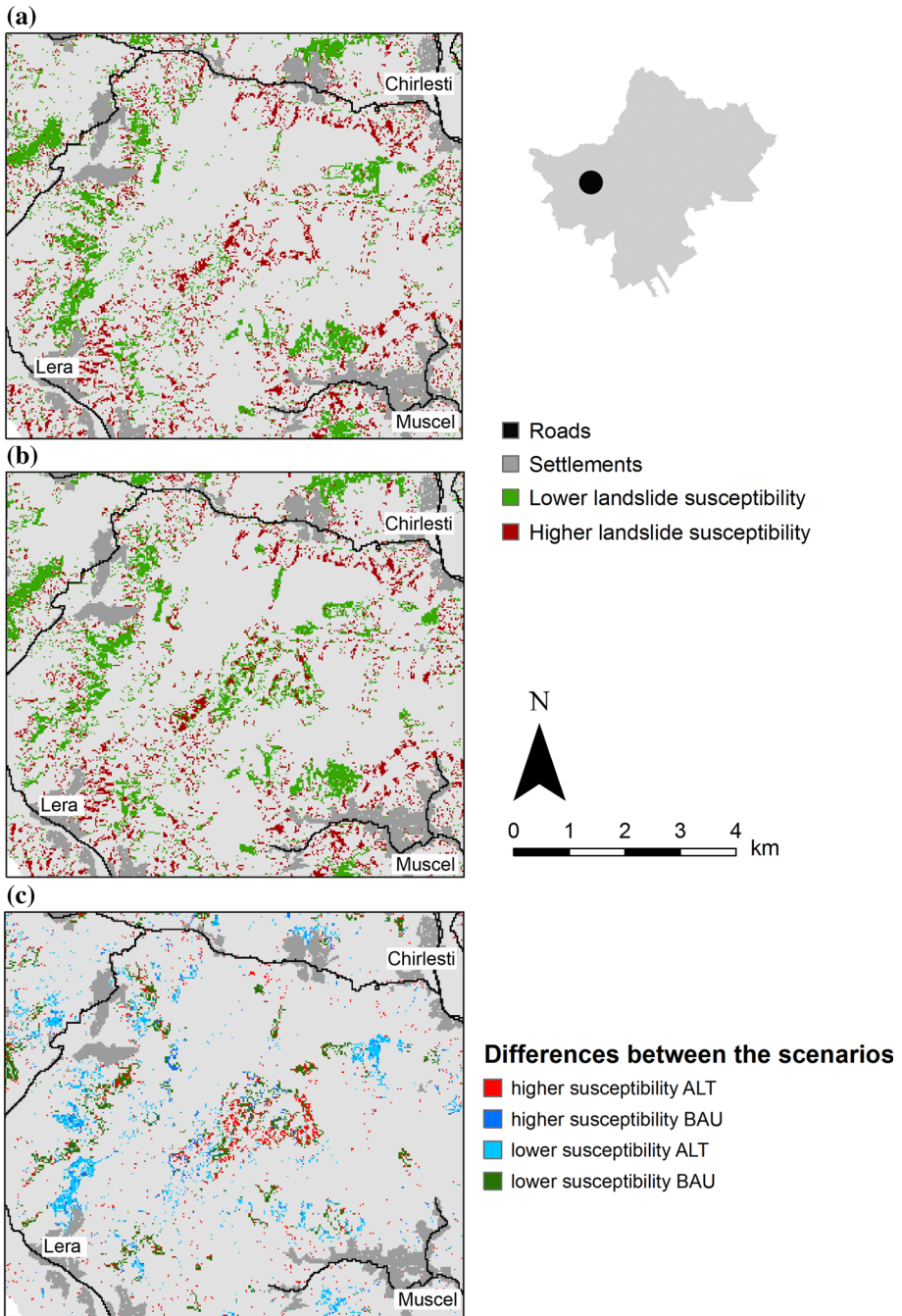


Fig. 6 Local-scale changes to landslide susceptibility between the localities of Patarlagele and Nehoiu in the **a** alternative and **b** business as usual scenario. Locally, significant increases to landslide susceptibility occur in the alternative scenario (**c**)

Table 2 Changes to the spatial pattern of HNV grasslands under the two 2040 scenarios of forest cover change

Landscape metric	2010	Future	Change in %
No. of patches	2592	6154	237
Mean patch area (ha)	21.1	7.4	-64.8
Median patch area (ha)	1.35	0.3	-80.0
Shannon index	0.625	0.579	-7.3
Simpson index	0.434	0.39	-10.1

Table 3 Gains and losses to landslide regulation under the two 2040 scenarios of forest cover change. Changes modeled only by a specific scenario present the differences between the two scenarios (areas where the projected changes to landslide susceptibility do not overlap)

Landslide regulation	Alternative scenario		Business as usual	
	Gain	Loss	Gain	Loss
Changes compared to 2010 (ha)	14,744	10,676	15,060	9835
Changes modeled only by the scenario (ha)	5954	2860	6408	1650

terms of quantity and location, 62% of the difference between the maps can be explained by changes in allocation, with the remaining 38% associated with changes to quantity in landslide susceptibility. Although the results are not dramatically different in terms of total net changes to landslide susceptibility, the changes to landslide susceptibility therefore have a high spatial variation. In several locations, the alternative scenario results in significant increases to landslide susceptibility compared to the BAU scenario (Fig. 6). Often, these areas are close to existing settlements and roads. In a landslide-prone area like the Buzau Subcarpathians, such local-scale changes are significant, as they can result in a local increase in occurrence and intensity of landslides.

5 Discussion

Similar studies on potential future changes to ecosystem service provisioning in the Carpathian region are rare. Existing research on land cover changes in the Carpathian region, however, suggests that their consequences are complex (Griffiths et al. 2012, 2014; Knorn et al. 2013). This study complements the understanding of a variety of possible consequences of forest cover changes and also addresses the spatial component of this issue.

The spatial assessment differs from other similar scale studies on ecosystem services. Previous studies have analyzed ES, often focusing only on the current land cover (Burkhard et al. 2010; Egoh et al. 2008; Grêt-Regamey et al. 2008; Nedkov and Burkhard 2012). Our study, however, quantified in spatial terms the potential future changes to ES. Using two scenarios based on a set of changes to the Romanian forest policy, we investigated how future changes to the forest cover can result in either gains or losses to ES.

This study offers an explanation on the consequences of increased deforestation trends. Seen as a means of regional economic development, forest harvesting can result in a variety of different consequences. First of all, deforestation due to clear-cut forest harvesting results in short-term financial gains, but at the same time decreases the potential of

the forest to provide a steady and continuous flow of wood resources. The alternative scenarios result in a 66.7% higher loss of tree cover. This affects the potential for wood provision in the form of traditional forest harvesting methods more than the business as usual scenario. Secondly, deforestation can result in a local increase in landslide risk, posing a threat to livelihoods and infrastructure. This was analyzed by modeling the changes to landslide susceptibility using the same static variables (elevation, slope, geology), while changing the land cover according to future forest scenarios. The business as usual scenario resulted in a 7.9% lower loss and a 28.5% higher net gain of the landslide regulation ecosystem service compared to the alternative scenario. Our results thus indicate that short-term gains from forest harvesting can have negative consequences in the form of increased landslide risk.

Forest expansion as the dominant future land use change in the area has positive and negative consequences to human well-being. On the one hand, it can result in the decrease in high nature value grasslands, leading to lower biodiversity levels, loss of significant habitats and a more homogeneous landscape (Fischer et al. 2008; MacDonald et al. 2000; Zimmermann et al. 2010). On the other hand, it can result in a lower risk to landslides, as areas covered with forests have a lower landslide susceptibility than areas covered with grasslands or low-intensity agricultural areas. The fact that it is less likely that a landslide occurs on a forested area is not surprising, as evidence shows the positive influence of vegetation for soil reinforcement (Schmidt et al. 2001). Reforestation therefore has the ability to increase slope stability and can be considered as a landslide risk reduction or soil and water conservation measure (Phillips and Marden 2005; Mansourian and Vallauri 2014). This is a trade-off between increased safety and economic gains (e.g., lower damages on infrastructure), and a lower cultural value of the landscape.

Using a spatially explicit pixel-based approach we were able to identify the spatial distribution of the gains and losses to ES. Pixels that have witnessed these changes are, however, subject to uncertainty, related to input data and the models used. Firstly, uncertainty is defined by the accuracy of the classified land cover maps serving as an input in forest change simulation. Secondly, the accuracy of the future forest change allocation model also implies that locations of future changes are subject to uncertainty (Malek et al. 2015a). However, the projected future scenarios are considered acceptable, as their accuracy is comparable with other high-resolution land cover change studies (Kamusoko et al. 2013; Maeda et al. 2011; Soares-Filho et al. 2002). Moreover, our susceptibility model also has a certain level of uncertainty, defined by both the model and the mapped landslide data used in the analysis. Finally, due to data scarcity our approach dealing with assessing the changes to wood and biodiversity provision is based on expert opinion. All these errors are aggregated in final maps and affect the results. Therefore, the results have to be analyzed through the prism of possible inconsistencies and errors when looking at the exact locations of these changes. We suggest the results should be discussed as suggestions for most plausible areas, where changes to ES might occur in the future.

For future research we suggest additional analysis of changes to ES provisioning. In case of resource provision, this could be performed with more detailed data and spatial distribution of forest types, age and quality. Moreover, data regarding the ownership and economic value of forests could improve the assessment of potential tradeoffs of future forest harvesting and forest expansion. In terms of biodiversity provision, deforestation and forest expansion can also have other consequences than the loss of HNV grassland, like changes to habitat fragmentation and landscape connectivity (Körner et al. 2005). This might affect vital habitats of large European carnivores present in the area (van Maanen et al. 2006). When analyzing potential changes to landslide regulation, improved spatial

and temporal resolution of landslide data could allow the use of more elaborate runoff models. Improving the data and the models can lead to prioritization of locations where measures for regulation of ecosystem services degradation can be considered. Moreover, other simultaneous processes of land cover change, such as urban expansion, could be considered (Malek et al. 2015b). These can be performed as reforestation or technical measures or grassland protection together with incentives for low-intensity agriculture. Through more accurate results, the approach could so fully utilize its decision support potential and could lead to more informed grassland and forest management.

6 Conclusion

Future forest cover changes can have a variety of effects to the environment, which is why it is useful to apply the ecosystem services (ES) concept to analyze a variety of potential consequences of such changes. In this study, we focused on biodiversity support and landslide regulation. To analyze the changes to ES provisioning in this data-scarce area, we applied two proxy indicators, describing the gains and losses of a particular ES.

The alternative scenario projected a 66.7% higher deforestation compared to the business as usual scenario. Both scenarios result in the loss of biodiversity support due to their prevalent transition of forest expansion. The scenarios also differ in terms of changes to landslide regulation. The business as usual scenario results in a 7.9% lower loss of landslide regulation potential compared to the alternative scenario, as a result of deforestation. On the other side, it also results in a 28.5% higher regional net gain of landslide regulation potential compared to the alternative scenario, as a consequence of the simulated forest expansion.

Despite the uncertainties of the data and models applied, the comparison of the two scenarios provides valuable information on the consequences of future forest harvesting. This helps to enable vital decision support when assessing forest harvesting policies and informing decision makers on potential gains and losses of future development. Finally, the approach supports the prioritization of areas where losses to ecosystem service provisioning are more likely to occur.

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