UDC 551.4+911.2; DOI 10.30970/gpc.2024.1.4425

MORPHOGENIC ECOREGIONS OF EAST CARPATHIANS BIOSPHERE RESERVE

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Abstract. The East Carpathians Biosphere Reserve is located at the junction of Poland, Slovakia, and Ukraine; and therefore, lacks harmonized and detailed ecological regionalization encompassing all national parts. Thus, within the biosphere reserve and the vicinity, we delineated and classified morphogenic micro- and mesoecoregions as regional ecosystems, which spatially coincide with morphostructures of the 3rd and 2nd ranks respectively. The microecoregions were manually delineated using altitude and slope geodata derived from the Shuttle Radar Topography Mission Digital Elevation Model as a primary input, and national geological, geomorphological, and geoecological regionalizations as collateral inputs. Then, microecoregions were grouped into mesoecoregions and attributed with zonal statistics on mean altitude and mean relative elevation within a 1000-m circular neighborhood – both metrics were derived from the digital elevation model. Finally, microecoregions were divided into orographic classes according to the mean altitude and mean relative elevation metrics using agglomerative cluster analysis.

We delineated 21 microecoregions and grouped them into five mesoecoregions. Overall accuracy of the resulting geodataset corresponds to a map of a 1:100,000 scale. Each microecoregion belongs to a certain structural-lithological zone (nappe), although the boundaries were modified by exogeneous processes. These are all flysch mountains, except one volcanic massif. Grouping of microecoregions into larger units – mesoecoregions – did not always follow hierarchy of geotectonic units. Cluster analysis on elevation metrics allowed to distinguish five orographic classes of microecoregions: 1) very low mountains, 2) low mountains, 3) dissected low mountains, 4) elevated low mountains, and 5) medium mountains. The regionalization and the classification reveal that mesoecoregions contain rather different microecoregions in terms of geological structure and orography. The latter also demonstrate rather significant internal heterogeneity. This study will be followed by a bioclimatic characterization and classification of microecoregions and subsequent descriptions of the potential natural and actual landcovers.

Key words: East Carpathians Biosphere Reserve; ecoregions; morphostructures; orographic classes.

МОРФОГЕННІ ЕКОРЕГІОНИ БІОСФЕРНОГО РЕЗЕРВАТУ "СХІДНІ КАРПАТИ"

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Анотація. Біосферний резерват "Східні Карпати" розташований на стику Польщі, Словаччини та України, і через це на його територію відсутня гармонізована та детальна екологічна регіоналізація, яка би охоплювала усі його національні частини. Отже, у межах резервату та його околиць ми виділили та класифікували морфогенні мікро- та мезоекорегіони як регіональні екосистеми, які просторово збігаються з морфоструктурами відповідно першого і другого порядку. Мікроекорегіони виділили мануально на підставі головно геоданих альтитуди та ухилів поверхні, отриманих з цифрової моделі висот Shuttle

Radar Topography Mission, а також з урахуванням національних карт геологічних, геоморфологічних і геоекологічних регіоналізацій. Після цього мікроекорегіони згрупували у мезоекорегіони, а також визначили показники зональної статистики за середньою альтитудою та середнім перевищенням у круглому околі радіусом 1000 м – ці метрики отримали через цифрову модель висот. На завершення мікроекорегіони поділили на орографічні класи згідно з середньою альтитудою та середнім перевищенням за допомогою агломераційної ієрархічної кластеризації.

Ми виділили 21 мікроекорегіон і згрупували їх у п'ять мезоекорегіонів. Точність отриманого набору геоданих не нижча, ніж у карти масштабу 1:100 000. Межі мікроекорегіонів загалом збігаються границями структурно-літологічних зон (тектонічних покривів), але модифіковані екзогенними процесами. Це все флішові гори, за виключенням одного вулканічного масиву. Групування мікроекорегіонів у більші одиниці – мезоекорегіони – не завжди наслідує ієрархію тектонічних одиниць. Кластерний аналіз за висотами дав змогу виділити п'ять орографічних класів мікроекорегіонів: 1) понижені низькогір'я; 2) низькогір'я; 3) розчленовані низькогір'я; 4) підвищені низькогір'я; 5) середньогір'я. Регіоналізація та класифікація виявили, що мезоекорегіони містять доволі відмінні мікроекорегіони з огляду на геологічну будову та орографію. Мікроекорегіони також характерні значною внутрішньою неоднорідністю. Це дослідження буде доповнене біокліматичною характеристикою мікроекорегіонів і визначенням їхнього потенційного природного та фактичного наземних покривів.

Ключові слова: Біосферний резерват "Східні Карпати"; екорегіони; морфоструктури; орографічні класи.

Introduction. The transboundary trilateral Polish-Slovak-Ukrainian East Carpathians Biosphere Reserve (BR) has been designed as an example of best practices in regional environmental management, which includes nature protection, sustainable development of local human populations and their economies, as well as harmonization of these efforts across political borders. Therefore, it is viewed as a complex social-ecological system (Taggart-Hodge & Schoon, 2016). Lithogenic components – georelief, geomorphic processes, and their geological substrate – are important factors of ecosystem structure and function, and thus their characterization is perceived as an indispensable part of a management plan for a BR (Minpryrody, 2005). Namely, orotectonic structures are used as a basis for the delineation of regional ecosystems (ecoregions, natural regions) of different spatial ranks, which are used as primary spatial units for sustainable environmental management (Kruhlov, 2020; Omernik & Griffith, 2014).

Geomorphological or geoecological regionalizations are available separately for the national parts of the BR region (Atlas…, 2006; Henkiel, 1997; Kočický & Ivanič, 2011; Kruhlov, 2008; Solon et al., 2018). However, there is no single medium- or large-scale geodataset encompassing the whole transboundary BR area and representing lithogenic components, which is suitable for further coherent characterization of regional ecosystems. Thus, the ***goal of this study*** was to delineate, in large scale, and characterize regional geomorphic units as the first step in the process of describing micro- and mesoecoregions of the BR. To reach this goal several steps were made: 1) the spatial units were delineated based on large- and medium-scale topographic data and thematic maps, 2) then, they were qualitatively characterized from the standpoint of geology as well as quantitively described using elevation data, 3) and finally, classified according to elevation metrics using agglomerative cluster analysis.

Study area. The study area is located at the NE extremity of the Eastern Carpathian Mountains, where territories of Poland, Slovakia, and Ukraine meet. It has a rectangular form of appr. 72*58 km (4 186 km²) and encompasses the East Carpathian Biosphere Reserve with its immediate environs. The georelief is characterized by a series of low and medium mountain ranges with moderately steep slopes stretching in the NW-SE direction. The ranges are separated by wider parallel and narrower transverse valleys. Altitudes span from ~180 m in the valley bottom of the Cirocha river in the SW up to 1346 m at Mnt. Tarnica located in the central part of the study region. The area is shared by three large drainage basins – the Tysa in the SW, the Sian in the N, and the Dnister in the E. From the geological standpoint, the region mostly belongs to the Outer Carpathians represented by several SW-NE verging flysch nappes – the Magura, the Dukla, the Silesian (Krosno Zone), and the Skyba. The nappes consist of allochthonous Late Jurrasic–Early Miocene deposits – predominantly alternating sandstone and shale strata (flysch). The SW periphery of the study region belongs to the Inner Carpathians, and it is formed by the Vihorlat Volcanic Massif consisting of the Middle-Late Miocene andesites and other igneous rocks that mostly obscure Jurassic formations of the Pieniny Klippen Belt (The Carpathians…, 2006). The regolith is well developed on all types of available rocks. The climate is temperate moderately continental with prevailing W and SW winds. It is strongly differentiated by local georelief (Nowosad, 2000). The natural landcover of broad-leaved (predominantly beech) forests on acid brown soils has been reduced by settlements, agriculture (mainly grassland), and managed needle-leaf forests (Kuemmerle et al., 2006; Ralska-Jasiewiczowa, Madeyska & Mierzeńska, 2006).

Conceptual framework. Morphogenic ecoregions are conceptualized as ecosystems of regional geographic dimension, which are spatially delineated based on orotectonic units – morphostructures. The latter are macrorelief forms (mosaics of mesorelief forms with areas usually over 10 km²), which are formed by the interaction of atmosphere with bedrock and neotectonics. Thus, morphogenic ecoregions are initially described from the standpoint of geology and geomorphology, and then they are attributed with climatic, biotic, and socioeconomic properties. Morphogenic ecoregions are usually characterized as individual entities with unique landform/ecosystem mosaics, which can be represented as nested hierarchical systems. Namely, micro-, meso-, and macroecoregions coincide with 3rd-, 2nd-, and 1st-rank morphostructures respectively (Kruhlov, 2020). This study concentrates on the delineation of individual micro- and mesoecoregions as well as on their geological and geomorphological characterization and classification, while omitting their further description as ecosystems.

Material and methods. Geodata were processed mainly with ArcGIS Pro software (https://www.esri.com/ en-us/arcgis/products/arcgis-pro/overview). We used a postprocessed Shuttle Radar Topography Mission Digital Elevation Model (DEM) with a 3-arc-second resolution (Jarvis et al., 2008) as a topographic basis. The original geodata were clipped and reprojected onto a WGS84, UTM Zone 34 grid with a resolution of 50*50 m using bilinear resampling algorithm. Then, focal statistics functions were applied to calculate slope as well as altitude range within a 1000 m circular neighborhood as relative elevation (REL). We also used available national geological, geomorphological, and geoecological maps (Haczewski, Kukulak & Bąk, 2007; Kočický & Ivanič, 2011; Kruhlov, 2008; Solon et al., 2018; Štátny…, no date; Tectonic…, 1986) as collateral data for defining boundaries and lithogenic properties of the morphogenic ecoregions.

Firstly, boundaries of microecoregions were manually vectorized using the slope geodata as a primary input and the available thematic maps as a collateral input. Slope geodata vividly convey differences in mesorelief texture and thus were most useful for precise manual tracing of morphostructure boundaries. Geological features, especially geotectonic lineaments (thrust sheet boundaries, faults), provided additional guidance – in essence, the lineaments were aligned with orographic boundaries thus “projecting” geological structure onto georelief. Secondly, each microecoregion was attributed with individual name (in some cases, these were two alternative designations borrowed from existing national regionalization schemes) and a geological characteristic – designation of a geotectonic unit it belongs to. Thirdly, the microecoregions were grouped (merged) into larger units – mesoecoregions. For this purpose, existing national regionalization maps (Atlas…, 2006; Kruhlov, 2008; Solon et al., 2018) were considered.

For each microecoregion polygon, several metrics were calculated using a zonal statics function on DEM and REL geodata: 1) altitude mean value and standard deviation; 2) REL mean value and standard deviation. Standard deviation values reveal homogeneity of microecoregions in terms of altitude and terrain roughness. Obtained quantitative indices were used for orographic classification of the microecoregions. The data were imported into STATISTICA software (https://www.statsoft.de/en/data-science-applications/tibco-statistica/), the values were standardized, and an agglomerative cluster analysis was performed using unweighted pair-group averages for calculating Euclidian distances. The resulting cluster dendrogram was stratified into several sections representing orographic classes of micro-ecoregions.

Results and discussion. There were 21 microecoregions delineated, and they were grouped into five mesoecoregions (Fig. 1, Table 1). Considering precision of the base topographic data used for the delineation, one can assume that overall accuracy of the resulting geodataset corresponds to a map of a 1:100,000 scale. Boundaries of the ecoregions were mainly defined by endogenic factors – bedrock lithology and neotectonics, although also modified by exogenic processes. Therefore, each microecoregion belongs to a certain geotectonic unit (structural-lithological zone). This peculiarity differs our regionalization from the natural regionalization of Poland by J. Kondracki, which was refined by J. Solon and co-authors (2018) at a mesoregion scale, and which rely on interpretation of topography in the first instance. As a result, our boundary between the Sian-Rika Verkhovyna (Gory Sanocko-Turczanskie) and the Polonyny (Bieszczady) is drawn somewhat differently. At the same time, the southern boundary of the Polonyny mesoecoregions generally coincides with the limits of the respective region of Slovak regionalization (Kočický & Ivanič, 2011), while regionalization of the Ukrainian portion fits into the schemes provided earlier (Kravchuk, 2021; Kruhlov, 2008). However, the main novelty of our geodataset is its finer detail, which distinguishes smaller units – microecoregions.

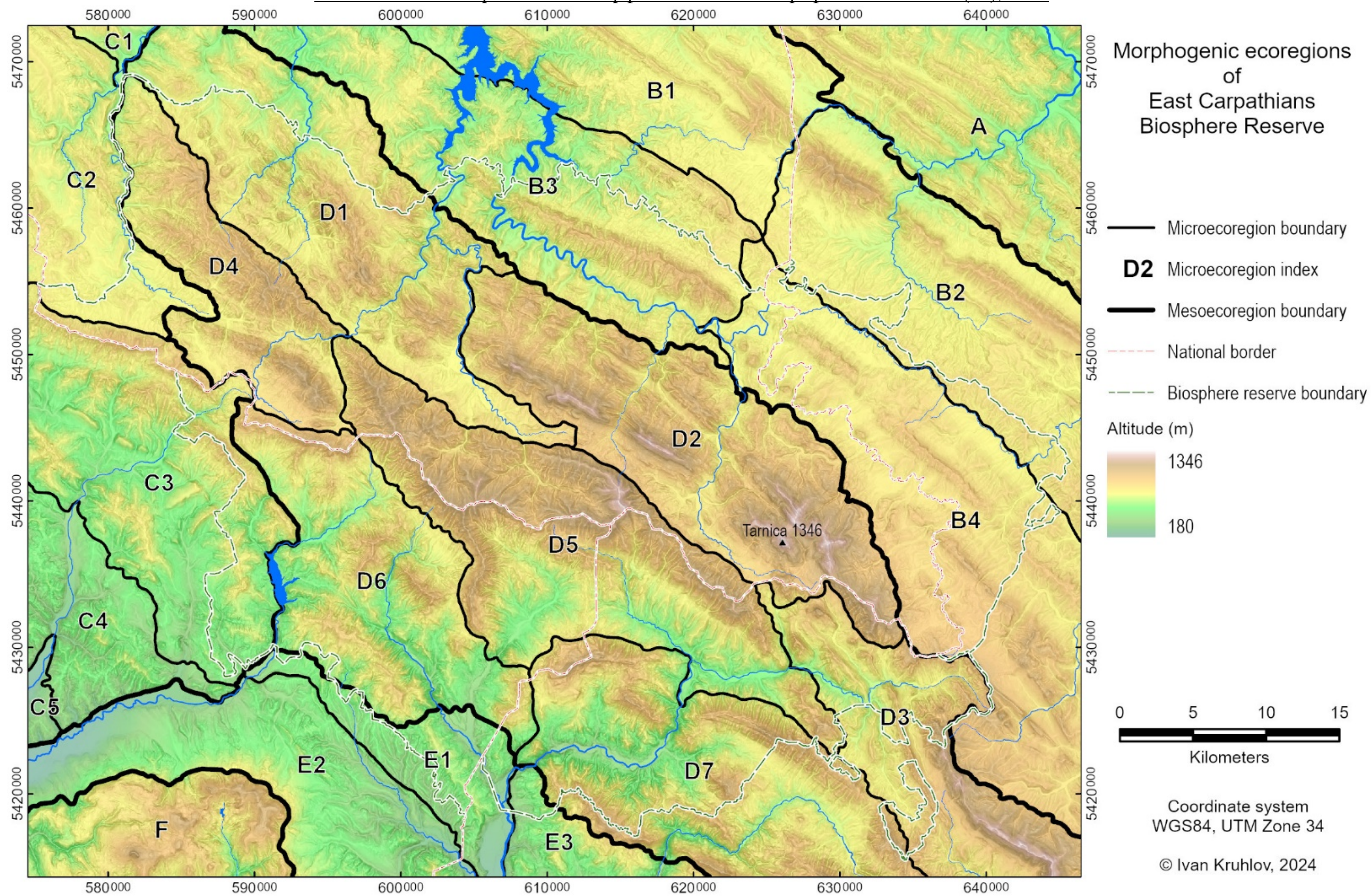

Fig. 1. Morphogenic ecoregions of the East Carpathians Biosphere Reserve and the environs. Description of the ecoregions is provided in Table 1

ISSN 2519–2620. Проблеми геоморфології і палеогеографії...2024. Вип. 1 (16), 3–19

Table 1. Characteristics of morphogenic ecoregions of the East Carpathians Biosphere Reserve and the environs (see Fig. 1)

<table>
<tr><th>Index</th><th>Name</th><th>Geotectonic unit</th><th>Orographic class</th><th>ALT[1] (m)</th><th>REL[2] (m)</th></tr>
<tr><td colspan="6">A. Mesoecoregion Eastern Carpathian Beskydy</td></tr>
<tr><td>A</td><td>Dnister Beskydy</td><td>Skyba Nappe</td><td>Low mountains</td><td>568</td><td>208</td></tr>
<tr><td colspan="6">B. Mesoecoregion Sian-Rika Verkhovyna (Gory Sanocko-Turczanskie)</td></tr>
<tr><td>B1</td><td>Strwiaz Verkhovyna</td><td rowspan="4">Silesian Nappe (Krosno Zone)</td><td rowspan="4">Low mountains</td><td>577</td><td>167</td></tr>
<tr><td>B2</td><td>Dnister Verkhovyna</td><td>641</td><td>166</td></tr>
<tr><td>B3</td><td>Otryt Verkhovyna</td><td>563</td><td>196</td></tr>
<tr><td>B4</td><td>Sian Verkhovyna</td><td>738</td><td>167</td></tr>
<tr><td colspan="6">C. Mesoecoregion Beskid Niski (Nizke Beskydy)</td></tr>
<tr><td>C1</td><td>Bukowica massif</td><td>Silesian Nappe</td><td rowspan="3">Low mountains</td><td>482</td><td>192</td></tr>
<tr><td>C2</td><td>Wielki Bukowiec massif</td><td rowspan="2">Dukla Nappe</td><td>588</td><td>157</td></tr>
<tr><td>C3</td><td>Outer Laborec Vrchovina</td><td>495</td><td>244</td></tr>
<tr><td>C4</td><td>Central Laborets Vrchovina</td><td rowspan="2">Magura Nappe</td><td rowspan="2">Very low mountains</td><td>332</td><td>202</td></tr>
<tr><td>C5</td><td>Inner Laborets Vrchovina</td><td>227</td><td>134</td></tr>
<tr><td colspan="6">D. Mesoecoregion Polonyny (Bieszczady)</td></tr>
<tr><td>D1</td><td>Oslawa-Wetlinka Bieszczady</td><td rowspan="3">Silesian Nappe</td><td>Elevated low mountains</td><td>639</td><td>246</td></tr>
<tr><td>D2</td><td>Wetlina-Halicz Polonyny</td><td rowspan="2">Medium mountains</td><td>860</td><td>326</td></tr>
<tr><td>D3</td><td>Bukovets Polonyna</td><td>768</td><td>331</td></tr>
<tr><td>D4</td><td>Wysoki Dzial-Hyrlata massifs</td><td rowspan="4">Dukla Nappe</td><td>Elevated low mountains</td><td>746</td><td>264</td></tr>
<tr><td>D5</td><td>Jaslo-Ravka Polonyny (Eastern Bukovske Vrchy)</td><td>Medium mountains</td><td>752</td><td>338</td></tr>
<tr><td>D6</td><td>Strop-Nastaz massifs (Western Bukovske Vrchy)</td><td>Dissected low mountains</td><td>561</td><td>310</td></tr>
<tr><td>D7</td><td>Stynka-Holytsia massifs</td><td>Medium mountains</td><td>633</td><td>369</td></tr>
<tr><td colspan="6">E. Mesoecoregion Cirocha-Rika low mountains</td></tr>
<tr><td>E1</td><td>Cirocha-Uzh external low mountains</td><td>Dukla Nappe</td><td rowspan="2">Very low mountains</td><td>329</td><td>199</td></tr>
<tr><td>E2</td><td>Cirocha-Uzh internal low mountains</td><td>Magura Nappe</td><td>343</td><td>185</td></tr>
<tr><td>E3</td><td>Uzh-Luta low mountains</td><td>Dukla Nappe</td><td>Dissected low mountains</td><td>434</td><td>316</td></tr>
<tr><td colspan="6">F. Mesoecoregion Vihorlat-Hutyn range</td></tr>
<tr><td>F</td><td>Vihorlat Vrchy</td><td>Vihorlat-Hutyn volcanic range</td><td>Medium mountains</td><td>683</td><td>334</td></tr>
</table>

[1]ALT – mean altitude; [2]REL – mean relative elevation within 1000 m circular neighborhood

According to geological structure, all of the microecoregions, except one (F. Vihorlat Vrchy), belong to the Outer Carpathian flysch class. Unlike other ecoregions, the Vihorlat Vrchy is formed by Neogene volcanic formations (predominantly andesites).

Within the study area, it is the only microecoregion belonging to the mesoecoregion of the Vihorlat-Hutyn volcanic range of the Inner Carpathians. Grouping of microecoregions into larger units – mesoecoregions – does not always follow hierarchy of geotectonic units. For example, the mesoecoregion Polonyny (Bieszczady) encompasses microecoregions belonging to the Silesian and the Dukla nappes. This is caused by two factors: 1) orographic similarity between microecoregions belonging to different large geotectonic units (e.g., the Wetlina-Halicz Polonyny of the Silesian nappe and Jaslo-Ravka Polonyny of the Dukla nappe) and 2) traditionally defined larger regions, such as Beskid Niski, which encompasses distinctly different massifs (low and very low mountains) formed by three different nappes (see Fig. 1; Table 1).

Cluster analysis on mean altitude and mean REL values allowed distinguishing five orographic classes of microecoregions: 1) very low mountains, 2) low mountains, 3) dissected low mountains, 4) elevated low mountains, and 5) medium mountains (Fig 2, 3; see Fig.1, Table 1). This classification follows the one used in the study on the Ukrainian Carpathians mesoecoregions (Kruhlov, 2008). The dendrogram, which reflects distances between the clusters, affords hierarchical appreciation of the classification. Namely, it reveals the two main orographic classes: 1) low mountains, elevated low mountains, and very low mountains; 2) medium mountains and dissected low mountains (see Fig.3). This classification implies on equal importance of altitude and REL, since both of the values were standardized prior to clustering and thus were assigned the same weight.

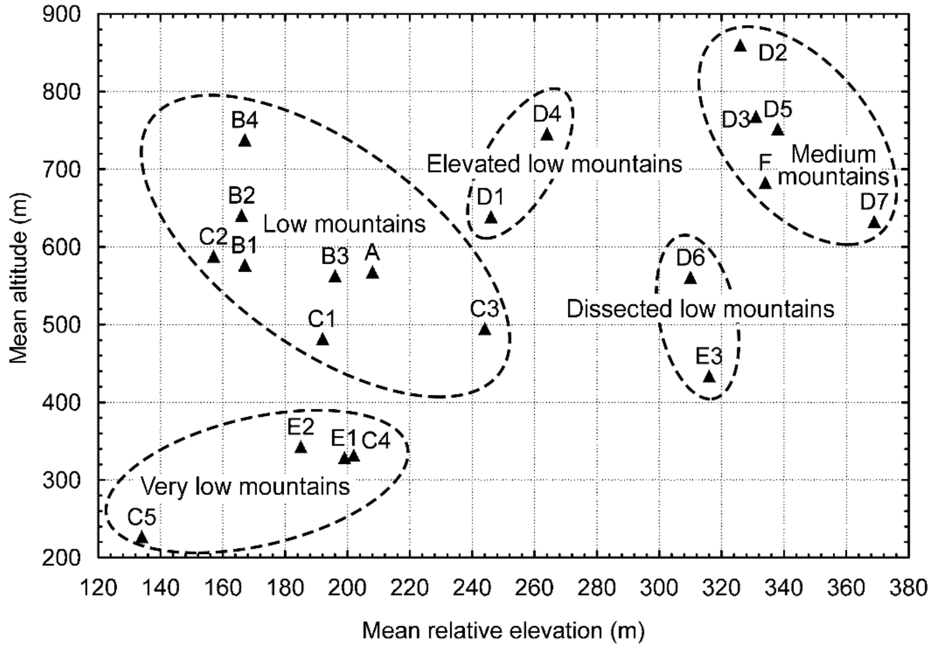

Fig. 2. Scatterplot representing orographic clusters of microecoregions. Descriptions of microecoregions (designated by alphanumerical indices) are provided in Table 1. See also Fig. 1

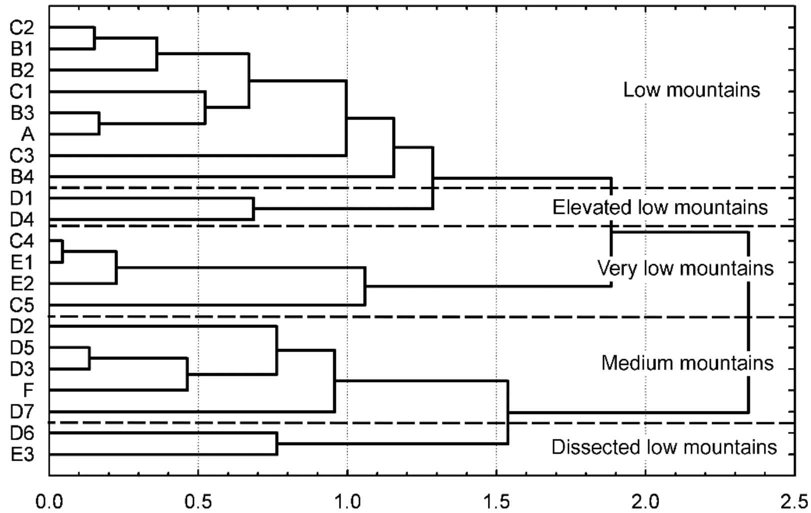

Fig. 3. Dendrogram representing clustering of microecoregions on mean altitude and mean relative elevation. Descriptions of microecoregions (designated by alphanumerical indices) are provided in Table 1. See also Fig. 1

The regionalization and the classification reveal that mesoecoregions contain rather different microecoregions. Namely, mesoecoregions of the Beskid Niski and the Cirocha-Rika low mountains are diverse in geological and orographic structure – they are formed by different nappes and consist of different orographic classes of microecoregions. At the same time, mesoecoregion of the Sian-Rika Verkhovyna is quite uniform from the same standpoint. However, it should be kept in mind that even microecoregions are rather heterogeneous spatial units. They may demonstrate rather strong dissymmetry, namely caused by the location on the boundary of the Tysa and the Sian/ Dnister basins with quite different erosion bases altitudes. Therefore, BR management plans should consider these peculiarities.

Conclusions. We delineated morphogenic meso- and microecoregions of the East Carpathians BR and the vicinity using large-scale topographic data as well as large- and medium-scale geological, geomorphological, and geoecological maps and schemes as collateral material. This is the most detailed and spatially accurate natural-geographic regionalization, which provides coherent spatial units for all three national parts of the region. Attribution with statistical elevation indices and subsequent cluster analysis afforded precise orographic classification of the microecoregions. It was also revealed that some mesoecoregions contain different orographic classes of microecoregions. This study is the first step of a more comprehensive research on the East Carpathians BR region, which will be supplemented by a bioclimatic characterization and classification of microecoregions and subsequent descriptions of the potential natural and actual landcovers. The information will be useful for sustainable management of the BR "East Carpathians".

REFERENCES

Atlas of representative geo-ecosystems of Slovakia. 2006. L. Miklós, Z. Izakovičová (Eds.). Bratislava: Slovak Academy of Sciences, 123.

Haczewski, G., Kukulak, J., Bąk, K., 2007. *Budowa geologiczna i rzeźba Bieszczadzkiego Parku Narodowego.* Kraków: Wydawnictwo Naukowe AR, 160.

Henkiel, A., 1997. Mikroregiony geomorfologiczne Bieszczadów polskich. In *Ann. UMSC*, Sec. B 52, 133–145.

Jarvis, A., Reuter, H. I., Nelson, A., Guevara, E., 2008. Hole-filled SRTM for the globe Version 4, available from the CGIAR-CSI SRTM 90m Database. Retrieved from: http://srtm.csi.cgiar.org.

Kočický, D., Ivanič, B., 2011. Geomorfologické členenie Slovenska. Retrieved from: https://www.geology.sk/maps-and-data/mapovy-portal/geological-maps/?lang=en.

Kravchuk, Ya., 2021. *Relief of the Ukrainian Carpathians*. Lviv: LNU im. I. Franka, 576. (In Ukrainian).

Kruhlov, I., 2008. Delimitation, metrization, and classification of morphogenic ecoregions of the Ukrainian Carpathians. In *Ukrainian Geographical Journal*, 3, 59–68. (In Ukrainian).

Kruhlov, I., 2020. *Transdisciplinary geoecology*. Lviv: LNU im. I. Franka, 292. (In Ukrainian).

Kuemmerle, T., Radeloff, V.C., Perzanowski, K., Hostert, P., 2006. Cross-border comparison of land cover and landscape pattern in Eastern Europe using a hybrid classification technique. In *Remote Sensing of Environment*, 103, 449–464. https://doi.org/10.1016/j.rse.2006.04.015.

Minpryrody, 2005. Regulations on the Project of organization of the area of a biosphere reserve and protection of its natural complexes. Order of the Ministry of Protection of the Natural Environment of Ukraine No 245 of 06.07.2005. (In Ukrainian).

Nowosad, M., 2000. Z badan nad zroznicowaniem klimatycznym Bieszczadow. In *Acta Agrophysica*, 34, 125–135.

Omernik, J.M., Griffith, G.E., 2014. Ecoregions of the conterminous United States: Evolution of a hierarchical spatial framework. In *Environmental Management*, 54, 1249–1266. https://doi.org/10.1007/s00267-014-0364-1.

Ralska-Jasiewiczowa, M., Madeyska, E., Mierzeńska, M., 2006. Vegetational changes in the montane grassland zone of the High Bieszczady mountains (southeast Poland) during the last millennium—pollen records from deposits in hanging peat-bogs. In *Veget. Hist. Archaeobot.*, 15, 391–401. https://doi.org/10.1007/s00334-006-0057-7.

Solon, J., Borzyszkowski, J., Bidłasik, M., Richling, A., Badora, K., Balon, J., Brzezińska-Wójcik, T., Chabudziński, Ł., Dobrowolski, R., Grzegorczyk, I., Jodłowski, M., Kistowski, M., Kot, R., Krąż, P., Lechnio, J., Macias, A., Majchrowska, A., Malinowska, E., Migoń, P., Myga-Piątek, U., Nita, J., Papińska, E., Rodzik, J., Strzyż, M., Terpiłowski, S., Ziaja, W., 2018. Physico-geographical mesoregions of Poland: Verification and adjustment of boundaries on the basis of contemporary spatial data. In *Geogr. Pol.*, 91, 2, 143-170. https://doi.org/10.7163/GPol.0115

Štátny geologický ústav Dionýza Štúra. Geological maps. URL: https://www.geology.sk/maps-and-data/mapovy-portal/geological-maps/?lang=en

Taggart-Hodge, T., Schoon, M., 2016. The challenges and opportunities of transboundary cooperation through the lens of the East Carpathians Biosphere Reserve. In *Ecology and Society*, 21. https://doi.org/10.5751/ES-08669-210429

Tectonic map of the Ukrainian Carpathians. Scale 1:200,000. 1986. V.V. Hlushko, S.S. Kruhlov (Eds.). Kyiv: Ministry of Geology of Ukrainian SSR (In Ukrainian).

The Carpathians and their foreland: Geology and hydrocarbon resources. 2006. J. Golonka, F.J. Picha (Eds.). Tulsa, Oklahoma: American Association of Petroleum Geologists, 608. https://doi.org/10.1306/M84985