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The assessment of regulatory ecosystem services: the case of the sediment retention service in a mountain landscape in the Southern Romanian Carpathians

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Abstract

The ecosystem services concept offers an interdisciplinary approach to the integrative study of both socio-economical and ecological systems. The sediment retention service is mentioned among the regulation ecosystem services in all the main international classifications (MA, TEEB, CICES). It refers to the capacity of ecosystems to regulate the quantity of eroded sediment reaching the stream network, and thus delivering benefits like maintaining soil and water quality and reservoir functions. This paper aims to assess the link between possible land cover changes and the sediment retention service provided by the vegetation cover. The analysis focuses on a mountain landscape from the upper catchment of Râul Târgului, Iezer Mountains in the Romanian Carpathians. To this purpose, we considered recent changes in the forest landscape (2005-2012) and, with the participation of local administrative stakeholders, we developed three land cover scenarios (Business-as-Usual, Conservation and Development). For each simulated land cover map we compared the supply of sediment retention services by using quantitative indicators: sediment retention, sediment export and the amount of potential soil loss. For the processing of spatial data we applied GIS techniques using the ArcGIS software (ESRI) and for the modeling we used the InVEST 3.2 software (Natural Capital Project). One of our major findings is that the landscape of 2012 retained approximately 3 million tons/year of sediment. Further on, our results show the highest decrease in the sediment retention service for the Development scenario and the highest increase for the Conservation scenario. However, these changes represent less than 2% of the 2012 values. Overall, our results show that the tools and models used proved to deliver credible and relevant results and can be used for future local landscape planning.

Peer-review under responsibility of the organizing committee of ECOSMART 2015

Keywords: regulating ecosystem services, sediment retention, land cover change scenarios, InVEST, Romanian Carpathians

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1. Introduction

The ecosystem services (ES) concept offers an interdisciplinary approach to the integrative study of both socio-economic and ecological systems. Land cover and land use (LULC) change is one of the main drivers to determine degradation of ecosystem properties and their ability to provide ES and goods [1]. The role of land cover in erosion and hydrological processes has been long recognized and studied [2, 3, 4, 5, 6, 7, 8, 9] with a special interest to forest vegetation [10, 11, 12, 13]. The role of the vegetation cover in providing ecosystem services such as the prevention and control of soil erosion has also been recognized in more recent times by all major international classifications of ES [1, 14, 15].

One of the first mentions of the sediment retention as a regulating ecosystem services was made by Constanza et al., who define it as a service provided by the function of an ecosystem to retain soil [16]. In 2010 de Groot et al. define the service of *erosion protection* as the *role of vegetation and biota in soil retention* and suggest as an indicator the amount of soil retained or sediment captured [17]. In more recent studies, there are more attempts to quantify and model the capacity of ecosystems to provide sediment retention services [18], erosion mitigation and prevention [19] or nutrients and sediment retention services [20] but most often together with other types of services in order to identify trade-offs or synergies [21, 22, 23, 24]. In our approach, the sediment retention service refers to the capacity of ecosystems to regulate the quantity of eroded sediment reaching the stream network, and thus delivering benefits like maintaining soil and water quality and reservoir functions [25, 18], as illustrated in figure 1.

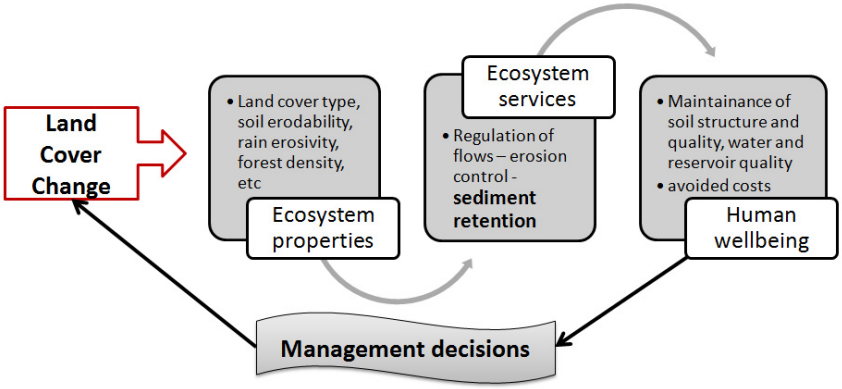

Fig. 1 The cascade framework applied for the retention service (after Haines-Young, 2010[26])

Soil erosion and the amount of sediment to reach the stream are influenced by the complex interactions between landscape properties such as geological and soil properties, rainfall regimes, topography, landscape connectivity and LULC [18, 19]. Human induced soil erosion reduces soil productivity compromises freshwater ecosystem services, and drives geomorphic and ecological change in rivers and their floodplains [13].

The approach of LULC scenarios does not strive to make predictions, but on the contrary, it aims to create a set of dissimilar alternatives to capture the uncertainty of future changes [27]. A scenario approach allows depicting plausible landscape development under different intensities of driving forces, and provides the opportunity to compare ecosystem service outcomes [28]. They have been used in global ecosystem assessments such as the Millennium Ecosystem Assessment [1], as well as in many Sub-Global Assessments such as the UK National Ecosystem Assessment [29]. The background of LULC scenarios consists in the well established science of land use modeling, which when utilized in a predictive capacity, provides valuable insights into possible land use configurations in the future [30, 31].

High mountain regions can often be perceived as economically unprofitable regions. Through the ecosystem services approach we can make more visible and more understandable to decision makers the wide range of benefits that people derive from mountain ecosystems, such as: protection against and mitigation of natural hazards, carbon sequestration and storage in mountain forests, natural resources, tourism and recreation, fresh water, and biodiversity [32, 33, 34]. Because of the high declivity, the erosion mitigation and sediment retention services are of great importance in these regions.

This study attempts to answer to two main questions: i) what is the amount of sediment retention services provided by the current landscape and how can changes in land cover (LC) influence provision of regulation services such as sediment retention and soil erosion mitigation. To this purpose we took the following steps: (i) we assessed the sediment retention service for 2012; (ii) we assessed the changes in the values of sediment retention services in relation to land cover changes between 2005 and 2012; and (iii) we modelled possible land cover changes (LULC scenarios) and their effect on this regulation service.

2. Data and methodology

2.1. Study area

The study area is situated in the Iezer Mountains of the Southern Carpathians and it is part of the upper Râul Târgului catchment (fig. 2a), within the boundaries of Lereşti administrative unit, Argeş County, Romania. It covers an area of 153 km^2, with an elevation ranging from 900-2470 m (fig. 2c), and slopes higher than 40˚ on more than 30% of the surface (fig. 2d). The area rests on dense metamorphic basement rocks and has a soil cover composed mainly of forest soils such as podzols and brown forest soils with a clay-sandy structure [35, 36]. The quantity of precipitations ranges from 850 mm in the area near the reservoir to 1300 mm on the top of the mountains [37, 38].

The reservoir Râuşor that forms the outlet of the watershed exists since 1986, covers an area of 1.45 km^2 and can hold up to 60 mil m^3 of water. The main uses of the reservoir are as follows: municipal water supply, control of peak flows, and energy generation in two small hydropower plants: CHE Lereşti (19 MW) and CHE Voineşti (5.2 MW) (data from the Basin Administration ABA Argeş-Vedea).

The study area is composed of four catchments (fig.2b) corresponding to the main rivers: Râuşor (1) - 3944.5 ha, Bătrâna (2) - 3123.6 ha, Cuca (3) - 2195.4 ha, Râul Târgului (4) – 2397 ha.

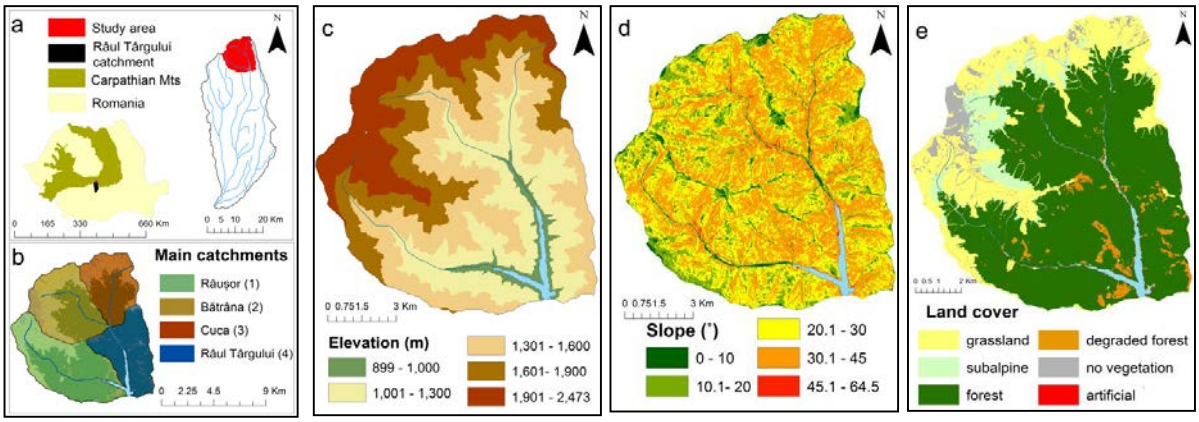

Fig. 2 a. The location of the study area in Romania and in Râul Târgului catchment; b. The four main catchments in the study area; c. Elevation map of the study area; d. Slope map; e. Land cover map for 2012.

The study area is predominantly covered by forests. Before 1948 the forests were administrated without management plans so the need for timber prevailed, which led to massive clear cuts. After the communist regime came to power, all forest areas were administrated by the state but with the same trend in exploitation (according to Săvulescu [35], between 1950 and 1996 the volume of timber exploited from the two forest units that form the study area was 2.2 and 1.7 higher than the volume recommended by the management plans).

Starting with the 1970s, under the National Program for the Conservation and Development of the Forestry fund, there was a decrease in timber exploitation and an attempt to increase the forested areas. This was done through reforestation with conifers, manly spruce (*Picea abies*), which changed to a great measure the natural forest associations, with the only purpose of increasing the production of high quality timber.

After 1990, there were several attempts made to return forests to their original owners from before 1948. The last legislative form of this retrocession dates from 2000 and reflected in a poor management of the new privately owned forests and in many cases illegal deforestation. In 2006 privately owned forests covered aprox.11.3 km^2 of the study area [37, 38].

The land cover in 2012 (fig. 2e) consists of 65 % forest, 23% grassland, 7 % subalpine vegetation, 0.5 % built-up areas and roads and the main land uses are for forestry and tourism.

Currently there are two types of legal protection status that apply to a large part of the study area: a NATURA2000 network SCI area (Munții Făgăraș ROSCI0122) which includes the two northern catchments Bătrâna and Cuca, and a "protection forest" status for the forests surrounding the reservoir, according to the forestry management plan[37,38]. However, the SCI protected area still does not have a management plan and also part of the protection forests are currently under private administration which increases the risk for illegal deforestation.

The main driver that impacts the forest ecosystems in the study area is windthrow damage [35, 37, 38]. The forest vegetation in the area shows an increased vulnerability to this natural hazard partly due to the past changes in composition as well as practices of exploitation that led to a degraded soil structure and erosion [34]. After such an event, the forest cover is lost even more with the clear cutting practices done in order to clean the area of any standing trees that are vulnerable to any future incident. Unfortunately, on many occasion the area cleared is much larger than the area affected by windthrow.

2.2. Data sources, workflow and software used

For this study we used both spatial as well as numerical data with different levels of processing. They are presented in table 1.

We derived topographic data such as elevation, slope, etc from a topographic map of Romania at a scale of 1:25,000 (Military Topographic Direction, 1980). For land cover data we used orthophoto images from 2005 and 2012 belonging to the National Agency for Cadastre and Land Registration) ANCPI, (http://geoportal.ancpi.ro/geoportal/viewer/index.html) and also forestry management planes for 2006 from the Institute for Forest Research & Management Institute ICAS. From the forest management plans we also derived the ownership of the land, tree species, forest density and age, past administrative measures.

Table 1. Data used and data sources

Primary data	Resolution	Source	Derived data
Topographic map (1980);	1:25000;	DTM	DEM, slope, stream network
Orthphoto images for 2005 - 2012;	1:5000	ANCPI	Land cover, road network
Forest management plans 2006;	1:20000	OS Câmpulung, ICAS	Forest density, tree species, ownership
Rainfall erosivity in Europe	500m	Panagos et al 2015a	Rainfall erosivity for the study area
Soil erodability in Europe	500m	Panagos et al, 2014	Soil erodability for the study area
Cover factor in Europe;	100m	Panagos et al 2015b	Cover factor for the land cover types
Monthly sediment fluxes for 2005 and 2012 ;	-	ABA Argeș Vedea	Yearly sediment yield for 2005 and 2012
Interviews with administrative stakeholders: local administration , forestry administration;	-	Lereşti town hall OS Câmpulung	Transition matrix for development scenario, factors for all scenarios
Favorability classes for forest vegetation	10m	Săvulescu, 2008	Factors for Conservation scenario

For the USLE factors we used preprocess raster data from Panagos [39, 40, 41, 42] available from the European Commission Joint Research Center, European Soil Data Center at http://esdac.jrc.ec.europa.eu/resource-type/soil-threats-data.

The data on monthly sediment fluxes were retrieved from ABA Argeș-Vedea. We accessed local knowledge through interviews and discussions with local administrative stakeholders, and also experts with experience in the area.

In order to assess the impact of changes in land cover on the sediment retention service in different scenarios, we used models provided by the InVEST 3.2 software (downloaded from http://www.naturalcapitalproject.org/invest/). This is a suite of free, open-source software models used to map and value the goods and services from nature that sustain and fulfill human life and to explore how changes in ecosystems are likely to lead to changes in benefits that flow to people. It contains three primary categories of models: supporting services that underpin other ecosystem services, but do not directly provide benefits to people, final services that provide direct benefits to people, and tools to facilitate ecosystem service analyses [24, 25].

All the pre and post-processing operations, as well as the quantifying of recent land cover changes were done using ArcGIS 10.2 [43].

The main workflow fluxes are presented in figure 3.

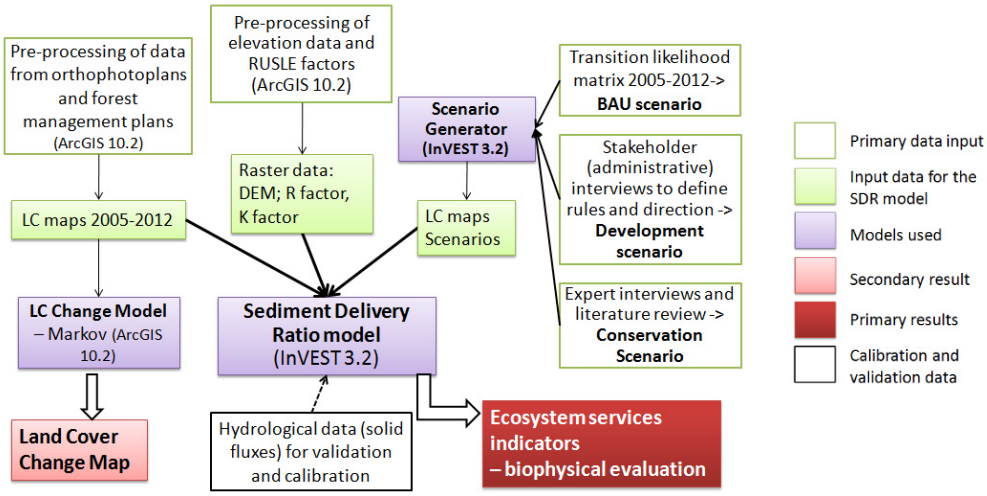

Fig. 3 Workflow diagram

2.3. Land Cover change models

2.3.1. Recent changes (2005-2012)

In order to quantify the recent changes in the landscape (in the 2005-2012 time interval) we used orthophoto images to digitize land cover types. The time interval was conditioned by the availability of data. The land cover types we mapped are defined in table 2. They serve as proxies for the ecosystems that provide services.

The next step was to code and convert into raster format the two land cover maps for 2005 and 2012. The land cover changes were quantified with a Markov changes based model, resulting in a frequency matrix and a transition likelihood matrix [44].

Table 2 Description of land cover types

Land cover type	Description
Grasslands	Alpine vegetation[45] – natural meadows, but also secondary pastures used for animal grazing.
Subalpine vegetation	Transitional vegetation between alpine and forest vegetation[45]– mostly bushy vegetation *(Pinus mugo, Vaccinium myrtillus, Junperus communis ssp. Nana*, etc) and mosaics of herbaceous and bushy vegetation.
High density forest	Areas with more than 80 % forest cover – according to the 2006 forest maps from the management plans[37,38].
Medium density forest	Areas with 60-70 % forest cover – according to the 2006 forest maps from the management plans[37,38].
Low density forest	Areas with lower than 60 % forest cover – according to the 2006 forest maps from the management plans[37,38].
Degraded forest	Areas affected by recent windthrow or clear cutting, but without a permanent change in use.
Areas with no vegetation	Areas affected by erosion in the alpine level or in the flood plain of rivers, water surfaces.
Built-up areas or roads	Permanent or temporary households, buildings, forestry roads, modern main road.

2.3.2. Possible future changes - Scenario Generator

Land use scenarios provide information on the comparative change in ecosystem services with possible futures. They can be developed using participatory methods or by technical experts but most commonly, scenarios are developed through a combination of both [22, 28, 46, 47].

InVEST software attempts to solve the multi-objective multi-criteria problem of allocating land parcels to various uses through the Scenario Generator tool [25, 27].

The major components of the input required by the model are: i) the transition likelihood (from 1 to 10); ii) the physical and environmental factors that influence change; iii) the quantity of anticipated change under a given scenario (percent of the current area). In return, the model generates spatially explicit results in the form of land cover maps for the input conditions.

For each scenario we used transition tables that were defined based on the recent changes identified (BAU) interviews with the administrative stakeholders (Development) or literature review (Conservation) and spatially explicit suitability factors in vector format. The factors were either polygon features where the suitability is defined by a attribute table field ("suit field") that ranges between 0 and 100 and defines the suitability of that polygon for a specific land cover, or polyline or point features where the suitability is determined by the distance (in meters) to which the factor is influential. We also used a constrain layer consisting in the reservoir area covered with water, which we considered not to suffer changes.

The scenarios used for this study were modelled based on the following rules in table 3.

Table 3 Scenario storylines

Scenario	Storyline
BAU	The trends observed in the 2005-2012 interval continue. The amount of change and transition matrix resulted from the Markov chains change model between 2005 and 2012. The same suitability factors as for the Development scenario were used.
Development	Intensification of touristic activities resulting in a doubling of built-up areas compared to 2012. The trend of forest damage stays the same as in the 2005-2012 interval (increase by 189%) but with a priority for privately owned forests. As suitability factors we used the proximity to roads and buildings for the new artificial surfaces (built-up areas and roads), slope and elevation suitable for artificial land cover and the ownership of land for the extension of degraded forest. We also used as override the land cover changes provided in a project for the development of the Iezer-Portăreasa Ski Resort proposed by a private developer.
Conservation	An increase in subalpine shrubs (predicted also by Săvulescu[35]), along with an increase in density of forest vegetation at the expense of grassland and areas with forest damage. We considered an increase of 30 % in the area of high and medium density forest after performing a sensitivity analysis to determine the value for which all degraded forest areas were converted to medium of high density forest. As suitability factors we used: elevation (1650-2200 m for subalpine vegetation and lower than 1800 for forest vegetation[48]) and also the favorability classes for forest vegetation developed by Săvulescu[35] to determine the most suitable areas to be covered by forest vegetation. We used the values for spruce favorability as it is the predominant species and also the most likely to develop at higher altitudes as an effect of current climate change, in concordance with the observed increase in annual temperatures by Săvulescu[35].

2.4. Sediment retention services modeling - Sediment Delivery Ratio (SDR) model

For the modelling of sediment retention service we used the Sediment Delivery Ratio model [18, 25] from the InVEST software. Its main objectives are to map overland sediment generation and delivery to the stream and to study the service of sediment retention in a catchment, important for reservoir management and in stream water quality. This approach is based on the concept of hydrological connectivity as it was proposed by Borselli et al. [49] and has received increasing interest over the past years [50, 51, 52].

For each cell, the model first computes the amount of eroded sediment, then the sediment delivery ratio (SDR), which is the proportion of soil loss actually reaching the catchment outlet.

The average amount of annual soil loss is calculated by the Revised Universal Soil Loss Equation (RUSLE) as presented in equation 1 [53]:

$$usle_i = \left(R \times K \times LS \times C \times P\right)_i \tag{1}$$

where: R is the rainfall erosivity; K is the soil erodibility, LS is the slope length–gradient factor, C is the cover-management factor and P is the support practice factor [53].

The sediment delivery ratio (SDR) is computed as a function of the hydrologic connectivity of the area, following an approach proposed by [54].

According to Hamel et al. [18] and Sharp et al.[25], the algorithm first computes an index of connectivity IC which determines the degree of hydrological connectivity of a pixel to the stream, based on its upslope contribution and flow path to the stream [49]. The sediment delivery ratio for a pixel i is then directly derived from the conductivity index IC using a sigmoid function (2) [54].

$$SDR_i = \frac{SDR_{\max}}{1 + \exp\left(\frac{IC_0 - IC_1}{k_b}\right)} \tag{2}$$

SDR_{Max} is the maximum theoretical SDR, defined as the maximum proportion of fine sediment which can travel to the stream; in the absence of detailed soil information, it has a default value of 0.8 [54]. IC_0 and k_b are calibration parameters that define the shape of the sigmoid function SDR–IC relationship [18].

The sediment yield from a given pixel i, sed_export is a direct function of the soil loss and SDR factor (3).

$$\text{sed\_export}_i = usle_i \times SDR_i \tag{3}$$

The model returns three main outputs that come as both average annual numeric data (amounts for each sub-catchment): i) total amount of sediment exported to the stream (tons/year); ii) total amount of potential soil loss calculated by the USLE equation (tons/year); iii) sediment retention as the difference in the amount of sediment delivered by the current land cover and a hypothetical watershed where all land use types have been cleared to bare soil (tons/year), as well as maps representing the per-pixel contribution to sediment yield (tons/pixel)

The preprocessing of data needed for the SDR model was done in ArcGIS 10.2 [43]. The digital elevation model was derived from 10 meters distanced contours from the topographic map (DTM) and the raster data for erosivity and erodability [39, 40] was resampled to match the cell size of the DEM. For the land cover input we used the orthophoto images derived data for 2005 and 2012 for past and current land cover, and also the land cover maps resulted from the Scenario Generator for future land cover configurations.

The values for the cover management factor (C) were derived for each land cover type from the work of Panagos et al [41] and for the P factor we used the value 1 as indicated in the literature for semi-natural areas without a specific type of practice [2, 42].

To estimate the flow accumulation threshold we first ran the *flow accumulation* tool from ArcMap to obtain a raster of flow accumulation. We overlaid the stream network from the topographic map to identify the value of 1000 as the threshold corresponding to the start of all permanent streams and also most of the intermittent streams.

We also used the road network as an additional drainage layer, as recommended by Hamel et al [18].

The next step was to compare the results from the uncalibrated model to the observed data for 2005 and 2012. We derived the yearly yield of sediment from the monthly sediment flux measured at a hydrometric station upstream of the reservoir. As recommended by Hamel at al.[18] and Vigiak et al.[54] k_b was the only parameter used for calibration. Vigiak et al. [54] suggest that IC_0 is landscape independent so that calibration should be based on k_b only. We selected the value k_b=1.8 which minimized the relative difference between predictions and observations for 2005 and 2012.

3. Results

3.1. Sediment retention services assessment for the landscape configuration in 2012

The absolute values for the three indicators (table 4) show watershed no. 2 (Bătrâna) to be the largeșt contributor to the sediment yield with the highest values for both sediment export (8366.5 tons/year – 43% of the total sediment exported) and Potential soil loss (126871.6 tons/year – 44%). Watershed no. 4 (Râul Târgului) shows the lowest contribution of only 302.6 tons/year (2%) of sediment exported and 8646.3 tons/year (3%) of potential soil loss. The watershed to provide the best sediment retention is no. 1 (Râușor) with an absolute value of 961178.64 tons/year (32% of total sediment retention) followed closely by the watershed no. 2 (Bătrâna) with 31% of the total sediment retention capacity.

Reported to the surface area (table 4), the highest exporter of sediment is watershed no. 3 (Cuca) with a value of 2.75 tons/ha/year followed by no. 2 (Bătrâna) with 2.68 tons/ha/year and the lowest values represent watershed no. 4 with a rate of 0.13 tons/ha/year. The highest potential soil loss reported to the surface is also registered in watershed no. 2 with a value of 40.6 tons/ha/year, almost double than the average for the whole study area (24.5 tons/ha/year). Reported to the watershed area, the best sediment retention is provided by the watershed no. 2 (292.3 tons/ha/year) and the lowest values are registered in watershed no.4 (215.2 tons/ha/year).

At the pixel level, the highest values for all three indicators can be found on the north rim of the study area, overlying areas with high slopes and herbaceous or no vegetation at all (figure 4).

Table 4. Sediment retention service indicators values for 2012

watershed	sediment export (tons/year)	sediment retention(tons/year)	soil loss (tons/year)	export/area (tons/ha/year)	retention/area (tons/ha/year)	soil loss/area (tons/ha/year)
1	4737.05	961178.6	77700.45	1.2	243.61	19.69
2	8366.51	913310.7	126871.6	2.68	292.31	40.61
3	6030.65	598484.5	75042.76	2.75	272.55	34.17
4	302.6	515997.9	8646.342	0.13	215.22	3.61
total	19436.8	2988972	288261.2	1.69	255.92	24.52

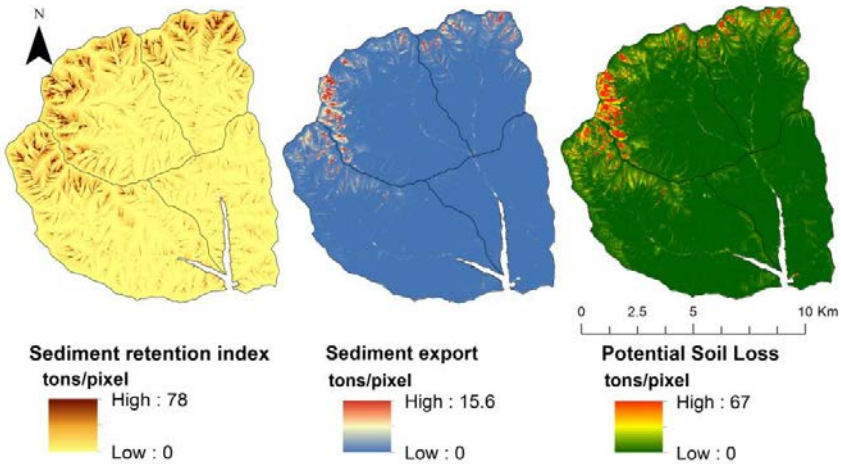

Fig. 4. Spatial representation of sediment retention service indicators for 2012, in the study area.

3.2. Changes in land cover and retention service indicators between 2005 and 2012

The comparative analysis of land cover between 2005 and 2012 shows decreases in grassland (by 1.5%), high and medium density forest (by 3% and 3.4%) covers in favor of subalpine vegetation (increase of 2.58%), low density forest (increase of 22.56%), degraded forest (increase of 188.8%), and artificial land cover (increase in roads f 49.9% and built-up of 69.8%). Reported to the entire study area, only 2.76 % changed its land cover (326.33 ha). 51 % of this change is from high density forest to degraded forest (165.72 ha) and 15 % from medium density forest to degraded. The next three changes, with approximately 5 % of the total changes are grasslands to subalpine or low density forest and low density to degraded forest (figure 5).

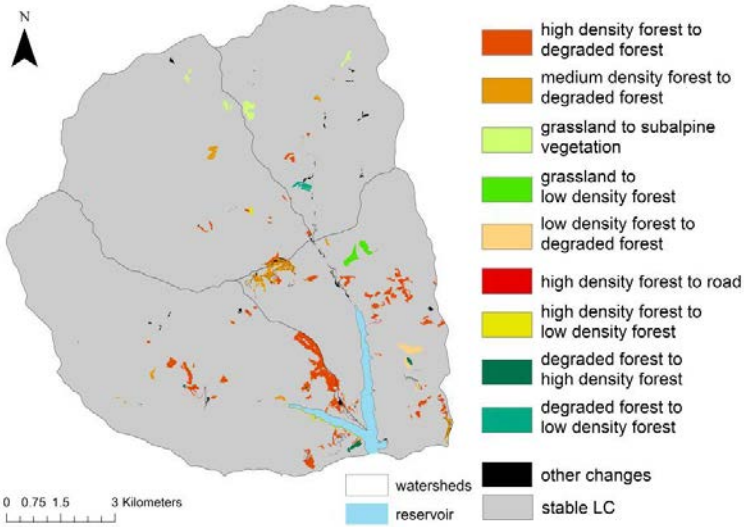

Fig. 5 Land cover changes between 2005 and 2012 in the study area

In terms of retention service indicators, the spatial results for the interval 2005 – 2012 are illustrated in the maps in figure 6. For the entire study area the quantitative analysis an increase of 75.5 tons/year in sediment exported, a decrease of 75.6 tons/year in sediment retained and an increase of 3805.34 tons/year in potential soil loss. Watersheds 2 and 3 show a decrease in sediment export and therefore an increase in the sediment retention of 17.6 tons/year and 33.6 tons/year. The highest decrease in sediment retention occurs in watershed no. 4 Râul Târgului (66.08 tones/year), followed closely by watershed no. 1 Râușor (60.8 tones/year).

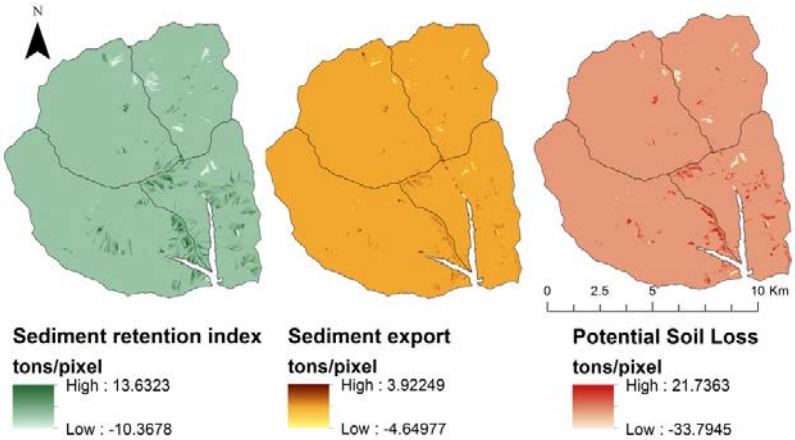

Fig. 6 Sediment retention indicators - changes between 2005 and 2012 in the study area

3.3. Land cover change scenarios

3.3.1. Land cover maps

Following the rules detailed in table 3, the Scenario Generator simulated the land cover maps in figure 7. Table 5 synthesizes the results of the quantitative analysis of land cover.

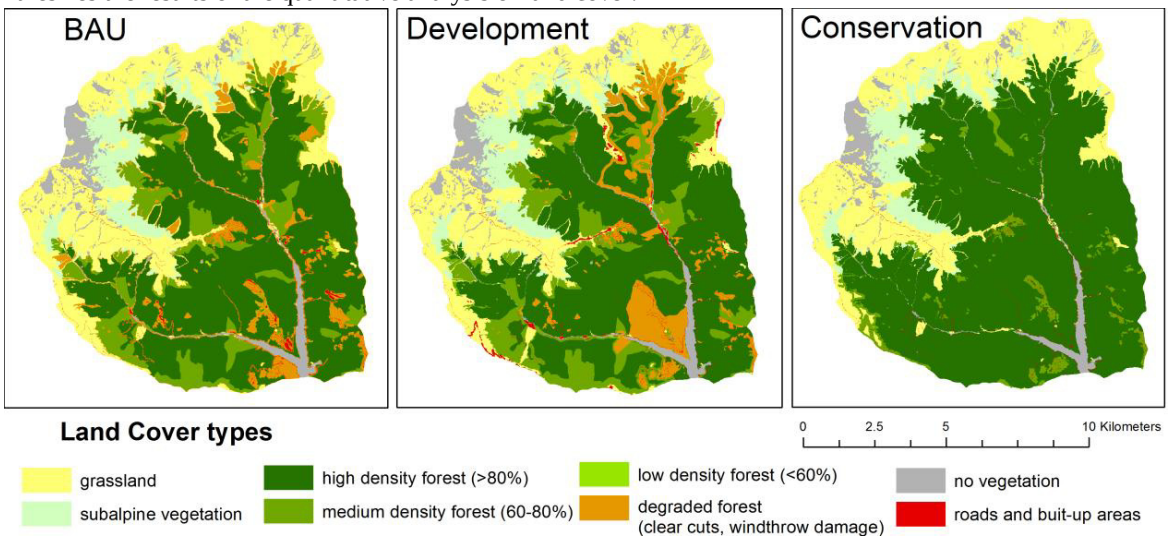

Fig. 7 Land cover maps for the three considered scenarios for the study area

The BAU scenario followed the same trends registered in the 2005-2012 period with an increase in degraded forest from 2.77% in the base map to 7.58% at the expense of all other forest types, scattered all over the landscape. Other land cover types that increase are grasslands and artificial surfaces (roads and built-up).

In the Development scenario the degraded forest cover reaches 8% of the total cover and artificial surfaces reach 0.9%. The forest areas affected by degradation are mostly located in the privately owned forests.

The Conservation scenario results in a total loss of low density and degraded forests and a decrease in medium density forests in favor of high density forests which reach almost 63% of all land cover. The only other land cover that increases is subalpine bushy vegetation (by 0.3%).

Table 5 Land cover types percentages in the considered cases

Land cover	2005 (%)	Base map - 2012 (%)	BAU (%)	Development (%)	Conservation (%)
grassland	23.04	22.70	22.76	22.17	21.18
subalpine	6.48	6.65	6.65	6.55	6.97
high density forest	49.80	48.30	45.38	43.27	62.86
medium density forest	13.31	12.85	11.33	13.25	3.87
low density forest	0.59	0.72	0.16	0.04	0.00
degraded forest	0.96	2.77	7.58	8.04	0.00
no vegetation	5.50	5.53	5.51	5.77	4.78
road and built-up	0.32	0.49	0.64	0.92	0.35

3.3.2. Sediment retention values for each proposed scenario

The results show sediment retention to be the indicator that varies the least between all three scenarios (figure 8). It decreases the most in the Development scenario compared to the values in 2012 (-0.06%) and increases in the Conservation Scenario by 0.12 %. At the watershed level, the maximum decrease is registered in watershed no. 3 for the Development scenario and the highest increase is of 0.25% also for watershed no. 3 in the Conservation scenario (table 6).

The sediment export increases overall the most in the Development scenario (8.91% increase from 2012) but at the watershed level, the highest increase is registered in the BAU scenario (68.94% in watershed 4). Conservation is the only scenario in which the sediment export decreases with an overall of 17.84% and a maximum value of 30.46 % in watershed 1.

Results show the same situation for the potential soil loss values. The highest overall increase is registered for the development scenario (8.5%) and at the watershed level for the BAU scenario in watershed no. 4 (44.19 %). Potential soil loss values decrease only in the conservation scenario with 13.63 % overall and a maximum of 26.24% at the watershed level (watershed no. 4).

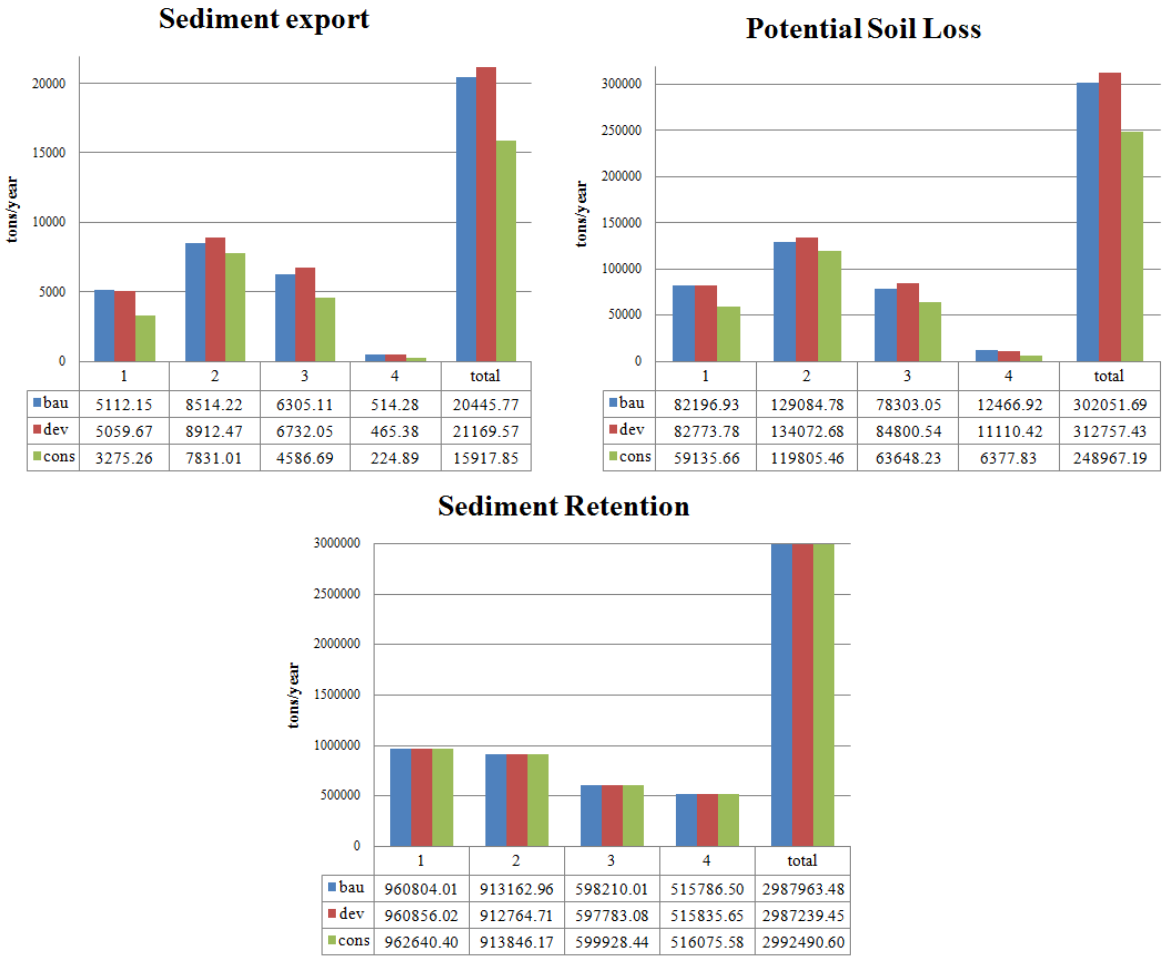

Fig. 8 Sediment retention service indicators variation for the three considered scenarios: BAU (bau), Development (dev) and Conservation (cons). The number 1-4 correspond to the four watercheds: 1- Râuşor; 2-Bătrâna; 3- Cuca; 4 – Râul Târgului

Table 6 Changes in sediment retention indicators between the three scenarios and the situation in 2012

ES indicator	BAU		Development		Conservation	
	total	Max/watershed	total	Max/watershed	total	Max/watershed
Sediment retention	- 0.04%	- 0.05 % - ws. 3	- 0.06%	- 0.12% - ws 3	0.12%	0.25% - ws 3
Sediment export	5.2 %	68.94 % - ws. 4	8.91%	52.63% - ws 4	- 17.84%	- 30.46% - ws 1
Potential Soil loss	4.78%	44.19% - ws. 4	8.5%	28.5% - ws 4	- 13.63%	- 26.24% - ws 4

4. Discussions

4.1. Sediment retention services in 2012 and changes between 2005-2012 as a result of land cover change

The overall results show values generally consistent with those specific to the Carpathian region in Romania (0.5 – 5.0 tons/ha/year) [55].

As expected, the results for 2012 show the highest rates of sediment exported in the two most northern catchments with a higher cover of grassland vegetation and also areas without vegetation and steep slopes characteristic to alpine environments. The higher rates of sediment export also mean a greater amount of sediment to be retained by the forest ecosystems in these areas and as a result, the highest sediment retention rates.

Overall, our major finding is that the amount of sediment retained by the 2012 landscape compared to the extreme scenario of the area cleared of any vegetation is of approximately 3 million tons/year of sediment. This compared to the capacity of the reservoir of approximately 60 mil tones of water reveals the significant value of sediment retention provided by the ecosystems upstream.

Because of the relatively small amount of time (7 years) and the remote character of the study area, the land cover changes in the studies interval are low (less than 3%) and mostly influenced by natural factors. However, the management practices coupled with the private ownership of some of these areas led to the clear cutting of areas larger than the ones originally affected by windthrow. It is important to notice that most of the changes affected high density forest ecosystems with a great contribution to the stabilization and retention of sediment.

Due to the relatively low land cover changes between 2005 and 2012 there were no major changes identified in the supply of sediment retention services. This may be due also to the great extent of forest ecosystems that cover more than 60% of the study area and have a great retention potential. However, significant changes were registered in the area surrounding the reservoir. At the pixel level, within a buffer area of 1 km around the reservoir we can observe a maximum increase of 0.7 tones/pixel of sediment exported and a maximum of 0.9 tones/pixel of sediment retained due to the increase in potential soil loss. This increase relates with the loss of forest cover on some of the slopes directly above the reservoir, and also to the intensification of the forestry roads network used to clear the windthrow affected areas.

4.2. Land cover change scenarios and changes in sediment retention services

The three proposed scenarios represent plausible but extreme storylines that describe future land cover change in the study area. They are not meant to predict in any way the evolution of land cover but rather to compare the provision of ecosystem services in very different landscape configurations.

As a result, the proposed changes in land cover are visible in the increased quantity of sediment exported to the stream both in the BAU and Development scenarios and a decrease for the Conservation scenario. However, the sediment retention values show little variation (less than 2% in comparison to 2012 values). This could be explained by the fact that all three scenarios still present a high percentage of forest ecosystems in order to keep the conditions plausible as this is a high mountain area and a too greater loss of the forest cover would not be likely in the foreseeable future.

The greatest loss in sediment retention services is registered in the Development scenario, even thou we kept the same amount of conversion into degraded forest (189% - the same rate as in the interval 2005-2012) as in the BAU scenario. The difference between the two scenarios is that in the BAU the change occurs scattered all over the

landscape and in the Development it is restrained to the privately owned forest patches which appear in compact blocks. This means a conversion from forest to degraded ecosystem on larger localized areas rather than smaller further apart patches. The other difference is that the Development scenario implies conversion to artificial surfaces two times higher than the BAU. Still, the area occupied by artificial surfaces is only 0.5% of the total land cover in 2012 so even if the surface doubles in the Development scenario it is still less than 1% of total land cover.

The Conservation scenario implies a total loss of degraded and low density land cover and an increase by 30 % in higher density forest ecosystems which relates with increases in the provision of erosion regulating services. Thus, the sediment export is 18 % lower than in 2012 and the potential soil loss is almost 14% lower. In return, the sediment retention capacity increases by 12%.

The sub-catchment with the biggest changes in terms of sediment export to the stream network across the three scenarios is number 4 (Râul Târgului). Even though is the smallest in surface and almost 100% forested, it is the most accessible from the main road and from the reservoir and also with the largest flood plain which makes it the most prone to the development of built-up areas or illegal deforestation on privately owned lands. These aspects are also revealed in the land cover changes described by the three scenarios.

To conclude, we found that the highest decrease in the provision of sediment retention service occurred in the Development scenario and the highest increase in the Conservation scenario.

4.3. Limitations of the study and future research

The most important limitation of the study comes from the Sediment delivery ratio model used, which relies on the RUSLE ecuation [53].This equation is widely used but is limited in scope, only representing rill/inter-rill erosion processes. Other sources of sediment may include gully erosion, stream bank erosion, and mass erosion. However, in the study area the mass and stream bank erosion are very limited and thus irrelevant for the sediment yield as the geological foundation of mainly metamorphic rocks offers relative stability. Gully erosion is present in the study area and we tried to include it in the model by considering in the stream network also intermittent water flows which in most cases form these torrential organisms. Still this is an issue we are trying to solve in the future by a linear erosion model including in the analysis.

Another limitation comes from the low resolution of the data used for the R and K factors. However, the computation of these data from local soil and climatic data would have been a very resource and time consuming operation and beyond the scope of our research. Also, given the small size of the study area and the fact that these two parameters usually show little spatial variation at the scale of one small mountain catchment, we consider the resolution of this data not to be problematic.

For the future land cover scenarios, one major limitation comes from the fact that we only included administrative stakeholders as they were the most accessible, representative for decision making and with a long term vision for the area. On the other hand, one of the main drivers of change in the forest ecosystem is natural disturbances and natural forest dynamics. Thus the next step in our research is to model the vulnerability to windthrow and other natural drivers, based on the forest ecosystem characteristics.

Another future research direction we are considering is the monetary valuation of the sediment retention service through the avoided costs for sediment removal from the reservoir and water quality maintenance. Also, another direction we intend to follow is the assessment of multiple ecosystem services and possible trade-offs or synergies between them as well as their benefits for human wellbeing.

5. Conclusion

The major findings of our study consist in the quantification and mapping the ecosystem service of sediment retention in a small mountain catchment. We obtained both baseline values for the current landscape (2012) and as well as temporal and spatial variation of the amount of services provided by the landscape. For this we identified, quantified and mapped past land cover changes (2007-2012) and simulated possible future changes based on these past trends, environmental factors, drivers of change and local knowledge (administrative stakeholder involvement). The last step was to assess the provision of retention services for each land cover configuration and compare the results in order to identify changes in ecosystem services related to the land cover changes.

Another major finding is that the models used from the InVEST software[25] proved useful even for this small scale study, local study and returned relevant and credible results for both land cover modeling and ecosystem services modeling.

Our results, coupled with assessments of other ecosystem services, can provide the basis for a more informed and conscientious decision making and also better local environmental and landscape planning. This can be accomplished through the gaining of a more complex understanding of the value of "nature", ecosystems and the benefits they provide by both stakeholders and decision makers.

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