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Morphometric features of the relief as a basis for conservation of forest ecosystems of the Transcarpathian region in Ukraine

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ABSTRACT

Mountain forests are not only valuable centres of biotic and landscape diversity but also perform important ecosystem services, including mitigating the adverse effects of exogenous processes. However, intensive economic intervention, especially clearcutting, leads to the development of weakened tree stands. The most sensitive to this impact are high-elevation and steep-slope forest ecosystems. The aim of our study was to determine the morphometric prerequisites for the forest ecosystem conservation in the Transcarpathia region. To this end, we performed a morphometric analysis of the SRTM digital elevation model and determined the steepness and exposure of slopes. Using the layer with forest cover types, we identified high-elevation forest ecosystems located at an altitude of more than 1,100 m above sea level, as well as steep-slope forest ecosystems, which include forests on steep and very steep slopes with a steepness of more than 20 degrees. The existing level of protection of high-elevation and steep-slope forest ecosystems was analysed by overlaying the layers of protected areas and officially adopted Emerald Network sites and those proposed to join the Network. It was found that about 73.1% of high-elevation and steep-slope forest ecosystems had different levels of conservation status. Of these, 31.1% were within the nature reserve fund. Based on the processed data, we have identified the areas with a high risk of adverse exogenous processes, where no nature protection measures are carried out. Their proportion in high-elevation and steep-slope forest ecosystems was 26.9%. The legal framework of Ukraine significantly restricts economic activity in these forests. In particular, clearcutting is prohibited in them. However, the absence of a clear definition of these forests as a protected area may lead to violations of existing regulations. That is why we recommend implementing additional measures to preserve these forest ecosystems.

Keywords: Transcarpathian region, forest ecosystems, mountain forests, nature conservation areas, Emerald network.

INTRODUCTION

Forests are important centres of biotic diversity. In addition, they provide a variety of important ecological functions and mitigate the negative effects of exogenous processes. However, today, forest ecosystems are mostly significantly disturbed and weakened by economic interventions. This often makes them more sensitive and susceptible to wind damage, wildfires, etc. [Stritihet al., 2021].

This is especially dangerous for mountain forests, as they perform erosion control, soil protection, and water regulation functions [Moos et

al., 2018, Min et al., 2024]. For this reason the conservation of forest ecosystems, especially in mountainous conditions, is of great importance for reducing the risk of negative exogenous processes [Sudmeier-Rieux et al., 2019].

The most effective way to preserve forest ecosystems in Ukraine is to create nature reserve areas. The expanding existing nature reserves and creating new ones are continuing today. It is also typical for the Transcarpathia region, which has the highest the reserve index. The expansion of forest protected areas in the region was largely facilitated by the Framework Convention on the Protection and Sustainable Development of the Carpathians (Carpathian Convention) adopted in Kyiv in 2003. In 2017, the Law No. 2063-VIII "On amendments to some legislative acts related to protection of forests in accordance with Framework Convention on the Protection and Sustainable Development of the Carpathians was adopted that provides for the establishment of virgin forest natural monuments. Relevant amendments were made to the Law "On the Nature Reserve Fund of Ukraine" and the Forest, Administrative and Criminal Codes, and the process of establishing is regulated by the "Methodology for Determining the Belonging of Forest Areas to Virgin, Quasi-Virgin and Natural Forests" approved by the Ministry of Ecology and Natural Resources of Ukraine [Teslovych and Krychevska, 2021]. It should be noted that virgin forests are not only model canonical ecosystems. Modern scientists argue that native forests with a slight anthropogenic impact provide a wide range of ecosystem services and have a higher level of biodiversity [Sutherland et al., 2016; Thom et al., 2019]. A number of domestic scientific publications are devoted to the assessment of the current legal status and criteria for the allocation of old-growth and virgin forests [Volosyanchuk et al., 2017].

Along with the Emerald Network development, studies related to the inventory of forest habitat types listed in Resolution No. 4 of the Bern Convention and the Annexes of Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora have become widespread [Prots and Kagalo, 2012].

It should be noted that the above studies are aimed at identifying valuable forest ecosystems mainly based on the bioecological principle. Instead, today, the generally accepted concept of forest biodiversity conservation is that each forest area performs several ecological, social and economic functions simultaneously [The World Bank, 2020]. That is why there is a need to implement certain restrictions as well as preserve and restore forests that provide important ecosystem services, including soil protection, erosion control, water regulation, etc. The largest range of these functions is characteristic of subalpine meadow and steep-slope forest ecosystems. In Ukraine, clearcutting in forests above 1.100 m above sea level is currently severely restricted. In particular, sanitation clearcutting is prohibited, under the guise of which environmentalists have often recorded facts of healthy forest cutting, which is illegal. Clearcutting is also restricted on steep slopes in the mountain fir and beech forests in the Carpathian region. Similar restrictions apply to protected forests. That is why, in our opinion, it is important to determine the existing level of protection of subalpine meadow and steep-slope forest ecosystems, as well as to identify promising areas that could become the basis for expanding the protected areas.

The aim of our study was to determine the morphometric prerequisites for the conservation of forest ecosystems in the Transcarpathia region. In particular, we aimed to identify the areas at high risk of developing dangerous exogenous processes, which require limiting anthropogenic pressure, preserving or restoring natural forest vegetation [Hartup et al., 2022], implementing close-to-nature forest management etc. [Krynitsky and Chernyavsky, 2014].

MATERIAL AND METHODS

The study area was the Transcarpathia region as an administrative-territorial unit. We consider the administrative-territorial unit to be a specific type of functional geo-ecosystems. The last are geospatial ecological models of the landscape, in which the system-forming component is the management infrastructure that ensures the management of other environmental components as natural resources: soils, forests, meadows, surface and groundwater, biodiversity, etc. [Kruhlov, 2014]. In addition, the Transcarpathia region is an integral basin system of the Tisza River, a tributary of the Danube River, which is separated from neighbouring

administrative regions by the mountainous system of the Ukrainian Carpathians.

Geodata on the orographic features of the study area were obtained by reclassifying the SRTM digital elevation model in GeoTIFF format with a cell size of 50 m. The pre-classification was carried out by the appropriate altitude intervals in such a way as to separate the part of the area located at an altitude of more than 1.100 m above sea level. According to the 'Sanitary Forest Regulations in Ukraine' and 'Rules for Improving the Quality Composition of Forests', as well as the 'Procedure for the Special Use of Forest Resources', final clearcutting, sanitation clearcutting, and forest formation and rehabilitation clearcutting are significantly limited in high-elevation forest ecosystems (above 1.100 m above sea level). Such clearcutting can only be carried out in planted forests, during elimination of consequences continuous windfalls, as well as in the stands completely affected by pests and diseases.

Similar restrictions are also typical for forests on steep and very steep slopes. According to the 'Rules of Final Felling in the Carpathian Mountain Forests', steep slopes are slopes with a steepness of 21–30 degrees on the southern (southeastern, southwestern and western) and 21–35 degrees on the northern (northeastern, northwestern and eastern) aspects. Very steep slopes have a steepness of more than 30 degrees on the southern (southeastern, southwestern and western) and 35 degrees on the northern (northeastern, northwestern and eastern) aspects. Accordingly, slopes with a steepness of less than 10 degrees are considered gentle ones, and those with a steepness of 10 to 20 degrees are considered moderately steep ones. This classification was used when grouping the slopes of the Transcarpathia region by their steepness. The steepness of the slopes was calculated using the SRTM digital elevation model. The results of the calculation in the form of a GeoTIFF file were vectorised and saved in Shapefile format for further calculations.

To present up-to-date information on the forested areas of the Transcarpathia region, spatial data obtained from The Copernicus Global Land Service (CGLS) [Buchhorn et al. 2020] in GeoTIFF format with a resolution of 100 m were used. They contain information on land cover classes, including forests and their types. Forest ecosystems with less than 70% canopy closure were classified as 'open', and those with more than 70% canopy closure were classified as 'closed'. We propose to equate 'open' forest ecosystems with sparse forests. Moreover, the spatial data provided contains information on the species composition of forests with their division into coniferous, broadleaved and mixed forests. These spatial data were vectorised and saved in Shapefile format.

Some of the high-elevation and steep-slope forest ecosystems are located within the the nature reserve fund, where environmental management is established and, accordingly, a higher level of control over compliance with these restrictions is applied.

To identify the conservation status of these forest ecosystems, we downloaded the layer with the territories of the nature reserve fund in Shapefile format from the Public Cadastral Map. The correctness of this data was verified by processing information obtained from the official website of the Department of Ecology and Natural Resources of the Transcarpathia region, large-scale maps of protected areas and detailed forest stand schemes. We overlaid the corrected layer on a digital elevation model and slope steepness and land cover class maps. Additionally, we downloaded layers with the officially adopted and proposed Emerald Network sites (Areas of Special Conservation Interest, or ASCIs) in KMZ format from the Emerald Network Viewer.

All primary geospatial materials were imported into the QGIS 3.16.8 and brought to a single coordinate system – UTM projection, zone 34 on the WGS84 geodetic basis. The results of the overlay of different layers were presented in the form of maps: 'Digital elevation model and protected areas of the Transcarpathian region', 'The steepness of the slopes and protected areas of the Transcarpathian region', 'Land cover (2020) and protected areas of the Transcarpathian region'.

The geographic information system was used to calculate the area and proportion of different types of forests on steep and very steep slopes and their conservation status. The results are presented in Table 1.

The existing levels of protection of high-elevation and steep-slope forest ecosystems were identified and mapped on the satellite image of 2020 (Fig. 4). The corresponding areas and proportions of these forests were calculated according to their protection levels. The point should be made that the sum of the areas of high-elevation and steep-slope forest ecosystems is higher than their total area.

Table 1. Distribution of nature conservation forests on steep and very steep slopes

Land cover class	Steep slopes		Very steep slopes		Total area of forests
	Thousand hectares	Share of the total area of forests, %	Thousand hectares	Share of the total area of forests, %	Thousand hectares
Closed forest	49.0	6.4	0.7	0.1	768.5
In areas protected through national laws, thousand hectares (%)	13.6 (27.8%)	8.3	0.2 (28.6%)	0.1	163.1 (21.2%)
Including adopted sites of Emerald Network, thousand hectares (%)	17.4 (35.5%)	8.4	0.3 (42.9%)	0.1	208.1 (27.1%)
Including proposed sites of Emerald Network, thousand hectares (%)	34.6 (70.6%)	8.5	0.5 (71.4%)	0.1	408.8 (53.2%)
Closed forest, evergreen needle leaf	9.3	8.2	0.1	0.1	112.8
In areas protected through national laws, thousand hectares (%)	3.4 (36.6%)	9.5	– (53.2%)	0.1	35.9 (31.8%)
Including adopted sites of Emerald Network, thousand hectares (%)	5.3 (57.0%)	9.8	– (63.4%)	0.1	54.1 (48.0%)
Including proposed sites of Emerald Network, thousand hectares (%)	6.8 (73.1%)	9.4	– (75.1%)	0.1	72.4 (64.2%)
Closed forest, deciduous broad leaf	31.6	5.6	0.5	0.1	559.9
In areas protected through national laws, thousand hectares (%)	7.2 (22.8%)	7.9	0.1 (20.0%)	0.1	90.8 (16.2%)
Including adopted sites of Emerald Network, thousand hectares (%)	8.4 (26.6%)	8.1	0.2 (40.0%)	0.2	103.6 (18.5%)
Including proposed sites of Emerald Network, thousand hectares (%)	21.7 (68.7%)	8.4	0.4 (80.0%)	0.2	257.4 (46.0%)
Closed forest, mixed	8.1	10.5	0.1	0.1	77.0
In areas protected through national laws. thousand hectares (%)	2.7 (33.3%)	14.6	– (32.6%)	0.2	18.5 (24.0%)
Including adopted sites of Emerald Network, thousand hectares (%)	3.6 (44.4%)	14.8	- (43.6%)	0.2	24.4 (31.7%)
Including proposed sites of Emerald Network, thousand hectares (%)	5.4 (66.7%)	13.3	- (63.6%)	0.2	40.6 (52.7%)
Open forest	2.0	1.2	–	–	163.5
In areas protected through national laws, thousand hectares (%)	0.5 (25.0%)	3.2	– (34.1%)	–	15.4 (9.4%)
Including adopted sites of Emerald Network, thousand hectares (%)	0.8 (40.0%)	3.7	– (41.6%)	–	21.7 (13.3%)
Including proposed sites of Emerald Network, thousand hectares (%)	1.2 (60.0%)	3.9	– (50.5%)	–	31.0 (19.0%)

RESULTS

The Transcarpathia region has one of the reserve index in Ukraine. According to our calculations, the total protected area is 181.7 thousand hectares and covers 14.2% of the region. It is necessary to note that according to the official data of the Department of Ecology and Natural Resources of the Transcarpathia region, this figure is 197.9 thousand hectares (15.5%).

Together with the Emerald Network sites (Emerald Network – General Viewer Retrieved), which are currently officially adopted by the Standing Committee to the Berne Convention, the total protected area (without duplication) is 238.4 thousand hectares (18.7%). If we also consider the sites of the Emerald Network, which were proposed by scientists to be adopted, the total area will be 449.7 thousand hectares and will occupy 35.3% of the region [Emerald Network - General Viewer]. However, it should also be noted that today the Ukrainian legislation does not provide a clear ASCI definition, which complicates full functioning of the Areas of Special Conservation Interest. Most of the protected areas are located within the mountainous part of the Transcarpathia region (Fig. 1).

The mountainous part of the region had the lowest degree of human intervention. This is also due to the peculiarities of the relief morphology,

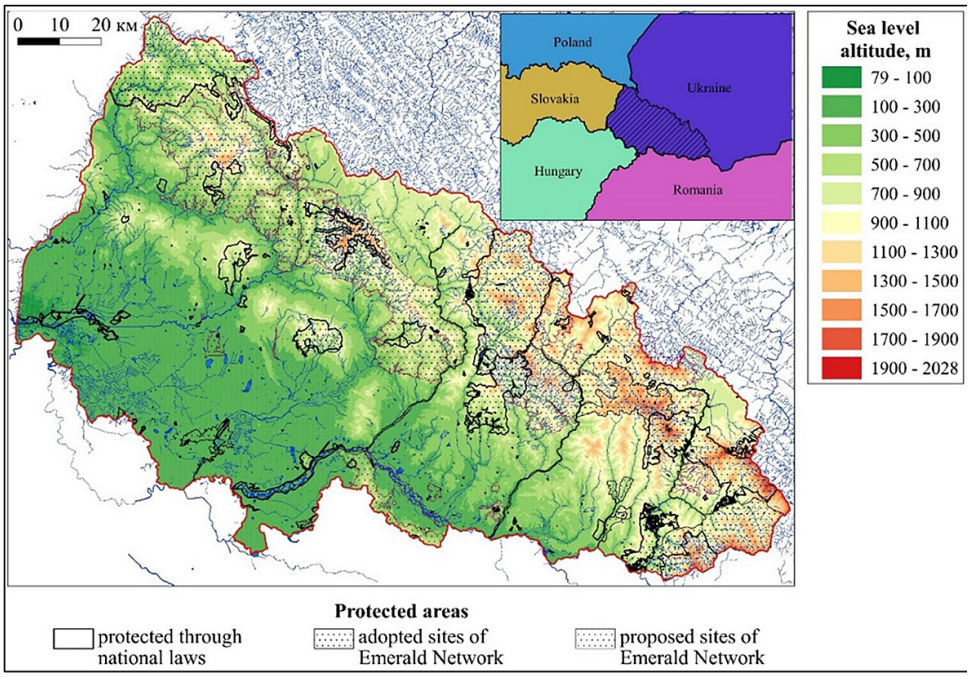

Figure 1. Digital elevation model and protected areas of Transcarpathia region

in particular the presence of steep and very steep slopes, which complicate economic activities. The proportion of these slopes in the total area of the region is about 4.3%. Of them, 27.7% are protected as nature reserve areas, 36.8% are protected considering officially adopted ASCIs, and 69.6% are protected considering proposed ASCIs.

By our calculations, 932.0 thousand hectares within the Transcarpathia region are covered by forest in total (Figures 2, 3). The forest cover is 73.1%. It should be mentioned that according to the official data of the Transcarpathian Regional Department of Forestry and Huntin, the area of all forests in the region is 687.9 thousand hectares (53.9%). This difference may be due to the presence of unaccounted self-sown forests. Often, they are sparse (open) forests, which, according to our estimates, amount to 163.5

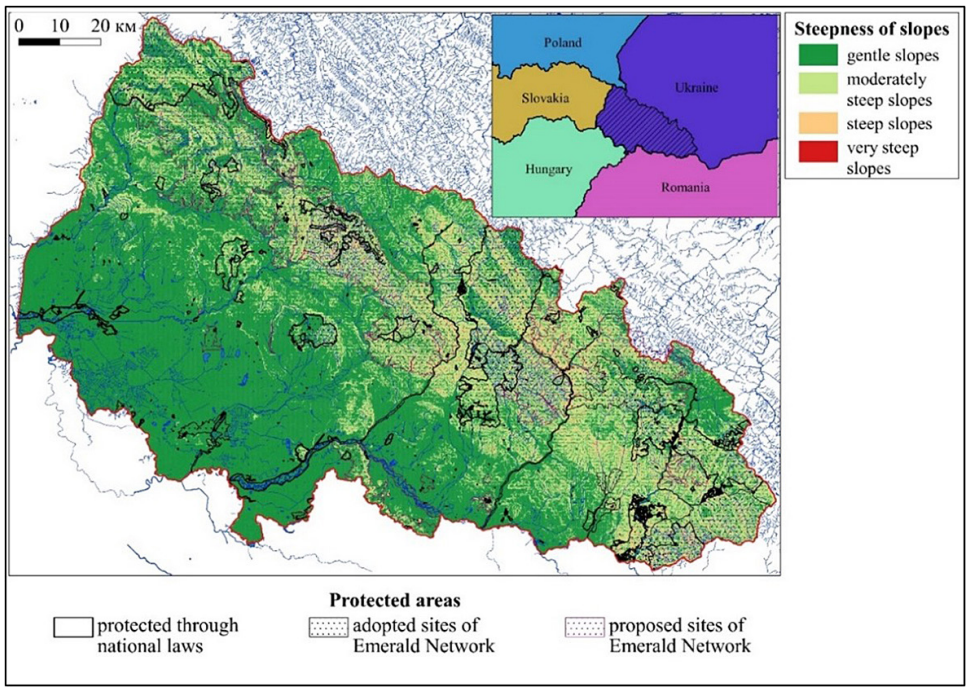

Figure 2. The steepness of the slopes and protected areas in Transcarpathian region

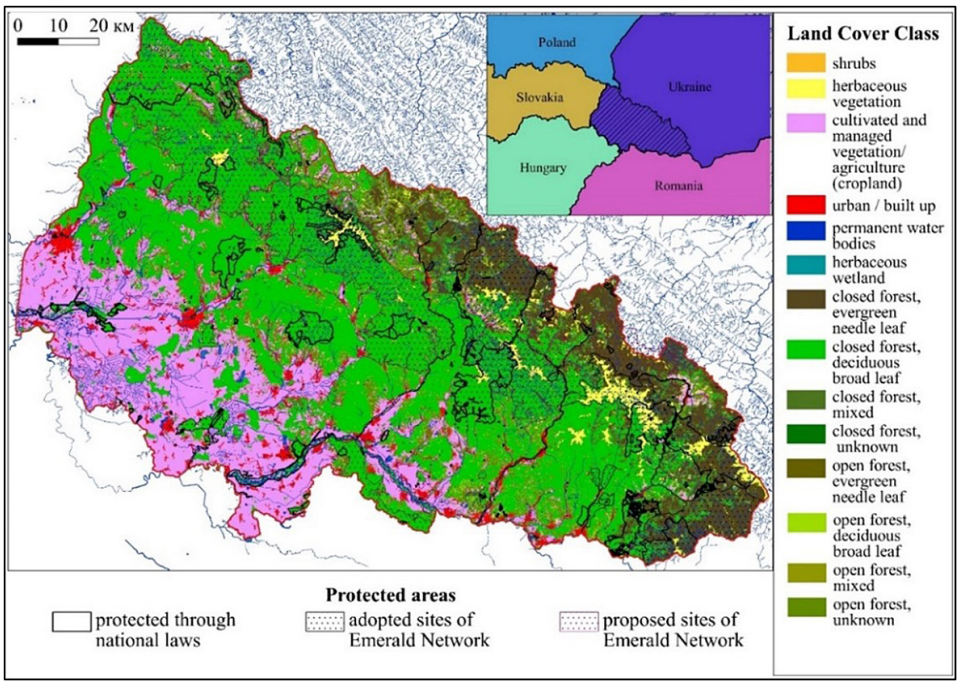

Figure 3. Land cover (2020) and protected areas of Transcarpathian region

thousand hectares, making 17.5% of all forest ecosystems in the region. Self-sown forests occupy mostly abandoned pastures and hayfields that are not used for their intended purpose.

In terms of forest cover types, the largest area is occupied by broadleaf forests, making 559.9 thousand hectares (60.1% of all forests). Coniferous forests occupy 112.8 thousand hectares (12.1%), and mixed forests grow on 77.0 thousand hectares (8.3%).

According to our estimates, 163.1 thousand hectares of forests are located within the territories of the nature reserve fund, which is 17.5%. Considering officially adopted ASCIs, the area is 208.1 thousand hectares (22.3%) and taking into account the proposed ASCIs, the area is 408.8 thousand hectares (43.9%).

About 97.8 thousand hectares of forests are at an altitude of more than 1.100 m above sea level. Such forests account for 10.5% of all forest ecosystems. Of them, 33.4 thousand hectares (34.2%) are protected as nature reserve areas, 52.2 thousand hectares (53.4%) are protected considering officially adopted ASCIs, and 74.4 thousand hectares (76.1%) are protected considering the proposed ASCIs. Accordingly, about a quarter of the high-elevation forests at an altitude of more than 1100 m above sea level do not have any conservation status.

The distribution of nature conservation forests on steep and very steep slopes is shown in Table 1. The calculations were made separately for continuous forest cover and open forests. It should be noted that only 1.2% of the area of open forests is concentrated on slopes with a steepness of more than 20 degrees.

Our calculations have shown that about 49.7 thousand hectares of forests in Transcarpathia region are located on steep and very steep slopes. They account for 6.5% of the total forest area. About 13.8 thousand hectares of these forests are within the territories of the nature reserve fund, which is 27.8%. Considering the officially adopted ASCIs, the area is 17.7 thousand hectares (35.6%), and considering the proposed ASCIs, this is 35.1 thousand hectares (70.6%). Consequently, about 29.4% of forest ecosystems on steep and very steep slopes do not have a nature conservation status.

In terms of forest cover types, the largest area of steep and very steep slopes is covered by broadleaf forests, making 32.1 thousand hectares (64.6% of all forests). Conifers occupy 9.4 thousand hectares (18.9%) and have the largest percentage of protected areas. This is due to the fact that their natural habitat is located at altitudes above 1.100 m above sea level. The highlands in Transcarpathia region are characterised by the most developed network of protected areas. The area of mixed forests on steep and very steep slopes is about 8.2 thousand hectares (16.5%).

In general, high-elevation and steep-slope forest ecosystems in Transcarpathia region have different protection statuses. There are 43.6 thousand hectares of forests within the territories of the nature reserve fund (without duplication), which account for 31.1%. It should be noted that some of them also have the status of Emerald Network sites. The largest areas of such ecosystems are protected within the Carpathian Biosphere Reserve, Synevyr and Uzhansky National Nature Parks, and reserves on the slopes of the Borzhava mountain range and Polonyna Rivna.

High-elevation and steep-slope forest ecosystems, which have the status of Emerald Network sites only, cover an area of about 21.4 thousand hectares, which is 15.2%. It was found that the largest number of such areas are concentrated within the Emerald Network sites, the Marmaroski and Chyvchyno-Hryniavski Hory (UA0000117), Black Tysa river valley and slopes of Bratkovskyi ridge (UA0000609), Polonyna Borzhava (UA0000263).

High-elevation and steep-slope forest ecosystems located within the proposed Emerald Network sites alone cover an area of about 37.7 thousand hectares, which is 26.8%. It was found that the largest number of such areas are concentrated within the Emerald Network sites, the Polonynskyi ridge (UA0000610), Forests near Kolochava (UA0000607), Black Tysa river valley and slopes of Bratkovskyi ridge (UA0000609), Forests near Kobyletska Polyana (UA0000608), Forests near Roztoky (UA0000606), Avashski Hory (UA0000562).

High-elevation forests and steep-slope forest ecosystems without a protected status are concentrated mainly in the south-east of Transcarpathia region. They cover the southern slopes of the Svydovets mountain range and the ridge-top slopes of Apetska mountain (1512 m), the interfluve area of the Kosovska and Chorna Tysa rivers (tributaries of the Tysa river), the upper reaches of the Balzatul and Lipovets river basins (tributaries of the Bila Tysa river), the Bertianka river (tributary of the Brusturyanka river) and the Mokryanka river with the Yanovets tributary. These forests cover an area of about 37.9 thousand hectares, which is 26.9% (Fig. 4).

There are no mechanisms for establishing environmental management. International and domestic experience shows that one of the ways to organise such management is to create multifunctional institutions that protect nature reserves. These could be regional or national nature parks or biosphere reserves with an appropriate qualified staff that should ensure both comprehensive biodiversity conservation and the implementation of ecosystem services of a particular protected area.

However, there is also another position on increasing the protected area. For example,

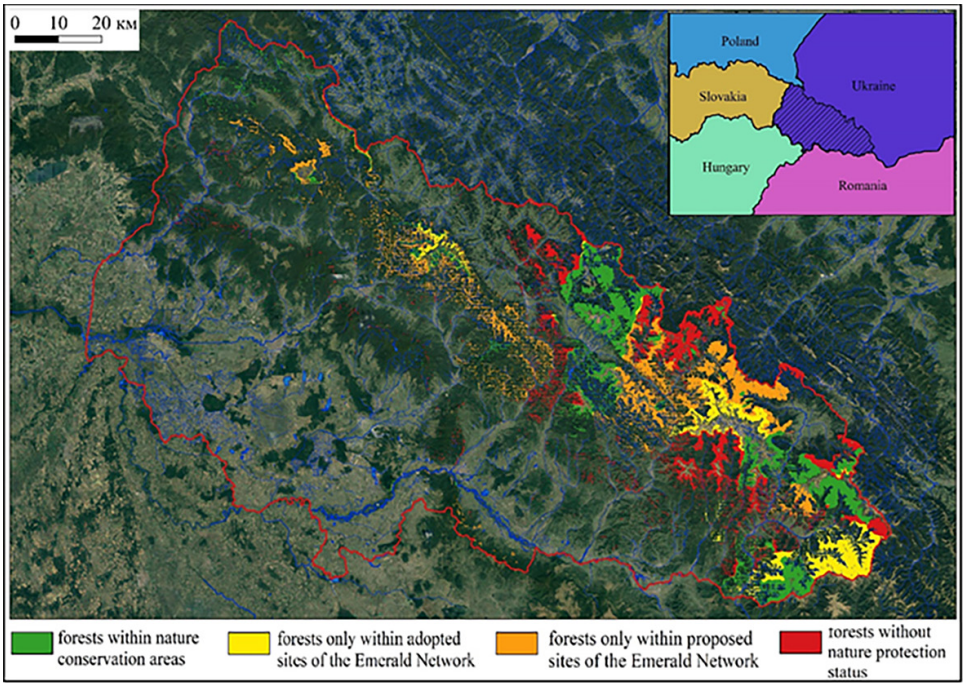

Figure 4. Nature protection status of forests at an altitude of more than 1.100 m above sea level and forests on steep and very steep slopes

Shparyk (2018) argued that the lack of active forestry measures within protected areas contributes to the ageing of forests and the formation of forest pest and disease foci that pose a threat to neighbouring forests. In our opinion, it is important to quickly detect forest infestations and localise them at the initial stages of their manifestation. This can be facilitated by a well-established monitoring system within existing and prospective multifunctional environmental institutions. In addition, it is important to take into account local conditions and forestry needs when creating new protected areas.

DISCUSSION

The article presents an in-depth exploration of the conservation needs for high-elevation and steep-slope forest ecosystems in the Transcarpathian region of Ukraine, emphasizing their significant ecological roles and the threats posed by both natural and human-induced factors. These forest ecosystems are critical for maintaining biodiversity [Pascual et. al., 2024], providing vital ecosystem services [Bai et. al., 2024], such as soil stabilization [Shi et. al., 2024], water regulation, and erosion control, and mitigating the adverse effects of exogenous processes like landslides and flooding.

Importance of mountain forests

Mountain forests in the Transcarpathian region [Smaliychuk and Gräbener (Eds), 2018] are described as invaluable centers of biotic and landscape diversity, contributing to various ecological, social, and economic functions. Their unique positioning in high-altitude and steep-slope areas makes them particularly susceptible to environmental degradation, yet they play a crucial role in controlling erosion, regulating water flow [Ruiz et. al. 2024], and maintaining soil integrity [Baumann et. al., 2022, Ottinger, Geiselman, 2023]. These forests are not only vital for local ecosystems but also contribute to broader environmental stability, including the prevention of natural disasters that could affect human settlements.

However, these forests are increasingly under pressure due to economic activities, primarily logging. While clearcutting is legally restricted in many of these areas, illegal or poorly regulated activities continue to pose significant threats [Smaliychuk and Gräbener (Eds), 2018]. The most vulnerable are forests located at altitudes above 1100 meters and those on slopes steeper than 20 degrees, where soil erosion and habitat destruction can occur rapidly in the absence of strict conservation measures.

Current protection status

The study provides a detailed analysis of the current levels of protection for these forest ecosystems. Approximately 73.1% of high-elevation and steep-slope forests in the region are protected to some degree, with 31.1% being part of the official nature reserve fund. These forests are also included in the Emerald Network, a system of protected areas aimed at conserving species and habitats recognized under the Bern Convention.

Despite these protections, around 26.9% of these critical forest areas lack any conservation status, leaving them exposed to potential deforestation, land degradation, and other harmful practices. The lack of legal protection for these forests presents a significant risk, as these unprotected areas are often in locations where natural disasters, such as landslides or erosion, are most likely to occur [Chabba et. al., 2022]. The absence of a clear legal definition for these areas in Ukrainian law exacerbates the problem, allowing for economic activities that may violate the spirit of existing conservation efforts.

Emerald network and legal challenges

The Emerald Network plays a pivotal role in the conservation of forest ecosystems in Ukraine, particularly in regions like Transcarpathia, where a high proportion of the forested area is located within designated or proposed Emerald sites. However, a key challenge identified in the article is the lack of legal recognition for many of the proposed Emerald Network sites. Without formal protection under national law, these areas do not benefit from the same level of oversight and management as those within officially recognized nature reserves.

The article calls for urgent reforms to Ukrainian conservation law, including the integration of the Emerald Network into the national legislative framework [Bevz, 2018]. This would not only provide formal protection for a larger portion of forest ecosystems but also facilitate the

development of management strategies tailored to the specific needs of high-elevation and steep-slope forests. The establishment of clear legal definitions and enforcement mechanisms would enhance the effectiveness of current conservation efforts and reduce the risk of illegal logging and other harmful activities.

Need for enhanced monitoring and management

Another critical point raised in the discussion is the necessity of improving forest monitoring and management practices [Mataruga et al., 2023]. The authors argue that while the legal framework provides some protection, the practical implementation of conservation measures is often lacking. One of the proposed solutions is the creation of multifunctional nature reserve institutions that combine biodiversity conservation with the sustainable provision of ecosystem services. These institutions could include regional or national parks, as well as biosphere reserves, staffed by qualified personnel who can manage both the ecological and economic needs of the region.

Additionally, the article highlights the importance of developing a robust monitoring system to detect early signs of forest degradation, such as pest infestations or disease outbreaks [Ritts et al., 2024]. Such a system would enable rapid intervention to prevent widespread damage to forest ecosystems. The authors point to international examples where proactive forest management, including close-to-nature forestry practices, has successfully reduced the impact of environmental stressors on vulnerable forest areas.

Challenges of forest restoration

The restoration of degraded forest ecosystems is another critical aspect of the discussion. The article emphasizes that passive restoration—allowing forests to regenerate naturally without human intervention—may not always be sufficient, especially in areas where economic activities have caused significant damage [Brodovych and Brodovych, 2016., Chazdon et al., 2021]. Active restoration, which may include reforestation efforts, soil stabilization, and the reintroduction of native species, is often necessary to restore the ecological balance and prevent further degradation.

The authors also caution against the potential negative impacts of creating overly restrictive conservation zones. They reference arguments from forestry experts who suggest that a lack of active management in protected areas can lead to the ageing of forests and the spread of pests and diseases, which may threaten adjacent forests. Thus, while conservation is vital, it must be balanced with sustainable forest management practices that allow for periodic interventions to maintain forest health.

Future conservation strategies

Looking to the future, the article proposes several strategies for enhancing the conservation of high-elevation and steep-slope forest ecosystems in the Transcarpathian region. One key recommendation is the expansion of protected areas to include the remaining unprotected forests, particularly those identified as high-risk for environmental degradation [Problems of Mountain Ecosystems Conservation and Sustainable Use of Biological Resources in the Carpathians, 2018, Areendran et al., 2020]. The establishment of new nature reserves or the expansion of existing ones would provide these ecosystems with the legal protection they need to thrive.

Moreover, the authors call for greater collaboration between local, national, and international conservation efforts. This includes aligning Ukrainian conservation policies with the goals of the Bern Convention and other international agreements, as well as securing the necessary funding and resources to implement effective conservation programs. The involvement of local communities in conservation efforts is also seen as crucial, as sustainable forest management often depends on the support and participation of those who live in or near forested areas.

CONCLUSIONS

The area of protected territories, combined with the Emerald Network sites, covers a significant part of the region, highlighting the importance of preserving high-elevation and steep-slope forest ecosystems. However, the lack of a clear legal status complicates their effective management. Most reserves have the highest level of protection and serve as centers of biotic

and landscape diversity. Nevertheless, there are difficulties in the clear regulation of areas of special conservation interest. There are gaps in legislation regarding the designation of areas of special conservation interest. The lack of a clear legal framework for these areas hinders effective management and protection. Emerald sites that do not have the status of nature reserve territories in Ukraine receive a lower level of protection. This applies to approximately 15.2% of high-elevation and steep-slope forest ecosystems, reducing their effectiveness in terms of protection. Expanding the areas included in the Emerald Network requires additional legal justification and recognition at the national level.

The identification of new areas for inclusion in the Emerald Network is a significant step toward expanding conservation efforts in the region. Scientists have identified and substantiated new sites that cover 26.8% of high-elevation and steep-slope forest ecosystems. This will enhance the conservation of species and habitats recognized by the Bern Convention. The introduction of effective management for these areas will improve protection levels. However, this requires resources and qualified personnel.

Approximately 26.9% of high-elevation and steep-slope forest ecosystems lack any conservation status, which poses a risk to the preservation of biodiversity in these areas. They are concentrated on the southern slopes of the Svydovets mountain range and other areas in the southeast of Transcarpathia. These areas require the implementation of environmental management mechanisms to prevent ecosystem degradation. The absence of such mechanisms leaves these sites vulnerable to violations. Establishing protected zones in these areas is an important step toward their preservation.

The implementation of an effective monitoring system and the creation of new protected areas are necessary to support the resilience of forest ecosystems. International experience shows that one way to organize such management is through the creation of multifunctional nature reserve establishments. These could be regional or national nature parks, as well as biosphere reserves. When creating new protected zones or expanding existing ones, local conditions and forest management needs should be considered. It is important to involve qualified personnel to ensure both biodiversity conservation and the provision of ecosystem services.

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