

Developing the GIS-based maps of the geomorphological and phytogeographical division of the Ukrainian Carpathians for routine use in biogeography

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SUMMARY

The paper introduces GIS-based maps of the geomorphological and phytogeographical division of the Ukrainian Carpathians (a part of Eastern Carpathian Mts.), which were developed for routine use in biogeography and based on the consolidation of the existing publications. The map of the geomorphological division includes 57 OGUs (operational geographic units), and the map of the phytogeographical division – 18 OGUs of the lowest rank. Geomorphological units are supported with available synonyms, which should help in work with different topic-related Ukrainian publications. Both maps follow strict hierarchical classification and are briefly discussed.

INTRODUCTION

The Ukrainian Carpathians (UC) is part of the Eastern Carpathian mountain province (Kondracki 1989), artificially delimited by the western border of Ukraine and covering about 24,000 km². In general, these are not high mountains – only seven peaks of the UC slightly exceed 2000 m of elevation, and all these peaks, including the highest point of Ukraine, Mt. Hoverla (2061 m a.s.l.), are concentrated in the same Chornohora mountain range (Hiletskyi 2006).

Tsys (1962, 1968) published the first complete geomorphologic division of the UC. Besides five mountainous regions, this division also included adjacent foothills and lowlands (Ciscarpathia and Transcarpathia) and comprised 36 districts. Such regionalization of the UC was further developed by many Ukrainian scientists (Herenchuk 1968, Marynych et al. 1985, 2003, Voropay & Kunytsia 1996, Melnyk 1999, Slyvka 2001, Kravchuk 1999, 2005, 2008, Rudenko 2004), including those working in the field of biogeography (Kruhlov 2008, 2012, Korzhyk et

al. 2015, Cherepanyn 2017, Korzhyk 2018). It also served as a basis for the floristic regionalization of the UC, which delimits nine floristic regions, and is most widely applied for phytogeographical purposes in Ukraine (Chopyk 1977, Chopyk & Fedoronchuk 2015). Despite the long history of investigation, divisions of the UC lack consistency in terms of a hierarchical classification of the operational geographic units (OGUs) and common principles of their delimitation (Hiletskyi 2012, Feoli et al. 2019). In particular, OGUs of the same hierarchical level can differ by area by orders of magnitude (e.g., Skolivski Beskydy or Transcarpathia), have no clearly argued limits (e.g., Krayovi Gorgany and Zovnishni Gorgany), are delimited without reason (e.g., Chyvchyn Mts., which are consistent with Marmarosh Mts., are often delimited in Ukrainian papers), or are excessively split (e.g., certain regions of Yalovychory Mts. and Ciscarpathia), even in the same publication (e.g., Tasenkevich 2004, Kruhlov 2012, Chopyk & Fedoronchuk 2015). The delimitation principles of natural geomorphological OGUs of the UC are best described by Hiletskyi (2012). A well-argued congruence of the natural geomorphological OGUs has been reached by Korzhyk et al. (2015) and Korzhyk (2018). However, these divisions cover only the part of the Ukrainian Carpathian Region (UCR) that includes the mountainous part (the UC) and adjacent territories.

Kondracki (1989) proposed the geomorphological division of the Carpathians with different regionalization of its Ukrainian part. Following this scheme, the UC covers five macroregions and 17 mesoregions (some of the macroregions have no subdivision). In contrast to the division of Tsys (1962), the division of Kondracki (1989) is much better known outside of Ukraine. It is often applied for contemporary biogeographical studies in the Carpathian region (Kukuła et al. 2003, Zemanek 2009, Mráz & Ronikier 2016, Kłapyta 2020). Also, Tasenkevich (2004) used Kondracki's scheme

to develop an advanced phytogeographical division of the Carpathians and delimited six counties and 18 regions laid on the Ukrainian territory.

Kruhlov (Kruhlov 2008, 2012), based on the ideas of Miller & Fedirko (1990) and Melnyk (1999), combined geomorphological and ecological data and proposed one of the most recent regionalizations of the UC. The first version of this division (Kruhlov 2008) included 33 'morphogenic meso-ecoregions', but later was completed (Kruhlov 2012), and covered 44 OGUs grouped in 15 main classes (including island OGUs attached to the main Carpathian mountain range). This division is one of the most comprehensive, combining different aspects of spatial, geological, geomorphological, and ecological analyses and clusterization of obtained OGUs. Like Korzhyk et al. (2015) and Korzhyk (2018), Kruhlov's division is also GIS-based, with the OGUs of comparable size and more or less strict hierarchy. However, due to the application of ecological factors (i.e., bioclimatic elevation belts that are delimited based on the vegetation belts, the sum of active annual temperatures, and insolation), the separation and delimitation of some meso-ecoregions (e.g., Hutsulska Verkhovyna, Inner and Outer Bukovyna Mts., Krayovi and Zovnishni Gorgany) are debatable.

In 2015, in the frames of the investigations of the distribution of endemic plants in the Carpathian Mts., the necessity of a GIS-based map of the geomorphological division of the UC arose (Novikoff & Hurdu, 2015). The map of Kruhlov (2008, 2012) was the only one completely covering the UC region and GIS-based simultaneously, but due to the above-mentioned issues, it was dismissed. Similarly, Kruhlov's map did not find wide application among other scientists. Hence, starting from all mentioned above publications, a consolidated scheme for the geomorphological division of the UC following ideas of hierarchy and nomenclature of biogeographic units (Cox 2001, Kreft & Jetz 2010, Morrone 2018, Cervellini et al. 2020)

was developed and reported at the conference “Biogeography of the Carpathians” in Cluj, Romania in 2017 (Novikov & Hurdu 2017).

The preliminary version of the geomorphological division of the UC comprised three hierarchical levels and 53 OGUs of the lowest level (mesoregions). Later, based on newly received data and revisions (e.g., Chorney 2011, Korzhyk et al. 2015, Korzhyk 2018), this scheme was improved (i.e., limits of some mesoregions were corrected, synonyms were completed, and the division was revised). Here we would like to introduce the final version of this scheme and an adapted scheme of Tasenkevich's (2004, 2005) phytogeographical division of the UC to help other scientists in their biogeographical explorations.

MATERIALS AND METHODS

The map was developed in QGIS 3 (<https://www.qgis.org/>) environment with the application of the Diva-GIS shapefile of the administrative borders (<https://www.diva-gis.org/Data>), the 15 arc-second resolution layer of the river network (<https://geodata.lib.utexas.edu/catalog/stanford-pv700jx1402>), and the sublayer of OpenStreetMap (OSM, <https://www.openstreetmap.org/>). First, the background sublayer of OSM was imported to the QGIS. After that, the shapefiles of administrative borders and water bodies were uploaded to the project and converted to the WGS 84 coordinate system (EPSG 4326). The initial maps of Tsys (1962), Kondracki (1989), Tasenkevich (2004, 2005), and Chopyk & Fedoronchuk (2015) were scanned and, after that, georeferenced in QGIS 3 with the following transformation settings: linear transformation type and the “Nearest neighbor” resampling method. Finally, the map of Kruhlov's division also was uploaded to the initial project. As a result, we obtained several overlapping semitransparent layers, which were visually inspected and analysed on consistency

to natural barriers (i.e., river valleys). In case if the limits of the OGUs did not correspond to the natural barriers (e.g., went along or crossed the mountain ridges, went along the river valley but was shifted to higher elevation), they were bookmarked as having problematic topology, and after that corrected using QGIS in-built facilities. Hence, the primary limits of geomorphological and phytogeographical OGUs were ascertained based on the mentioned maps and later clarified and corrected concerning other published materials. In particular, the consolidated map of geomorphological division of the UCR was developed based on the analysis of the following principal publications dealing with physical and geographical aspects of the UCR regionalization: Dolenko (1962), Tsys (1962), Kondracki (1989), Gofstein (1995), Voropay & Kunytsia (1996), Melnyk (1999), Kravchuk (1999, 2005, 2008), Slyvka (2001), Marynych et al. (2003), Rudenko (2004), Kruhlov (2008, 2012), Korzhyk et al. (2015), and Korzhyk (2018). The map of phytogeographical division of the UCR was developed based on the map published by Tasenkevich (2004, 2005) and, after that, partly adapted to the natural limits of geomorphological units.

The final maps, represented in this paper, were reprojected using pseudo-Mercator WGS 84 coordinate system (3857) and extracted as independent ESRI shapefiles excluding other sublayers.

RESULTS AND DISCUSSION

The map of the geomorphological division of the UCR includes three main levels of OGUs – subprovinces, macroregions, and mesoregions. The intermediate OGU level between macro- and mesoregions was additionally ascertained. In total, 57 OGUs of mesoregional level were delimited in frames of this map (Figure 1, Table 1, Supplementary File 1).

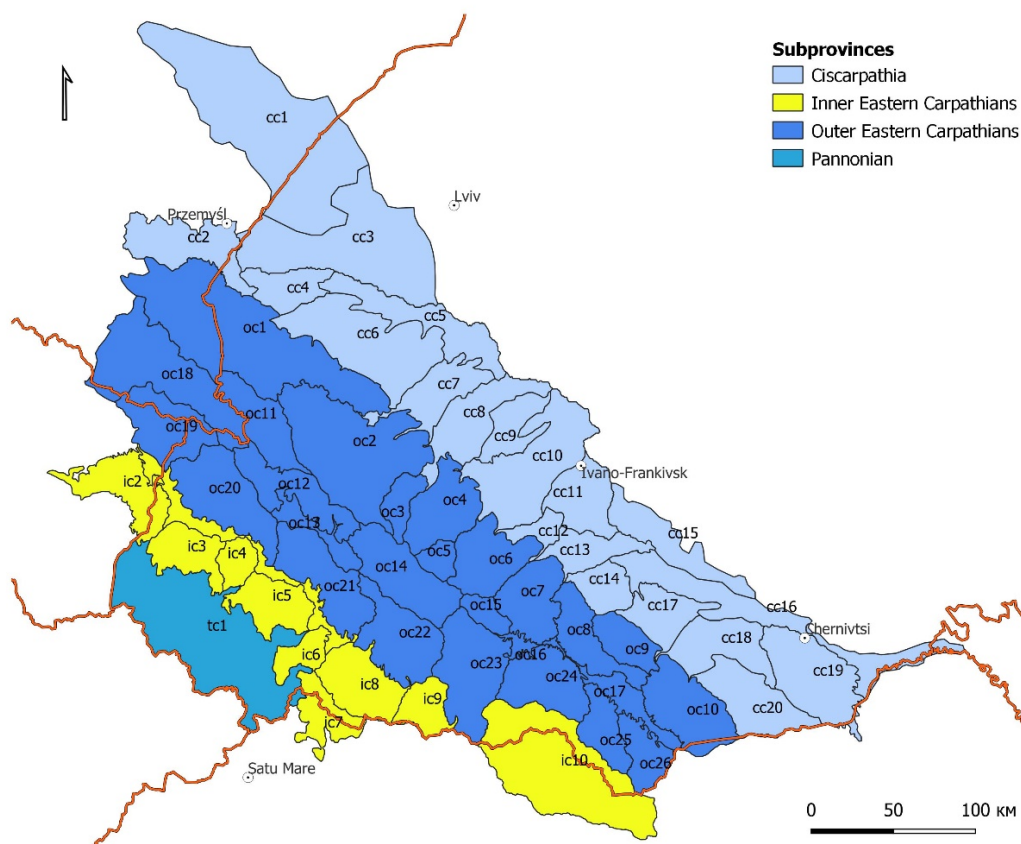


Figure 1. Map of the mesoregional geomorphological division of the Ukrainian Carpathians. cc – Ciscarpathia mesoregions, oc – Outer Eastern Carpathian mesoregions, ic – Inner Eastern Carpathian mesoregions, and tc – Transcarpathia. The abbreviations are transcribed in the Table 1. Bold brown lines indicate the country borders. Narrow black lines indicate the limits of mesoregional OGUs. The top arrow indicates the North direction. For a better perception of the map, some of the main cities in the region are indicated by white circle with central point.

Table 1. Hierarchy and synonymy of OGUs delimited for the map of the geomorphological division of the Ukrainian Carpathians.

ID	OGU Level 1 (Subprovinces)	OGU Level 2 (Macroregions = Oblasts)	OGU Level 2 synonyms	OGU Level 3 (Intermediate sub- macroregional OGUs)	OGU Level 3 OGU synonym	OGU Level 4 (Mesoregions = Districts)	OGU Level 4 synonyms
cc1	Ciscarpathia	Ciscarpathia	Peredkarpathia, Prykarpattia	Sandomierz Basin	Kotlina Sandomierska	Ternogorod Plateau	Plaskowyż Tarnogrodzki
cc2				Beskyd Ciscarpathia	Prybeskidske Peredkarpathia	Peremysheľ- Dobromyr Highland	Pogórze Przemyskie
cc3						Sian-Dniester Lowland	Oversian Basin
cc4						Stryvigor- Bolozivka Highland	Stryvigor Highland
cc5						Upper-Dnister Depression	Dnister-Svicha Lowland
cc6						Drohobych Highland	
cc7						Morshyn Highland	Bolekhiv-Zhuravne region

cc8						Zalissia Highland	Dolyno-Bolokhivskyi region
cc9						Rozhniativ-Kalush Depression	Limnytsia region
cc10						Prylukva Highland	Lukva Highland
cc11				Gorgany Ciscarpathia	Gorganske Peredkarpathia	Bystrytsia Depression	
cc12						Interbystrytsia Highland	Mizhbystritske Horbogarria, Gvizdtske Horbogarria
cc13						Deliatyn-Nadvirna Highland	Prut-Bystritsia Highland
cc14						Prut-Lyuchka Highland	
cc15						Tlumach-Obertyn Highland	
cc16						Kolomyia-Chernivtsi Plain	
cc17				Pokuttia-Bukovyna Ciscarpathia	Pokutsko-Bukovinske Peredkarpathia	Pokuttia Highland	
cc18						Seret-Cheremosh Highland	
cc19						Seret-Prut Highland	
cc20						Bukovina Highland	
oc1	Outer Eastern Carpathians	Beskyds		Eastern Beskyds	Shidni Beskydy	Upper Dnister Beskyds	Verkhniiodnisterski Beskydy
oc2						Skole Beskyds	
oc3		Gorgany		Chunk Gorgany	Skybovi Gorgany	Svitsko-Mizunski Gorgany	
oc4						Arshytsia-Ilemski Gorgany	
oc5						Verkhniolimnytski Gorgany	
oc6						Syvuliansko-Stanymyrski Gorgany	
oc7						Dovbushanski Gorgany	
oc8						Zaprutski Gorgany	
oc9		Pokuttia-Bukovyna Mts.	Pokutsko-Bukovynski Karpaty			Pokuttia Mts.	
oc10						Bukovyna Mts.	
oc11		Waterdivided-Verkhovyna Carpathians	Vododilno-Verhovynski Karpaty	Sian-Rika Verkhovyna	Siansko-Ritska Verkhovyna	Striy-Sian Verkhovyna	
oc12						Waterdivided Mountain Range	
oc13						Volovets-Mizhgoriia Verkhovyna	
oc14				Waterdivided Gorgany	Pryvododilni Gorgany	Torunsko-Bertianski Gorgany	
oc15						Bratkivski Gorgany	
oc16				Bystrytsia-Selatyn Lowland	Hutsulska Verkhovyna	Yasinia Depression	
oc17						Vorokhta-Putyla Valley	
oc18		Polonynas-Chorhohora Carpathians		Polonynas		High Bieszczady	Bieszczady Wysokie
oc19						Bukovske Vrchy	Bukovské Vrchy
oc20						Polonyna Rivna	Polonyna Runa
oc21						Polonyna Borzhava	
oc22						Polonyna Krasna	
oc23				Svydovets-		Svydovets	

oc24				Chornohora Carpathians		Chornohora	
oc25				Gryniava-Yalovychory Carpathians		Gryniava	
oc26						Yalovychory	Losoviy
ic1	Inner Eastern Carpathians	Volcanic Carpathians		Tsyrokh-Borzava Valley	Berezhne-Lipshansk Valley	Tsyrokh-Borzava Valley	Berezhne-Lipshansk Valley
ic2				Vygortat-Gutyn Carpathians		Vygortat	
ic3						Makovytsia	
ic4						Syniak	
ic5						Velykiy Dil	
ic6						Tupiy	
ic7						Oas	Gutyn
ic8	Maramures	Marmarosh		Maramures Depression	Khust-Solotvyno Depression	Tereblia Massif	
ic9						Apshytsia Massif	
ic10				Maramures Mts.	Marmarosh Mts.	Maramures Mts.	Marmarosh Mts.
tc1	Pannonian	Transcarpathia	Zakarpattia			Transcarpathian Lowland	Tysa Lowland, Prytysenska Dolina, Tysenska Dolina

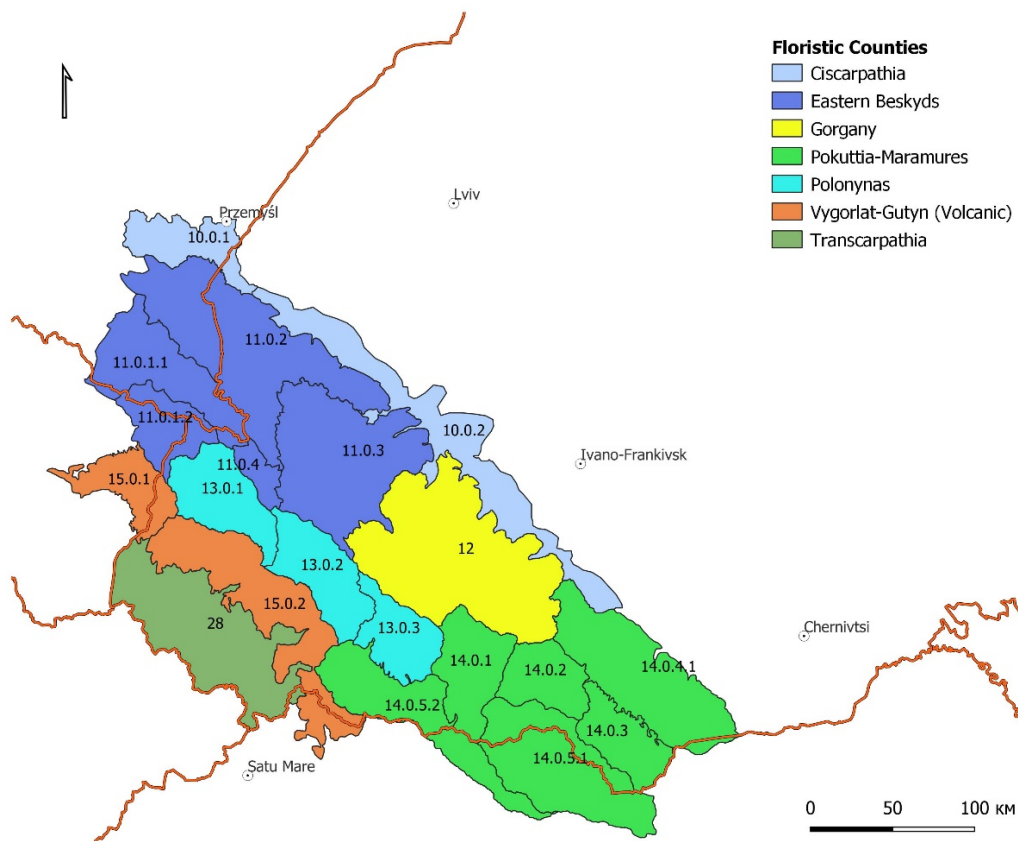


Figure 2. Map of the phytogeographical division of the Ukrainian Carpathians. The abbreviations are transcribed in the Table 2. Bold brown lines indicate the country borders. Narrow black lines indicate the limits of phytogeographical OGU. The top arrow indicates the North direction. For a better perception of the map, some of the main cities in the region are indicated by white circle with central point.

Challenges were found in the use of different toponyms for the same OGU in Ukrainian publications (e.g., Transcarpathian Lowland sometimes is also mentioned as Tysa Lowland, Prytysenska Dolina, or Tysenska Dolina). Therefore, special attention was paid to the search and verification of available synonyms, which, if recognized, were provided in the select columns near each OGU.

The hierarchy, subdivision, and IDs of the OGUs of the developed map of the phytogeographical division of the UCR strictly

follow Tasenkevich's concept, which ascertained three main levels of phytochorions – sector, county, and district. Besides this, Tasenkevich also distinguished a fourth level of subdistricts for certain OGUs, but only a few of them lay in the UC. The only exception was the additional inclusion of the Transcarpathian Lowland as an independent unit to this map. As a result, this map has three hierarchical levels with 19 lowest OGUs (Figure 2, Table 2, Supplementary File 2).

Table 2. Hierarchy and synonymy of OGUs delimited for the map of the phytogeographical division of the Ukrainian Carpathians.

ID	Sector	County	District	Subdistrict
10.0.1	Eastern Carpathians	Ciscarpathia	Peremysheľ-Dobromyr Highland	
10.0.2			Ukrainian Ciscarpathia	
11.0.1.1		Eastern Beskyds	Bieszczady	High Bieszczady
11.0.1.2				Bukovské Vrchy
11.0.2			Upper Dniester Beskyds	
11.0.3			Skole Beskyds	
11.0.4			Bukovets	
12		Gorgany	Gorgany	
13.0.1		Polonynas	Rivna	
13.0.2			Borzhava	
13.0.3			Krasna	
14.0.1		Pokuttia-Maramures	Svydovets	
14.0.2			Chornohora	
14.0.3			Gryniava-Yalovychoy	
14.0.4.1			Pokuttia-Bukovyna Mts.	Pokuttia
14.0.5.1			Maramures Mts.	Maramures
14.0.5.2				Maramures Depression
15.0.1		Vygorlat-Gutyn (Volcanic)	Vygorlat	
15.0.2			Makovytsia-Oas	
28	Pannonian	Transcarpathia	Transcarpathia	

The map of the phytogeographical division of the UC does not fully correspond to the outlines of the map of geomorphological division due to several reasons. First, as mentioned before, Tasenkevich (2004, 2005) developed her map based on the Carpathian division of Kondracki (1989), which was schematic and, as a result, not always clearly followed the natural limits. Moreover, Kondracki omitted the Ciscarpathia and Transcarpathia in his division because they do

not belong to the Carpathian Mountains in a strict sense (Kliment et al. 2016, Mráz & Ronikier 2016) but rather represent adjacent independent highland and/or lowland territories (Kondracki 1989, Kravchuk 1999, Tasenkevich 2004). Similarly, in his first version, Kruhlov (2008) did not consider these territories. However, he introduced them to the second extended version of the map (Kruhlov 2012) as independent geomorphological units belonging to the UCR in a broad sense. Interestingly,

Ciscarpathia and some of Transcarpathia OGUs were introduced by Kruhlov (2012) as isolated island units.

Nevertheless, the Carpathian Mountains have a strong influence on the flora of the adjacent territories, and therefore they are often considered a part of the UCR and included in analyses by Ukrainian florists (Fodor 1974, Chopyk 1977, Tkachyk 2000, Pryhara 2013, Chopyk & Fedoronchuk, 2015). On the other side, Transcarpathia is a floristically unique territory that belongs to the Pannonian biogeographic region (Fodor 1974, Tasenkevich 2006, Sundseth 2009, Fekete et al. 2016). This was the reason why Tasenkevich (2004) included to her map only a narrow strap of Ciscarpathia basing on the eastern distribution limit of the mixed fir-beech forests and did not include Transcarpathia.

It was not our intention to engage in the debates about the appropriateness of inclusion of Transcarpathia and Ciscarpathia in the UC, and our decision was based on simple technical reason: these regions can be helpful for the analysis of the distribution of some taxa that are spread out of the UC (e.g., subendemics) and as transitional/buffer biogeographical zones (Lenormand et al. 2019). The built maps can be modified for different purposes, and, if needed, Transcarpathia and Ciscarpathia OGUs can be easily excluded from the analyses. If we would not include these regions, their delimitation could be challenging for other researchers due to scattered and published mainly in Ukrainian data.

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advice regarding limits about some problematic mesoregions of the UC.

SUPPLEMENTARY FILES

Supplementary File 1. Compressed archive in .rar format with shape files for the mesoregional geomorphological division of the Ukrainian Carpathians.

Supplementary File 2. Compressed archive in .rar format with shape files for the phytogeographical division of the Ukrainian Carpathians.

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