Highland forest ecosystems in Rila mountain and their role in providing climate regulation services at a regional level

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НАУКА ЗА ГОРАТА, КН. 2, 2021
FOREST SCIENCE, No 2, 2021

HIGHLAND FOREST ECOSYSTEMS IN RILA MOUNTAIN AND THEIR ROLE IN PROVIDING CLIMATE REGULATION SERVICES AT A REGIONAL LEVEL

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Abstract: Ecosystems in mountainous regions provide a wide variety of ecosystem services. Forests regulate climate at regional and global levels by *i*) providing sources or sinks of greenhouse gases (affecting global warming) and sources of aerosols (affecting temperature and cloud formation), and *ii*) their physical characteristics which can regulate local and regional climate. Bulgarian mountains have large amounts of carbon 'locked up' in its forests and soils and this potential depends on the type of forest, management regime and natural disturbances. Land-use changes and climate changes are significantly affecting the quality of ecosystem services especially in highland mountainous regions. There is wide range of sustainable management options to improve climate related regulating services, which would also benefit other ecosystem services. Our main knowledge gaps concern the quantification of the climate regulation provided by highland forest ecosystems thus this research focuses on assessment and mapping the carbon storage and sequestration in highland ecosystems in Rila Mountain (Bulgaria) as main indicators for climate regulating services. The quantification encompasses the biomass carbon pool and the dead organic matter (dead wood and litter). The analysis of carbon storage and sequestration is realized according to biophysical methods for evaluation of ecosystem services by combining data from direct and indirect measurements considering all factors, which affect highland forests. The results are summarized and presented within the context of their potential to supply climate regulation ecosystem services.

Key words: carbon sequestration, carbon stock, ecosystem services, mapping and assessment

INTRODUCTION

Mountain areas are typically recognized as ecosystems supplying a vast variety of provisioning, regulating and cultural ecosystem services (Grêt-Regamey et al., 2012; Baral et al., 2017). They have an important role in climate regulation, water cycle, providing of recreation, cultural or spiritual values. The mountain forest ecosystems contribute substantially to the sustainable development of the mountainous regions (Koulov, 2013) and provide values not only to the local people, but also to people beyond the mountain areas. Assessment of these values is a key component for a comprehensive understanding of the ecosystem services (ES), which these areas provide and for setting policy direction for its management.

There are multiple definitions about the ecosystem services – Daily et al. (1997), MEA (2005), De Groot (2002) etc., but in the most cases they are recognized as the direct and indirect contributions of ecosystems to human well-being (TEEB, 2010). To be able to evaluate these contributions, information on the ecosystem state is needed.

This refers in most cases to the physical, chemical, and biological characteristics of an ecosystem at a particular point of time and at specific scale.

Large part of the territory of Bulgaria consists of mountain forests (Mishev (Ed.) et al., 1989, Panayotov et al., 2016). They are characterized by richness and diversity in vegetation which is determined by their physico-geographic and climatic features. Forest ecosystems are dominant in mountain areas of Bulgaria and as such play a significant role in maintaining and stabilizing natural processes. Their role in processes related to the regulation of the water balance, atmospheric composition, climate, etc. is essential. In socio-economic terms, the main function of forest ecosystems is the timber production and its derivatives, as well as the extraction of non-wood products. As a result of the increased anthropogenic activity and its impact on the natural environment and its resources, the importance of the protective and restorative functions of forests is gaining more attention such as soil protection from erosion, regulation of water resources, their contribution to biodiversity conservation and reduction of the adverse effect of climate change. All these functions and processes of forest ecosystems contribute to provisioning of wide variety of ecosystem services. And while some of the services are direct, such as the extraction of wood and non-wood products, others remain indirect, such as the nutrient cycle and the carbon sequestration. The concept of ecosystem services, which comprise the need for mapping and assessment of the ES and their valuation, ensures the recognition of the importance not only of the products and services directly derived from ecosystems, but also of the less tangible ones, as well as of the ecological processes that are the basis for providing these benefits.

With the growing public and political commitment to tackling global warming, there is a growing interest in forests and their role in climate change mitigation processes. Regardless of the geographical location, forests play an important role in CO_2 fixation (Bravo et al., 2008), as they are important components of the terrestrial C cycle, and store large amounts of C in vegetation, detritus and soil. Forest ecosystems absorb CO_2 from the atmosphere via photosynthesis and release it through auto- and heterotrophic respirations. Thus, the C dynamics in forests depends on the natural processes as well as management activities such as harvest interventions, afforestation activities, protection, and restoration.

Considering the growing interests in the mitigation potential of forests and the limited analysis in that respect in highland forest ecosystems in Bulgaria, the aim of the study is to assess and map the carbon storage and sequestration potential of the highland ecosystems in Rila Mountain, as the main indicators for capacity of the ecosystem to provide climate regulating services according to the Common International Classification of Ecosystem Services (CICES v.5.1, 2018).

METHODS AND MATERIALS

The carbon storage and sequestration in Rila Mountain highland ecosystems have been evaluated following the conceptual basis and principles of the National

Methodological Framework for Mapping and Assessment of ecosystems and their services (Bratanova-Doncheva et al., 2017). The assessment has been performed in two case studies, which encompass area of both the National Park "Rila" and the neighbouring State Forest Enterprises – Dupnitsa, Samokov, Yakoruda and Belitsa. One case study is in the Nord-West Rila mountain also known as Malyovitsa region. It encompasses the area of the Seven Rila Lakes, Urdini lakes all the way to Mechit peak. The second case study encompasses an area in south-eastern part of Central Rila (Fig. 1).

The case studies have been defined based on several selection criteria as altitude, accessibility, tree species diversity, management practices etc. The total area of the case studies amounts to 16 222 ha of which 68% is forested. The main tree species are *Pinus mugo* L. – 41%, *Picea abies* (L.) H. Karst. – 28%, *Pinus peuce* Griseb. – 18%, *Pinus sylvestris* L. – 11%, others – less than 2%. The average age of the stands is 101 years with an average growing stock of 193 m^3/ha (Table 1).

Carbon storage in biomass

The assessment of C stock in biomass of the high mountain forest ecosystems is prepared based on the data for growing stock from the forest management plans of the "Rila" National Park and the four neighbouring State Forest Enterprises. The carbon stock in living biomass of a stand has been estimated following the equation based on the 2006 IPCC Guidelines:

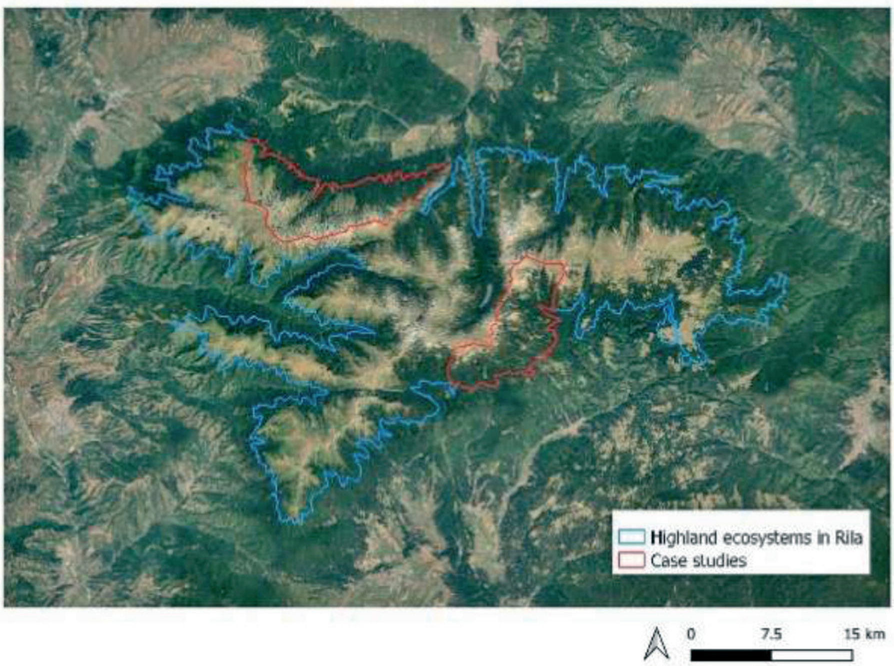

Fig. 1. Highland ecosystems in Rila Mountain (blue line) and the selected case studies (red line)
Фиг. **1.** Високопланински екосистеми в Рила (със синя линия) и опитните участъци (с червена линия)

Table 1. Main forest characteristics of the two case studies
Таблица 1. Основни характеристики на горите в двата опитни района

Tree species	Age, mean	Growing stock, m3/ha	Yield class, mean
Fagus sylvatica L.	83	290	3
Pinus sylvestris L.	86	207	3
Pinus peuce Griseb.	96	210	3
Abies alba Mill.	53	188	3
Pinus mugo L.	137	75	5
Picea abies (L.) H. Karst	92	237	2
Total	101	193	3

$$C = A \cdot V \cdot BEF_2 \cdot D \cdot (1 + R) \cdot CF\text{c}$$

Where:
- area, ha
– growing stock volume, m^3 ha^{-1}
– biomass expansion factor
– basic wood density, tonnes d.m. m^{-3}
– root-to-shoot ratio, dimensionless
– carbon content in dry biomass, tonnes C (tonne d.m.)$^{-1}$

The evaluation has been made at the level of sub-compartment within the territory of each enterprise. Overlay analysis and different geospatial tools in the open software QGIS were applied. The software allows extracting spatial information and attributes of each mapping unit encompassed within the case studies. In the cases where there is no data on the growing stock volume per hectare for a sub-compartment with age of the stand >20 years, but with information on tree species, age and yield class, the growing stock was assigned based on average values for the growing stock for the respective tree species, age and site quality. The mountain pine (*Pinus mugo*) stands were assessed based on average values for the growing stock of stands with Scots pine (*Pinus sylvestris*) of site quality 5 and age between 101-120 years as the mountain pine lacks species-specific yield table. In such cases the modelling of the growth is based on the Scots' pine yield table, which is a domestic common practice in case of no species-specific table is available in Bulgaria. The choice of the site quality and the age reflects the slow growth, which is typical for the mountain pine considering the severe climatic conditions, where the species is developing in Bulgaria.

Carbon storage in dead organic matter

The volume of the dead wood and litter was estimated as ratio from the standing biomass stock. The ratio was defined as the average for Europe based on the Forest Europe report (2020). The carbon stock in dead wood and litter has been assessed based on indirect measurements by using the conversion factors. The wood density was defined based on Di Cosmo et al. (2013) but adopted for the main tree species in Bulgaria. Default factor for carbon content (IPCC, 2006) has been used – 0.5 for dead wood and 0.38 for litter.

Carbon sequestration

To assess the ability of the highland forest ecosystems in Rila Mountain to sequester carbon, we estimated the carbon stock changes in biomass as the difference between the biomass carbon gain associated with vegetation growth and the biomass carbon loss associated with logging and/or natural disturbances. The current annual growth has been calculated based on a growth model, considering the tree species, the age of the stands and their yield class. Since no commercial harvesting is conducted on the territory of the national park the carbon losses from loggings for the territory of the National Park "Rila" have not been estimated. All the losses associated with timber extraction, from the areas of the case studies outside the National Park boundaries, have been assessed. There is no information for major natural disturbances within the areas of the case studies. Thus, C losses from natural disturbances have not been estimated. The carbon sequestration rate is served as an indicator to assess the provisioning of the carbon sequestration service. The latter is assessed based on a scale from 0 to 5 - from no capacity (0) to very high (5) (Burkhard et al., 2009; 2012).

RESULTS AND DISCUSSION

The analysis shows that the carbon storage ranges from 1 to 174 tC/ha in the case studies area (Fig. 2, B). The carbon stock varies mostly with the species composition, age structure and yield class of the stands. The carbon stored in the living biomass is higher in the subalpine areas, where forests of Norway spruce (*Picea abies*), Macedonian pine (*Pinus peuce* Griseb.) and Scots pine (*P. sylvestris*) prevail. It is estimated that the alpine area, covered with stands of mountain pine, stores between 23-36 tC/ha (Fig. 2).

The carbon stock in dead organic matter is estimated to range from 1 to 22.3 tC/ha with mean value of 6.3 tC/ha. Considering the different fraction of the dead organic pool, the average C stock in litter is estimated to 4.44 tC/ha, whereas the average C stock in dead wood – 3.21 tC/ha. Although the evaluation is not based on direct measurement, the results are consistent with national measured data. For example, the results for the litter pool show that the figures are comparable with monitoring data across Bulgaria related to the ICP Forest Programme (Table 2). The average volume of dead wood (estimated to 14.6 m^3/ha) is comparable with the average dead wood volume for the European countries as reported in Forest Europe report (2020), where the weighted average volume of dead wood for the EU-28 is estimated to 11.5 m^3/ha with a range from 2.3 to 28 m^3/ha.

The annual C storage in forests depends mostly on disturbances, forest succession, and climate variation (Gough et al., 2008) and forest management

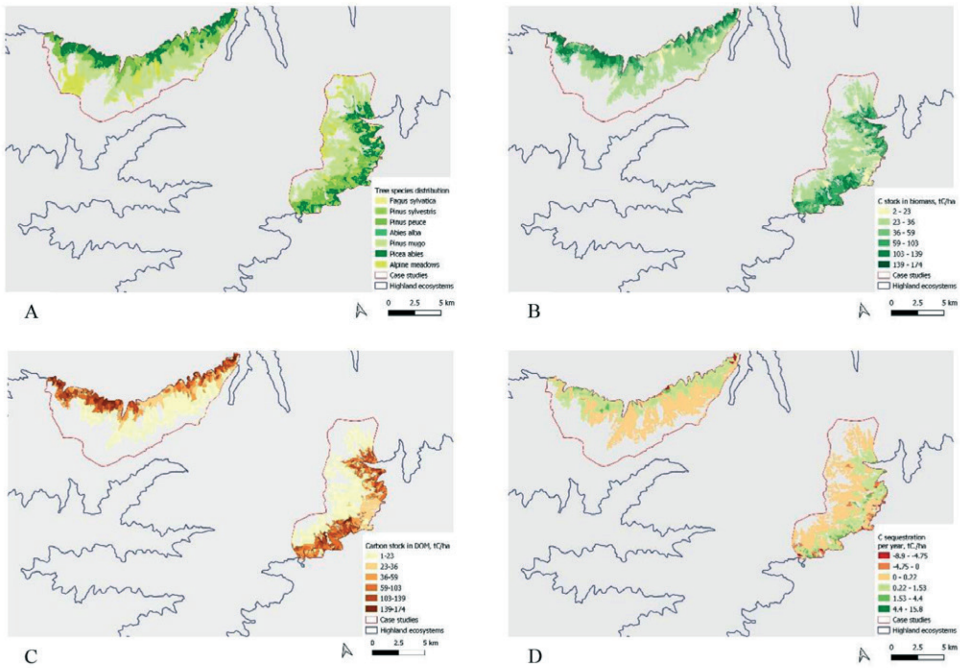

Fig. 2. Mapping and assessment of the carbon storage and sequestration in highland forest ecosystems in Rila MountainA – Map of tree species distribution; B – Map of the carbon storage in living biomass; C – Map of the carbon storage in dead organic matter; D – Map of the carbon sequestration in living biomass per year

Фиг**. 2.** Картиране и оценка на запаса на С и секвестирането на С във високопланински горски екосистеми в Рила планина А – Карта на разпространението на основните дървесни видове; В – карта на запаса на С в биомасата; С – карта на запаса на С в мъртва органична материя D – карта на секвестирането на С

Table 2. Comparison between the average carbon stock in litter in the case studies with the measured data from the ICP Forest Programme in Bulgaria

Таблица 2. Сравнителни данни между средните стойности на запас на С в мъртва горска постилка за опитните райони и горския мониторинг по МКП Гори

Data	Min	1st Qu.	Median	Mean	3rd Qu	Max
ICP data	0.37	1.97	4.12	5.84	7.61	22.86
Case studies, calculated	0.07	1.52	4.43	4.44	6.56	13.72

activities. Thus, forests under specific circumstances – after natural disturbance or unsustainable forest management - could become carbon emitters instead of carbon sinks (Kurz, Apps, 1999; Reichstein et al., 2002). This is confirmed in our analysis on the carbon sequestration by forests stands. The net gain in carbon is estimated to range between 8.8 to 15.9 tC/ha with mean value of 0.28 tC/ha (Fig. 2). The negative gains in carbon, which means that the loss of carbon prevails, are estimated in stands

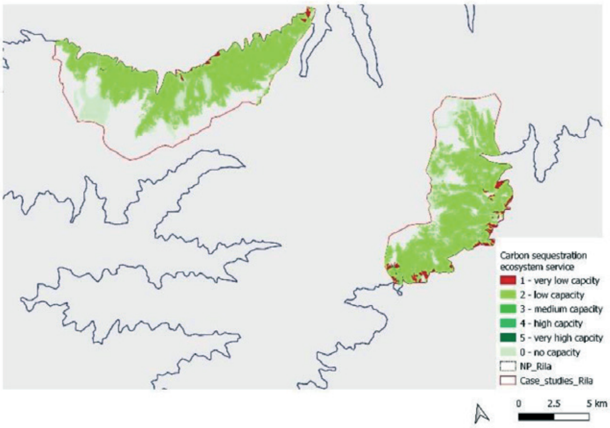

Fig. 3. Mapping and assessment of the capacity of highland forests in Rila Mountain to provide carbon sequestration ecosystem service

Фиг. **3.** Картиране и оценка на потенциала на високопланинските екосистеми в Рила да предоставят екосистемната услуга „секвестиране на С“

with active regeneration fellings, which are located outside the area of the National Park. The net gains in carbon are higher in the first three age classes with an age of the stands up to 60 years. For forest stands with age between 60 and 80 years, the net gains in carbon decrease with almost 20% for all the analyzed species. The decreasing trend in the net gains in carbon is observed for the older stands as well, which is normal considering the increase in the age of the forest stands.

The assessment of the carbon sequestration ecosystem service shows that the ecosystems with low capacity to provide this service prevail (Fig. 3). This is explained with the predominance of the mountain pine forests. High and very high capacity to provide the carbon sequestration ecosystem service is observed in small areas with younger stands. The accumulation of biomass and carbon in forest stands may be increased through different management options such as fire protection, pest control, increasing the length of time to rotation (harvest), regulation of tree densities, changes to the management of residues, etc. (Gracia et al., 2005).

CONCLUSIONS AND RECOMMENDATIONS

The results show that the highland forest ecosystems in Rila Mountain have a limited potential to provide climate regulation ecosystem service in terms of GHG regulation at a broader spatial scale. However, they play an essential role in conserving and maintaining the carbon stock in living biomass and dead organic matter as the larger part of the highland forest ecosystems in Rila are under protection, as part of the National Park "Rila". Thus, minimum sylvicultural activities are performed, which could affect the carbon stock. The losses of carbon in living biomass at these areas are mostly driven by natural disturbances or natural processes, such as mortality.

The carbon dynamic is higher in the areas which are outside the boundaries of the national park. They are characterized with forest stands with high productivity and age at which active management activities are carried out, such as thinning and regeneration fellings. Although the polygons, where fellings are performed, have currently very low capacity in providing climate regulation service in terms of GHG sequestration, this would change in the long-term if the regrown of the forests is successful and their management is aimed at increasing their productivity and thus their carbon mitigation potential.

The increase in carbon sequestration could be improved by undertaking of management actions, considering the specific aspects of the role of these ecosystems, such as their protection, vulnerability, and their sensitivity to the changing climate. Any changes in the management activities should be undertaken after thorough trade-off analysis and detailed study of the carbon pools dynamics at broad temporal and spatial scale.

Acknowledgements: This study was performed under the project "Assessment and mapping of ecosystem services in high-mountain territories in Rila and Pirin for sustainable management of natural resources" - MAPESMOUNT, funded by Bulgarian National Science Fund, under grant agreement No КП-ОПР 03/6/17.12.2018 and Mapping and Assessment for Integrated ecosystem Accounting (MAIA) project of EU call H2020-SC5-2018-1 (Grant Agreement Nr. 817527).

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ВИСОКОПЛАНИНСКИТЕ ГОРСКИ ЕКОСИСТЕМИ В РИЛА ПЛАНИНА И ТЯХНАТА РОЛЯ В ПРЕДОСТАВЯНЕТО НА ЕКОСИСТЕМНИ УСЛУГИ ЗА РЕГУЛИРАНЕ НА КЛИМАТА НА РЕГИОНАЛНО НИВО

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Екосистемите в планинските райони предоставят голямо разнообразие от екосистемни услуги. Горите регулират климата на регионално и глобално ниво, като отделят и поглъщат парникови газове (влияещи върху глобалното затопляне) и аерозоли (влияещи върху температурата и образуването на облаци). Настоящото изследване се фокусира върху оценката и картографирането на съхранението и поглъщането на въглерод във високопланинските екосистеми в Рила планина (България) като основен индикатор за екосистемните услуги, регулиращи климата. Количественото определяне обхваща въглеродните депа – биомаса и мъртва органична материя (мъртва дървесина и мъртва горска постилка). Анализът на съхранението и поглъщането на въглерод

се осъществява съгласно биофизични методи за оценка на екосистемните услуги чрез комбиниране на данни от преки и косвени измервания, като се вземат предвид всички фактори, които са специфични за планинските гори. Резултатите са обобщени и представени в контекста на техния потенциал да предоставят екосистемни услуги за регулиране на климата.

Ключови думи: секвестиране на въглерод, запас на въглерод, екосистемни услуги

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