Hungary
Slovakia
Romania
Ukraine

Co-financed by the European Union

PARTNERSHIP
WITHOUT BORDERS

ENVIRONMENTAL ISSUES OF ZAKARPATTIA

Manual

Hungary Slovakia Romania Ukraine

Co-financed by the European Union

PARTNERSHIP
WITHOUT BORDERS

ENVIRONMENTAL ISSUES OF ZAKARPATTIA

Manual

Project HUSKROUA/1901/6.1/0075
“Environment for the Future by Scientific Education”

Uzhhorod – 2023

UDC 502+504(477.87)
E45

Reviewers:

Dmytro Dubyna – Doctor of Biological Sciences, professor, chief researcher of the Department of Geobotany and Ecology, M.G. Kholodny Institute of Botany, National Academy of Sciences of Ukraine

Svitlana Hapon – Doctor of Biological Sciences, Professor of the Department of Botany, Ecology and Teaching Methods of Biology, Poltava V.G. Korolenko National Pedagogical University

Yuriy Tyukh – Candidate of Biological Sciences, Deputy Director for Scientific Research, Synevyr National Nature Park

Mykhailo Haydur – Candidate of Pedagogical Sciences, Deputy Director of the Department of Ecology and Natural Resources, Transcarpathian Regional State Administration

Recommended for publishing by the Academic Council of STATE UNIVERSITY «Uzhhorod National University», protocol No. 11 of December 18, 2023

Environmental Issues of Zakarpattia. Manual / N. Kablak, Ya. Hasynets, L. Felbaba-Klushyna, V. Mirutenko and others ; Gen. Ed. prof. N. Kablak and prof. L Felbaba-Klushyna. – Uzhhorod : RIK-U, 2023. – 324+356 p.

ISBN 978-617-8276-79-9

The manual contains scientific materials devoted to the coverage of contemporary environmental issues of Zakarpattia. Considerable attention is paid to the peculiarities of its natural conditions. Emphasis is placed on the preservation of biodiversity in the face of climate change. While devising this textbook, the authors resorted to the analysis of literary sources as well as the findings of their own research. It will benefit school teachers, students and postgraduates of higher educational institutions majoring in natural sciences, employees of the nature reserve fund, and representatives of the authorities.

This manual was produced with the financial support of the European Union within the project HUSKROUA/1901/6.1/0075 “Environment for the Future by Scientific Education” (EFFUSE) of ENI CBC Programme Hungary-Slovakia-Romania-Ukraine 2014-2020. Its contents are the sole responsibility of NGO “Institute of Development of Carpathian Region” and do not necessarily reflect the views of the European Union.

UDC 502+504(477.87)

More information on the project is available on the links below:
https://idcr.info/current-project.php?id=11&lang=en
https://effuse.science.upjs.sk/index.php/en/

ISBN 978-617-8276-79-9

CONTENTS

Introduction 5

Chapter 1. Geographical Location: Features and Natural Conditions of Zakarpattia 7

1.1. Orographic and Hydrographic Features *(V. Sabadosh)* 7

1.2. Natural Conditions and Anthropogenic Factors Affecting the Hydroecological State of the Upper Reaches of Tisza River Basin *(V. Leta, M. Karabiniuk)* 14

1.3. Hydroecological State of the Upper Reaches of the Tisza River Basin *(V. Leta)* 38

1.4. Characteristics of Current Climatic Conditions and Climate Change Manifestations *(R. Ozymko, M. Karabiniuk)* 47

1.5. Soils and Vegetation Cover *(V. Sabadosh)* 65

1.6. Territorial Faunal Complexes *(V. Sabadosh)* 70

1.7. Landscape Tiering and Its Features *(M. Karabiniuk)* 75

1.8. Contemporary Landscape Structure *(M. Karabiniuk)* 84

Chapter 2. General Characteristics of Environmental Disequilibrium Manifestations in Zakarpattia Oblast *(L. Felbaba-Klushyna, N. Kablak, Ya. Syvokhop)* 94

Chapter 3. Air Pollution Issues in Zakarpattia Oblast *(M. Vakerych)*.... 99

3.1. Air Pollution Sources, National Issues of Their Conservation 99

3.2. State of the Air in Zakarpattia: Main Pollution Threats and Conservation Issues 116

Chapter 4. Pollution Issues of the Water Bodies of Zakarpattia *(M. Vakerych)* 119

4.1. Sources of Polluting Water Bodies, National Issues of Their Preservation 119

4.2. Water Resources of Zakarpattia: Major Pollution Threats and Conservation Issues 123

Chapter 5. Issues of Soil Pollution in Zakarpattia *(Ya. Hasynets)* 132

5.1. Sources of Soil Pollution and Types of Soil Degradation. National Issues of Soil Conservation. 132

5.2. Soil Resources of Zakarpattia: Main Threats of Pollution and Degradation, Problems of Conservation. 145

Chapter 6. Environmental Threats to the Landscape Diversity of Highland Areas in Zakarpattia *(M. Karabiniuk)* 159

6.1. Genesis and Evolution of Highland Landscape Complexes 159
6.2. The Impact of Climate Change on Development and Modern Landscape Diversity 166
6.3. Ecological Threats and Anthropogenisation of Highland Landscape Complexes 177

Chapter 7. Modern Changes in the Structure of the Forest Cover of Zakarpattia *(L. Felbaba-Klushyna, V. Klushyn, L. Miklovsh)*............ 192
7.1. Forest Structure and Trends in Their Change............ 192
7.2. Functional Importance of Forest Cover (Hydrological and Soil Protection Role) 196

Chapter 8. Changes in the Biodiversity of Zakarpattia in the Context of Anthropogenic Pressure............ 205
8.1. Impact of Anthropogenic Factors on the Microbiota of Natural Ecosystems *(M. Kryvtsova, M. Savenko)* 205
8.2. Problems of Floral Diversity Preservation *(R. Kish)*............ 211
8.3. Protection of Phytocoenotic Diversity of Zakarpattia (*L. Felbaba-Klushyna, V. Klushyn, L. Miklovsh)* 233
8.4. Influence of Anthropogenic Factors on the Fauna *(F. Kurtiak, O. Mateleshko)* 247
8.5. Threats and Decline of Amphibians *(F. Kurtiak)*............ 249
8.6. Changes in the Composition of the Ichthyofauna *(F. Kurtiak)*........ 256
8.7. The Influence of Anthropic Factors on the Entomofauna of Main Biotopes *(O. Mateleshko)*............ 259
8.8. Threats of Spread and Impact of Invasive Species *(R. Kish, Yu. Shpontak, D. Tomenchuk, V. Mirutenko, I. Besehanych)* 267

Chapter 9. The Impact of Climate Change on the Ecosystems of Zakarpattia and Adaptation Measures *(O. Stankiewicz-Volosianchuk)*.. 276

Chapter 10. Development of Natural and Technogenic Processes in Zakarpattia Oblast 292
10.1. Geological and Geomorphological Exogenous and Technogenic Processes *(N. Kablak, M. Nychvyd, I. Kalynych)* 292
10.2. Dangerous and Spontaneous Meteorological Phenomena *(R. Ozymko, M. Karabiniuk)*............ 308

Chapter 11. Environmental Education 315
11.1. Features and Place of Environmental Education in Our Life *(M. Vakerych, Ya. Hasynets, V. Mirutenko, M. Balazh, H. Popovych, A. Hiutler)* 315
11.2. Scientific Education of Environmental Issues *(Ivana Slepakova)*............ 318

Chapter 6.

ENVIRONMENTAL THREATS TO THE LANDSCAPE DIVERSITY OF HIGHLAND AREAS IN ZAKARPATTIA

(M. Karabiniuk)

6.1. GENESIS AND EVOLUTION OF HIGHLAND LANDSCAPE COMPLEXES

The subalpine and alpine highlands in the Ukrainian Carpathians are located at altitudes above 1450-1500 m, representing a complex combination of unique denudation, glacial-exaration and nival-erosion landscape complexes (Melnyk et al., 2018; Karabiniuk, 2020a). A distinctive feature of the alpine landscape tier is its rich landscape diversity, which has evolved over an extended period under the influence of internal and external factors. These factors include abrupt climate changes, substantial glacial deglaciations, and anthropogenic impacts. The highlands exhibit distinct morphological characteristics, formed by a combination of extensive levelled denudation surfaces of mountain ranges and their spurs, along with steep slopes that house various glacial landforms like cirques, glacial troughs, and others (Kravchuk, 2006; Karabiniuk and others., 2017).

The alpine landscape tier preserves remnants of the ancient history of the Ukrainian Carpathians mountain system's formation. It combines landscape complexes of various ages, each with notably distinct properties, both morphological and morphometric. In the current climatic conditions of the highlands in the Ukrainian Carpathians, characterised by very cold temperatures in January (-10 to -12 °C) and cool temperatures in July (+9 to +12 °C), as well as high humidity (with over 1500 mm of annual precipitation), subalpine vegetation (including mountain pine, green alder, Siberian juniper, etc.) and alpine vegetation (such as lying fescue, three-split fescue, etc.) thrive. These plants grow on sturdy, skeletal, and low-power mountain-meadow-brown soils (Miller and others, 1997; Barannik, 2018; Karabiniuk, 2020a) (see Fig. 6.1.1). The high lithomorphic nature of these landscape complexes renders them susceptible to various physical and geographical processes and phenomena, including landslides and erosion.

Fig. 6.1.1. Subalpine and alpine highlands of the Chornohora massif in the Ukrainian Carpathians (Photo by the author)

The limited distribution and the ongoing anthropogenic impact, combined with the effects of significant climate change, are contributing to an escalation in environmental threats to the contemporary landscape diversity of the highlands. This poses challenges to the preservation of relict plant species and landscape complexes distinguished by their unique origins and characteristics. These factors play a pivotal role in the current ecological condition of the highland landscape complexes of the Ukrainian Carpathians, with a particular focus on Zakarpattia Region.

The subalpine and alpine highlands situated within the Zakarpattia Region are confined to the highest mountain ranges, including Chornohora, Svydovets, Borzhava, the Marmarosh massif, and others. These highlands predominantly occupy the central watershed ranges of these massifs, imparting specific highland characteristics to them. The alpine landscape layer is most prominently exhibited in the highest mountain landscapes of Chornohora, encompassing two geographically limited areas with a combined area of 80.5 km² (see Fig. 6.1.2) (Karabiniuk, 2019a, 2020a). These areas are demarcated by the peaks of Hoverla and Petros, where the watershed ridge is lower, and spruce forests become prevalent, which is characteristic of mid-mountain landscape complexes (Melnyk, 1999; Melnyk et al., 2018). Highland landscape complexes are unique in terms of their genesis, exhibiting substantial differences in their functionality, development, and resilience to adverse external factors.

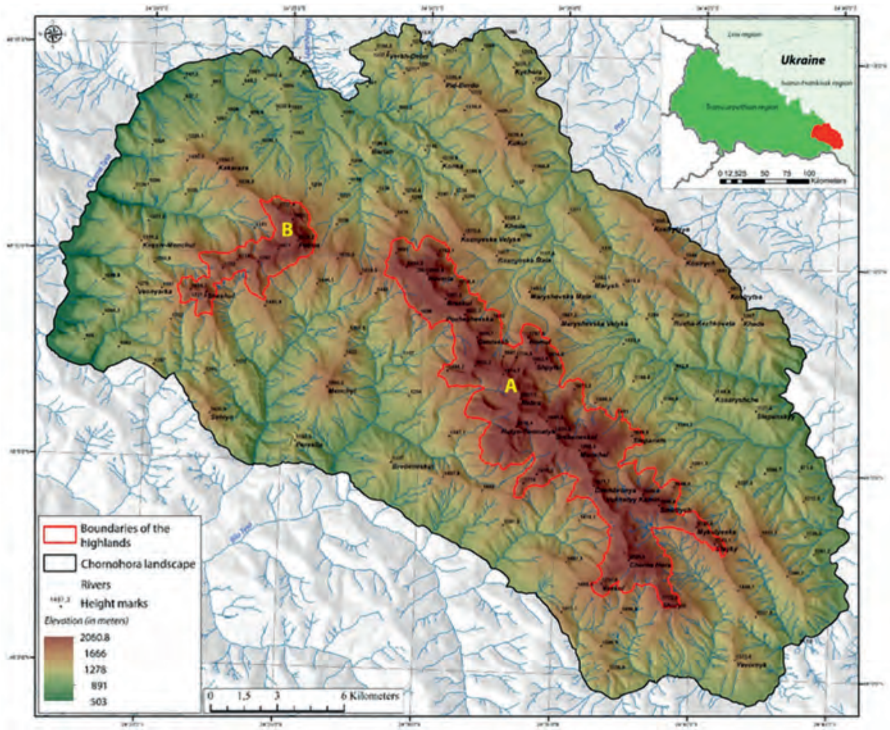

Figure 6.1.2. Location of the highland landscape tier in the highest mountain landscape of the Ukrainian Carpathians – Chornohora (Karabiniuk et al., 2022a)

In the historical formation and evolution of the highland landscape tier in the Ukrainian Carpathians, especially in Zakarpattia Region, significant changes have occurred in the natural components, such as the lithogenic base, climatic conditions, surface waters, and more. Landscape development was a result of the intricate interplay between endogenous and exogenous factors, leading to the complexification of the morphological structure and the formation of new extensive landscape complexes known as high-altitude terrains (Karabiniuk, 2020a). Each high-altitude area is characterised by specific attributes, including its elevation, surface steepness, moisture content, insolation characteristics, as well as the presence of modern processes, which were predominantly determined during the development of the lithogenic base under the decisive influence of specific morphogenic factors.

In the broader context of the highland landscape complexes in the Ukrainian Carpathians, two distinct stages can be identified in their historical development, each associated with different dominant factors governing landscape formation (Karabiniuk, 2020a).

- Lower Miocene – denudation processes prevailed);

- Meso-Neopleistocene – glacial exaration processes prevailed.

In the modern subalpine and alpine highlands of the Ukrainian Carpathians, three distinct altitudinal areas have formed, each shaped during different stages of landscape development under various morphogenic factors. The oldest among them, known as the *denudation highlands*, originated during the Lower Miocene (Karabiniuk, 2020a). The prominent mountain range crests and extensive saddles represent remnants of the initial formation phase, retaining the most significant traces of ancient denudation (see Fig. 6.1.3). Denudation landscape complexes also encompass convex surfaces of dome-shaped peaks and their slopes, primarily located along the central watersheds of mountain massifs, rising approximately 150-200 metres above crystal surfaces. These areas constitute the most ancient tracts within the highlands of Chornohora, Svydovets, and other mountain ranges, establishing their Lower Miocene-Holocene age (Karabiniuk, 2020a)

Fig. 6.1.3. Denudation surfaces of the main watershed ridge of the Chornohora massif of the Ukrainian Carpathians (Photo by the author)

Throughout the Miocene, against the background of alternating upward movements and their periodic attenuation with characteristic very active denudation processes, active formation of denudation slope tracts took place (Karabiniuk, 2020a). From the Lower Miocene to the Pleistocene, catchment areas were important for the further development of the landscape structure of the highlands. Their active formation was the result of widespread erosion processes and intensive development of the river network, which began a long process of dismemberment of the mountain ranges of the Ukrainian Carpathians. As a result, by the time of the last glaciation, massive and deeply incised catchment basins were formed in the upper reaches of the streams, which significantly diversified the landscape structure of the highland landscape tier. Their deepening was especially intense during periods of tectonic instability with upward processes of geological basement development, when active dismemberment of the highland relief occurred (Karabiniuk and others, 2022a).

An important stage in the formation of modern landscape features of the highlands of the Ukrainian Carpathians was the Pleistocene, during which significant climate cooling and snowline depressions occurred twice, leading to the most powerful Risian and Wurm glaciations of the highest mountain ranges (Karabiniuk, 2019b, 2020a). Therefore, it is relevant to study the impact of glaciations on the formation of the modern landscape structure of the alpine landscape tier, as well as to determine the mechanism and features of the formation of specific alpine natural territorial complexes that have influenced the current parameters of landscape diversity in the study area.

As a result of the exhumation activity of ancient glaciers, a significant part of the denudation highlands of the Ukrainian Carpathians was subjected to nival processing and dismemberment – a peculiar complex of ancient glacial landforms was formed, represented by numerous cirques, corrie, nival niches, glacial troughs, etc. They are confined to the headwaters of river valleys along the main watershed ranges of Chornohora, Svydovets, Marmarosh and other massifs at altitudes ranging from 1450-1500 to 1800 m (Miller and others, 1990; Melnyk and Karabiniuk, 2018; Karabiniuk, 2020a). On their basis, in the Pleistocene, the high-altitude terrain of the *ancient-glacial-exaration* highlands was formed (Fig. 6.1.4).

The relics of ancient glaciation are widespread almost throughout the entire territory of the highland landscape tier of the Ukrainian Carpathians and vary significantly in size, shape, depth of incision, steepness of walls and other morphological features (Kravchuk, 2006). They are best preserved in the highland part of the leeward northeastern macro-slope of the Chornohora and Svydovets massifs.

A set of ancient-glacial-exaration landforms (cirque, nival niches, glacial troughs, etc.) with a characteristic strong dismemberment, significant steepness of slopes and the presence of sharp ridges form the so-called alpine relief (Kravchuk, 2006). In fact, the presence of alpine relief gives the highest mountain ranges of the Ukrainian Carpathians the features of alpine landscapes and is an integral element of the alpine landscape layer (Miller and Fedirko, 1997; Karabiniuk, 2020a). The most characteristic relics of Pleistocene glaciations in the highlands of the Ukrainian Carpathians are complex cirque tracts formed as a result of intensive exhumation of the raked slopes by ice masses moving down to the nearest erosion base. Most of the cirque are characterised by clearly defined very steep back and side walls, where the collapse and scree parts are clearly visible. The scree walls of the karsts are adjacent to moraine bottoms with peat bogs, and occasionally small bogs and lakes – Brebeneskul, Vorozheska, Ivor, etc. The ancient glacial-exaration forms in the highlands inherited the character of the Pliocene-Pleistocene system of catchment funnels. The main accumulation of snow and glacial masses during glaciations initially occurred in the depressions of the massif relief, which were mainly the highest catchment erosion hollows. Subsequently, they were transformed into cirques under the exarationary action of glaciers (Karabiniuk, 2020a)

Fig. 6.1.4. High-altitude terrain of the ancient-glacial-exaration subalpine highlands in Chornohora (a tract of heavily incised cirque in the south-eastern exposure with Lake Brebeneskul) (photo by Yana Karabiniuk)

During the development of glacial exaration under the influence of Pleistocene glaciations, intensive nival-erosion processes also took place in the highlands of the Ukrainian Carpathians, which played an important role in the further development of the landscape structure of the territory. As a result of intensive nival-erosion processes in the then nival tier of the highest mountain ranges, peculiar amphitheatres of ancient firn fields were formed on warmer and gentler southwestern macro-slopes. They are genetically linked to Pleistocene glaciations, are characterised by nival-erosion origin and form the high-altitude terrain of the *nival-erosion highlands* (Karabiniuk, 2020a, 2021b). Their defining feature is the stepped structure of concave and rounded large mesoforms with levelled bottoms (Fig. 6.1.5). The largest amphitheatres of ancient form fields are located in the highlands of Chornohora in the upper reaches of the Hoverla River basin, the largest of which (Ozirnyi amphitheatre) covers an area of about 2 km^2 (Karabiniuk, 2020a).

Fig. 6.1.5. High-altitude terrain of nival-erosion highlands of the subalpine highlands in Chornohora (tract of the amphitheatre of the ancient firn field of the southwestern exposure of the slope of Mount Turkul) (photo by the author)

The amphitheatres of ancient form fields possess a rounded shape, somewhat resembling complex carr tracts. They are enclosed by exceptionally steep scree walls, varying in height from 5-10 metres to 50-75 metres. At the base of these walls, coarse boulder cones and accumulations of colluvial deposits are formed. These colluvial deposits are mainly found on the undulating, stepped surfaces, which can extend up to 350 metres in width. The size and depth of these amphitheatre bottoms of ancient firn fields increase in the presence of rocks, particularly mudstones, which are susceptible to nival and water erosion. The lower portions of the amphitheatres exhibit a predominantly rounded shape but are severed by steep ledges, occasionally reaching heights of 75-80 metres (Karabiniuk, 2020a). These ledges are characterised by accumulations of coarse boulder sediments, which accumulate as embankments in the densely forested midlands (Karabiniuk, 2021b).

Hence, the Meso-Neopleistocene epoch of morphogenesis in the upper landscape layer of the Ukrainian Carpathians is closely linked to glaciations, marked by extensive cirques formation and vigorous nival-erosion processes. These processes gave rise to the third high-altitude terrain, known as the nival-erosion highlands, primarily characterised by the presence of amphitheatres of ancient form fields. The stepped morphology of these landscapes results from the interplay of lithological and structural features inherent to the highlands, modulated by external factors, particularly nival-erosion processes. Some of these amphitheatres are further enriched by nival karsts, adding to the uniqueness of these natural territorial complexes within the highland tier of the Ukrainian Carpathians, and specifically in Zakarpattia Region.

6.2. THE IMPACT OF CLIMATE CHANGE ON DEVELOPMENT AND MODERN LANDSCAPE DIVERSITY

Our landscape studies regarding the genesis and characteristics of the modern spatial organisation of the Ukrainian Carpathian highlands reveal significant landscape diversity and the progressive development of geocomplexes. These changes in structure and properties occur under the influence of external factors and self-development (Karabiniuk, 2020a). Global climate change, along with its local manifestations, stands out as a primary driver of landscape structural modifications. Climate change during various stages in the development of modern landscape diversity has been characterised by abrupt shifts and significant deviations from contemporary trends. These changes have played a pivotal role in shaping the evolution of several highland landscape complexes. Present-day alterations in highland climatic conditions primarily manifest as increased aridification during summer and shifts in the annual distribution of precipitation (Karabiniuk and Shuber, 2019; Karabiniuk and Markanych, 2020). These shifts contribute to heightened environmental risks for the valuable natural highland complexes in Transcarpathia and, more broadly, to the modern landscape diversity.

The modern landscape structure comprises landscape complexes of varying ages and origins, characterised by different sizes and properties. In the highland landscape stratum of the Ukrainian Carpathians, three genetic types of highlands have been identified: *denudation highlands, glacial-exaration highlands, and nival-erosion highlands* (Karabiniuk, 2020a). Denudation landscape complexes in the Ukrainian Carpathian highlands are the oldest, with their formation dating back to the Lower Miocene. Nevertheless, their current features were significantly shaped by the Pleistocene glaciations and subsequent modifications during the Holocene. The landscape structure underwent substantial changes and development, largely driven by global shifts in climate conditions, which continue to influence the region today.

The degradation of the last Wurm glaciation's glaciers in the highlands of the Ukrainian Carpathians occurred in several stages, varying significantly in duration (see Fig. 6.2.1). This process gradually complexified the landscape structure of the territory's highlands during the Holocene, resulting in a notably different morphological pattern. Amidst the backdrop of overall climate warming, intermittent episodes of renewed glaciation took place, giving rise to dynamic landscape features, including nival niches, fragmented catchment areas, and deep erosion hollows, among others. Towards the end of the Pleistocene epoch, most of the glaciers in Chornohora vanished. However, as the Holocene began, there was a resurgence of glacial activity. Around 10.3 to 12.3 thousand years ago, coinciding with the climatic optimum, a significant number of small glaciers at lower elevations in the highlands melted, while the remaining glaciers in the deepest and highest karsts of Chornohora experienced a reduction in their size and capacity (Karabiniuk, 2020a, 2021b).

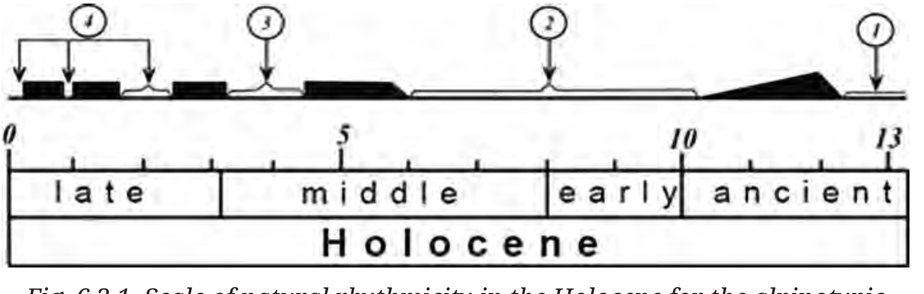

Fig. 6.2.1. Scale of natural rhythmicity in the Holocene for the alpinotypic midlands of the Carpathians (on the example of Chornohora) (Kovalukh et al., 1985)

Numbers in rings are cold periods: 1 – late Jurassic degradation of mountain glaciation, accumulation of lower horizons of fluvio-glacial deposits; 2 – resumption of glaciation, formation of final moraines of stages 4, 5, 6, accumulation of middle horizons of fluvio-glacial deposits; 3 – formation of the youngest moraines, accumulation of upper horizons of fluvio-glacial deposits; 4 – accumulation of nival-fluvial fine-grained soil near large migrant snowfields. Black fill – warm periods, vegetation optima.

During the early and first half of the Middle Holocene (6-10 thousand years ago), there was a significant period of climate cooling, which triggered a substantial resurgence of glaciation in the highlands of the Ukrainian Carpathians. This cooling phase was marked by intense glacial exaration processes and the widespread rejuvenation of the ancient-glacial-exaration highlands. It was during this time that many dynamic landscape features were formed, including deeply incised nival niches, which primarily developed on the walls of cirques and the steep, elongated slopes of ridge spurs (Karabiniuk, 2020a). The decline of this glaciation, or more precisely, its degradation, was driven by the Middle Holocene climatic optimum (Kovaliukh et al., 1985). As a result of the intermittent glacial re-advances in the highland landscape zones of Chornohora, Svydovets, and other mountain ranges in the Ukrainian Carpathians, combined with the influence of intense glacial exaration processes, the floors of the karsts and cirques became filled with young moraines.

Fig. 6.2.2. Dome-shaped peak of Hoverla Mountain with erosion strips and deeply incised carr on the northern slopes (Photograph by Dmytro Fisheryuk)

The development of the river system and active erosion processes during the Holocene significantly contributed to the dismemberment of the cirque floor tracts, resulting in a substantial alteration of their morphological structure and external morphometric features. Additionally, the evolution of geocomplexes of glacial origin can be attributed to the accumulative processes of biogenic sediments in low-lying areas of the relief and the encroachment of glacial lakes (bogs) into the bottoms of the karsts and cirques. Gravitational processes played a significant role in shaping the highlands of the ancient glacial-exaration highlands, with numerous landslides and collapses accelerating the degradation of gully walls and leading to the infilling of their bottoms with debris.

Consequently, most of the cirque bottoms with small lakes were filled with debris for an extended period, indicating the intensive degradation of the cirque walls and other components of glacial-excision tracts (Miller and Fedirko, 1990; Miller and others, 1997). During this time, changes in climatic conditions, coupled with a decrease in the snow line, also resulted in the modification of nival niches under the influence of erosion.

The evolution of the denudational highlands of the Ukrainian Carpathians during the Holocene is closely linked to the increased erosive impact of water flows. Their intense action has contributed to the rejuvenation and formation of new catchment areas, furrows on steep slopes, and other features. Linear erosion processes have significantly dismembered the massive steep slopes of ridge spurs, domed peaks, and other areas in the highland tier (refer to Fig. 6.2.2). Notably, landslide processes have become a defining feature of landscape changes in this period, with powerful manifestations leading to the formation of intricate landslide tracts (Karabiniuk, 2020a). The most prominent of these tracts take on a cirque-like shape and consist of a cascade of landslide bodies, with their direction aligned with the bedrock's dip. For instance, within the Chornohora alpine landscape tier, the largest landslide tracts are situated in the upper reaches of the streams basins, including Brebeneskul (Lemska tract and the western slopes of Mount Brebeneskul), Baltsatul (on the western slopes of Mount Pip Ivan), among others.

Thus, the current landscape structure of the highlands in the Ukrainian Carpathians has developed over an extended period, shaped by various morphogenesis factors that have determined the primary spatial organisation of the region. It is characterised by considerable landscape diversity, encompassing landscape complexes of varying ages, origins, sizes, and properties. For instance, the landscape structure of the Chornohora highlands is composed of the following elements (Fig. 6.2.3, Table 6.2.1) (Karabiniuk, 2020a):

- *2 sectors;*
- *5 types of high-altitude areas;*
- *20 types of landscape structures;*
- *73 types of complex tracts;*
- *273 types of sub-tracts and simple tracts.*

As a result of the typological classification of the tracts in the alpine landscape tier of Chornohora, it was determined that the denudation alpine-subalpine highlands are composed of 7 types and 17 subtypes of complex tracts. The highest diversity is observed in the type of complex tracts on steep and very steep ridgetop slopes of the main ridge's spurs, which includes 5 subtypes and 23 types of complex tracts. Similarly, the type involving steep and steep ridgetop slopes of the main ridge's spurs encompasses 4 subtypes and 45 types of complex tracts. Notably, the former has the most extensive range of contours for complex tract types, totaling

144 contours. Conversely, the types associated with relict catchment areas and the system of tectonic landslides are unique. Each of these is represented by only 1 subtype and 1 type of complex tract (Karabiniuk, 2020a).

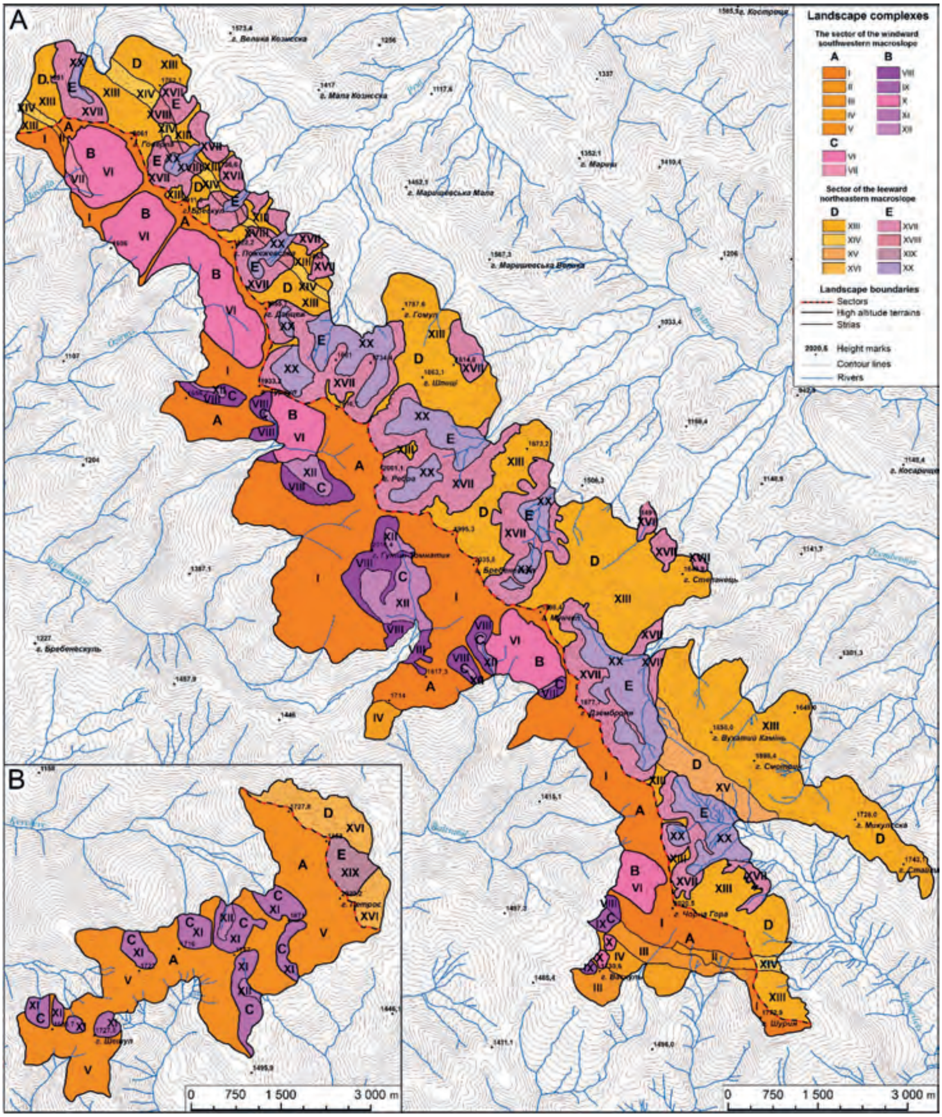

Fig. 6.2.3. Landscape map of the subalpine and alpine highlands of Chornohora (sectors, altitudes, strata): A) Hoverla-Shuryn section; B) Sheshul-Petros section (Karabiniuk, 2020a).

Table 6.2.1.

Sectors, Altitudes and striys of the Subalpine and Alpine Highlands of Chornohora (Legend to Fig. 6.8) (Karabiniuk, 2020a)

Sector	High-Altitude Area	S triya	Names of Natural Territorial Complexes
SECTOR of the southwestern windward heavily moistened macro slope drained by a parallel system of rivers with dominance of beech and spruce-fir-beech forests	A		***The softly convex denudational alpine-subalpine highlands formed mainly in conditions of coherent rock stratum are very cold (average temperature of the coldest month is -12 °C; warmest month +9 °C) and very humid (up to 2000 mm), with whitebush-blueberry-bilberry heathlands and pike-sitnik-fescue meadows on mountain-meadow-brown loam and mountain-peat-brown loam soils***
		I	Steeply sloping convex dome-shaped peaks, wavy crest surfaces and steep ridge slopes are consistent with the direction of dip of layers of non-calcareous mica coarse-layered and massive multi-grained grey sandstones, conglomerates and gravels with white-wood and juniper-bilberry heaths on mountain-meadow-brown loam and mountain-peat-brown loam soils
		II	The steep raked slopes of the spurs of the main ridge are composed of thin-coritic sandstone and mudstone flysch with interbedded greenish-grey mudstones and layers of siltstones, sandstones and marls with lying fescue and bluegrass and pike-white grasslands and spruce forests on mountainous meadow-brown soils
		III	The steep raked slopes of the main ridge spurs are composed of quartzite-like dark grey sandstones with thin layers of black and green mudstones with juniper-mountain-pine forest on mountainous meadow-brown soils
		IV	The steep raked slopes of the main ridge spurs are composed of limestone thinly laminated black mudstones with sandstone and silica layers with blueberry-juniper-mountain-pine forests on mountainous meadow-brown soils
		V	Steeply sloping convex dome-shaped peaks, wavy crest surfaces and steep ridge slopes are mainly coincident with the downfall of layers of non-calcareous mica coarse- and massively laminated grey sandstones and sandstone flysch packs with white-bowberry meadows and juniper-blueberry heaths on mountain meadow-brown soil

	B	***Concave nival-erosion subalpine highlands formed in conditions of coherent occurrence of rock stratum, cold (July +10...+12 °C, January -10 °C), very humid (over 1500 mm) with mountain-pine and green alder crooked forest on mountain-meadow-brown loam and mountain-peat-brown loam soils***	
		VI	The geographically disconnected system of steeply sloping amphitheatres of ancient firn fields of the southwestern exposure complicated by landslides with waterlogged stepped bottoms are coordinated with the direction of dip of layers of non-calcareous mica coarse-layered and massive multi-grained grey sandstones, conglomerates and gravelites with dominance of juniper-mountain-pine and green alder crooked forests on mountain peat-brown earth soils
		VII	The area of the steeply sloping amphitheatre of the ancient firn field is composed of thin-coritic sandstone-argillite flysch with interbedded greenish-grey argillites and layers of siltstones, sandstones and marls with mountain-pine forests on weakly skeletal mountain-peat-brown soils
	C	***The sharply concave glacial-exaration subalpine highlands formed mainly in the heads of rock stratum are cold (February -12 °C July +10 °C) and very humid (over 1500 mm), with waterlogged gully bottoms with deciduous and coniferous shrubs on mountain-meadow and mountain-peat-brown soils in combination with stony scree and bedrock outcrops***	
		VIII	A geographically disconnected system of heavily incised karsts and trough valley walls with very steep and steep walls mainly at the head of layers of non-calcareous mica coarse-grained and massive multi-grained grey sandstones, conglomerates and gravels with formations of deciduous and coniferous shrubs on mountain meadow-loamy soils
		IX	The geographically disconnected system of weakly incised karsts with steep walls is embedded in dark grey quartzite-like sandstones with thin layers of black and green mudstones with mountain-pine forest on mountain-meadow brown soils
		X	The geographically disconnected system of weakly cut karsts is embedded in thin-coritic black mudstones with sandstone and silica interlayers with pike-mountain pine forests on mountainous meadow-brown earth soils
		XI	Geographically disconnected system of karsts with very steep walls embedded in coarse- and massively layered, non-lime micaceous grey sandstones and sandstone flysch with dominance of juniper and green alder formations on mountain meadow-brown earth soils
		XII	Steep and declining wavy surfaces of loamy-boulder moraine and alluvial deposits with dominance of mountain pine, green alder and juniper formations on mountain peat and brown loam soils

Sector of the northeastern leeward macro-slope with a colder (by about 2°C) vegetation period than in the southwestern sector, lower (200-300 mm) annual precipitation, and dominated by spruce and beech-fir forests	D	***Softly convex denudational alpine-subalpine highlands formed at the heads of rock stratum, very cold (average temperature of the coldest month -12 °C; warmest month +7 °C) and very humid (up to 2,000 mm), with white bilberry-bilberry-blueberry heaths and pike meadows on mountain meadow-brown loam and mountain peat-brown loam soils***	
		XIII	Convex dome-shaped peaks and steep raked slopes are formed at the heads of layers of non-lime micaceous coarse-layered and massive multi-grained sandstones, conglomerates and gravels with blueberry-blueberry heaths and beechnut meadows on mountain meadow-brown soil and mountain peat-brown soil
		XIV	Steep ravine slopes and saddles are formed by thin-coritic sandstone-argillite flysch with white-bush and broom meadows on mountain meadow-brown soil
		XV	Steep hilly raked slopes are composed of limestone thinly laminated black mudstones and quartzite-like dark grey sandstones with fescue-bilberry heaths, spruce forests and mountain-pine crooked forests on mountain meadow-brown earth and mountain peat-brown earth soils
		XVI	Very steep raked slopes are formed at the heads of layers of non-calcareous micaceous coarse- and massively laminated grey sandstones and sandstone flysch, with blueberry-blueberry heaths and pike meadows on mountain meadow-brown soil
	E	***Sharply concave glacial-exaration subalpine highlands formed at the heads of rock stratum, cold (February -12 °C; July +8 °C), very humid (over 1,500 mm) with deciduous and coniferous shrubs on mountain-meadow and mountain-peat-brown soils in combination with stony scree and bedrock outcrops***	
		XVII	A geographically disconnected system of karsts with very steep and cliffy walls, embedded at the head of layers of non-calcareous micaceous coarse-layered and massive sandstones, conglomerates and gravels dominated by juniper, mountain pine and green alder on mountain-meadow-brown earth and mountain-peat-brown earth soils
		XVIII	Geographically disconnected steep and very steep walls of the karsts are embedded in a thin-coritic sandstone-argillite flysch with mountain pine formations and beech-bunchgrass meadows on mountain peat-brown loam and mountain meadow-brown loam soils
		XIX	The karsts with very steep and steep walls are laid at the head of layers of non-lime micaceous coarse- and massively laminated grey sandstones and sandstone flysch packs, with blueberry, juniper and green alder formations dominating on mountain meadow-brown soil
		XX	Strongly sloping undulating surfaces of loamy-boulder moraine and sedimentary rocky bottom of karsts with juniper-mountainous pine forests on mountain peat-brown soils

The sector of the upwind southwestern macro-slope covers 48.3 % of the Chornohora highlands' territory (38.9 km^2). It comprises three types of high-altitude areas, twelve types of landscape structures, forty-one types of complex tracts, and 154 types of sub-tracts and simple tracts. The largest area is the high-altitude zone of gently convex denudation alpine-subalpine highlands, mainly formed in conditions of coherent rock layers (Type A), covering an area of 25.6 km^2. Within the same sector, the remaining 12.3 km^2 of highlands are occupied by 124 areas of concave nival-erosion subalpine highlands formed in conditions of coherent rock layers (Type B), and sharply concave glacial-exaration subalpine highlands formed mainly at the heads of rock layers (Type C). The latter two terrains were shaped by powerful Pleistocene glaciations but differ in the complexity of their morphological structure.

Within the sector of the leeward northeastern macro-slope of the Chornohora highlands (46.6 km^2), there are two types of high-altitude areas, eight types of landscape structures, thirty types of complex tracts, and 122 types of sub-tracts and simple tracts. In terms of territory, the high-altitude area of the gently convex denudational alpine-subalpine highlands, formed at the heads of rock layers (Type D), takes a slight advantage, covering 23.5 km^2. It is represented by four types of landscape structures, nineteen types of complex tracts, and seventy-eight types of sub-tracts and simple tracts. The remaining 18.1 km^2 of this sector is occupied by the high-altitude terrain of the sharply concave glacio-excision highlands (Type E), which, in terms of landscape structure, consists of four types of landscape structures, eleven types of complex tracts, and forty-four types of sub-tracts and simple tracts (Karabiniuk, 2020a).

The intricate landscape structure of the Chornohora highlands leads to substantial landscape diversity, particularly in the denudation and glacial-exaration highlands. Taxonomic diversity (Ptax) at the altitudinal area level is 5 and at the strata level is 20. Meanwhile, topological diversity encompasses 64 and 126 habitats, respectively. It's worth noting that the study area exhibits an unevenly polidominant form of taxonomic differentiation (Karabiniuk, 2020a).

Regarding topological diversity or mosaicism (Rtop), the study area presents 64 habitats at the altitudinal level and 176 at the strata level. To put it simply, the five types of high-altitude areas are associated with 64 habitats, while the twenty types of landscape systems are connected to 126 habitats. The specific indicators of individual topological diversity and taxonomic representativeness (Ptax) differ significantly concerning altitude, as presented in Table 6.2.2.

Table 6.2.2.

Landscape diversity of the high altitude areas of Chornohora (Karabiniuk, 2020a).

Types of High-Altitude Areas	Individual Topological Diversity	Taxonomic Representativeness
Softly convex denudational alpine-subalpine highlands primarily formed under coherent rock layer conditions (Type A).	3 areas	31,8 %
Concave nival-erosion subalpine highlands formed in conditions of coherent rock layers (B)	23 areas	8,2 %
Sharply concave glacial-excavation subalpine highlands formed mainly in the heads of rock layers (C)	6 areas	8,3 %
Softly convex denudational alpine-subalpine highlands formed in the heads of rock layers (D)	17 areas	29,5 %
Sharply concave glacial-excavation subalpine highlands formed in the heads of rock layers (E)	16 areas	22,5 %

Significant variations in the sizes of landscape structures within the Chornohora highlands have resulted in marked differences in taxonomic representation at the structural level. The highest percentages are found in the following strata:

- Convex dome-shaped peaks and steeply inclined slopes, which are associated with non-calcareous mica-coarse layered and massive, multi-grained sandstones, conglomerates, and gravels (Stratum XIII) – 25.0 %.
- Steeply sloping convex dome-shaped peaks, undulating crest surfaces, and ridge slopes that align with the directional dip of non-calcareous mica-coarse layered and massive, multigrained grey sandstones, conglomerates, and gravels (Stratum I) – 19.9 %.
- A geographically fragmented system of pits characterised by very steep and steep walls, situated within non-calcareous mica-coarse layered and massive sandstones, enriched with conglomerates and gravelites (Stratum XVII) – 13.3 %.

Through the analysis of taxonomic representativeness, we have identified the type of taxonomic differentiation (DT) in the Chornohora highlands, which is characterised by an unevenly polydominant pattern at both the altitudinal area and landscape structure levels.

Changes in the current landscape structure and significant environmental threats are contingent on the levels of anthropogenic influence and climate change. The analysis of contemporary alterations in climatic conditions within the highlands of the Ukrainian Carpathians reveals an upward trend in air temperatures, including average, maximum, and minimum temperatures, along with modifications in precipitation patterns and annual distribution. For instance, data from the Pozhezhevska avalanche station indicates a notable increase in the average annual air temperature, up by +1.1 °C when compared to previous climatic norms, now averaging 3.8 °C (Karabiniuk and Markanych, 2020). This has implications for the transformation of vegetation cover and amplifies the perils to the conservation of relict Arcto-Alpine plant species in the highland landscape stratum. The overall rise in air temperatures also results in shifts in the altitudinal distribution of plant zones in the mountainous landscapes of the Ukrainian Carpathians, leading to an expansion of the natural upper limit of forests. This, in turn, has a direct adverse impact on the landscape diversity within the highland layer and is instrumental in diminishing its total area (Baitzar, 1994; Karabiniuk and Markanych, 2020).

The significant increase in air temperatures, exceeding 2 °C, is most pronounced in the highlands of Chornohora, Svydovets, and other mountain ranges during the summer period. This temperature rise leads to a general aridification of climatic conditions and has a notable impact on the functioning of highland landscape complexes. This trend is further exacerbated by a slight decrease in summer precipitation in the highlands of the Ukrainian Carpathians, which diminishes by 15-20 mm, whereas other seasons witness increased precipitation. The most substantial increases occur during spring and winter, with a rise of 88.3 mm and 70.2 mm, respectively (Karabiniuk and Markanych, 2020). Consequently, this heightened precipitation intensifies erosion and avalanche-erosion processes, contributing to the formation of catchment funnels, swales, avalanche niches, avalanche trays, and alpine landscape complexes. Additionally, the rising spring temperatures lead to rapid snowmelt, primarily on sun-exposed southern and southwestern slopes, resulting in increased erosion and disintegration of lengthy steep slopes, cirque bottoms, and trail valleys. These processes, in turn, give rise to the development of erosion furrows on the slopes, thereby complicating the morphological structure of the landscapes and indicating their ongoing erosion.

6.3. ECOLOGICAL THREATS AND ANTHROPOGENISATION OF HIGHLAND LANDSCAPE COMPLEXES

The subalpine and alpine highlands of the Ukrainian Carpathians are a unique exsolutioncombination of relict and distinctive landscape complexes, which are characterised by their limited distribution and significant scientific, environmental and economic importance. The complex landscape structure and growing anthropogenic impact in the context of climate change increase the threat of deterioration of the ecological state of the highlands.

One of the primary external indicators of landscape complex functioning and its role in shaping the ecological conditions in the highland landscape layer of the Ukrainian Carpathians is the occurrence of modern physical and geographical processes (Stadnytskyi and Kravchuk, 1970; Tikhanovych, 2016; Karabiniuk, 2020b; Karabiniuk et al., 2020, 2022a, 2022c). These processes exhibit diversity and manifest differently across various highland areas, depending on their specific geographic characteristics, landscape structure organisation, and geocomplex properties. Consequently, the active development of this range of physical and geographical processes significantly impacts the overall ecological conditions in different highland areas and influences their potential for effective utilisation.

Our landscape analysis of contemporary physical and geographical processes in the subalpine and alpine highlands of the Ukrainian Carpathians reveals a significant diversity and dynamism. For instance, within the Chornohora highlands, we have identified 1258 process development centres (PDs). The most prevalent (63%) among these are geological and geomorphological processes, specifically landslides, linear erosion, and landslips. Hydrometeorological processes (34%) rank second, with avalanches and waterlogging being the primary representatives. The remaining 3% are attributed to biotic processes, including the drying of shrubs such as mountain pine (Pinus mugo Turra), Siberian juniper (Juniperus sibirica Burgsd), and green alder (Alnus viridis (Chaix) DC.). In general, the highest intensity of manifestation within the highland tier of Chornohora is observed in landslides (4.2 units/ km^2), avalanches (3.6 units/ km^2), linear erosion (2.9 units/km^2), and rockfalls (2.4 units/km^2). Landslides (0.3 people/ km^2) and shrub drying (0.4 people/ km^2) exhibit the lowest intensity (Karabiniuk, 2020a).

Each alpine landscape complex exhibits a distinct set of adverse processes that reflect its unique characteristics and operational aspects. The structure and intensity of these processes are closely related to the origin of the landscape complexes (see Fig. 6.3.1). Within our study area, the highest intensity of negative processes, at 25.5 units/km^2, is observed in the old glacial-exaration highlands (B, D) covering an area of 24.8 km^2 (30.8 %). This category is predominantly affected by avalanches (7.5 units/ km^2), rockfalls (6.7 units/km^2), and screes (5.6 units/km2). The nival-erosion highlands, which span 6.6 km^2 (8.2 % of the total area), display a slightly lower overall intensity of negative processes (18.0 individuals/km^2). However, they are particularly susceptible to waterlogging (3.9 individuals/km^2) and shrub drying (0.8 individuals/ km^2). In contrast, the denudation highlands (A, D), with a collective area of 49.1 km^2 (61.0 %), exhibit nearly half the intensity (10.3 individuals/km^2) of negative physical and geographical processes. The most prevalent issues in this region are linear erosion and landslides, with respective intensities of 3.4 and 3.3 units/ km^2 (Karabiniuk, 2020a).

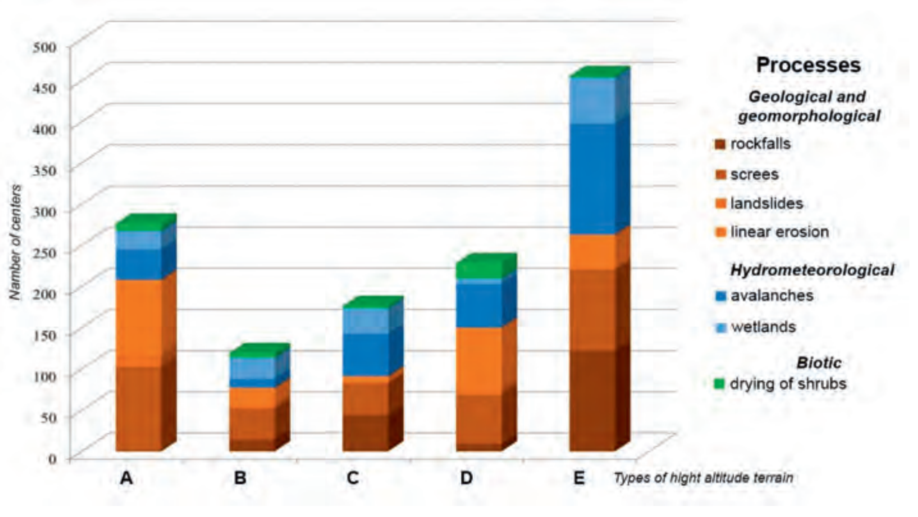

Fig. 6.3.1. The structure of modern negative physical and geographical processes in the high-altitude terrain of the subalpine and alpine highlands of Chornohora (Karabiniuk, 2020a)

A particular category of physical and geographical processes that holds a significant role pertains to biotic processes. These processes serve as vital indicators of environmental destabilisation, posing a threat to highland regions in the context of climate warming. In the highlands of the Ukrainian Carpathians, biotic processes are primarily represented by both sporadic and continuous shrub drying (Karabiniuk, 2020b). These manifestations are commonly observed in areas featuring mountain pine *(Pinus mugo Turra)* and Siberian juniper (*Juniperus sibirica* Burgsd.). They are predominantly found on the steep southern slopes, in the amphitheatres of ancient firn fields, and various other highland tracts. For instance, notable instances of continuous drying of mountain pine (*Pinus mugo* Turra) are documented in Chornohora, particularly in several pockets on the southern slopes of Mount Smotrych. In these areas, the affected regions exceed 250 to 300 square metres (Fig. 6.3.2).

Fig. 6.3.2. Continuous drying of mountain pine (Pinus mugo Turra) in the highlands of Chornohora in the tract of wavy raked slopes of the southern exposure with landslides (south of Smotrych) (Photo by the author)

The regions affected by the drying of Siberian juniper (*Juniperus sibirica* Burgsd.) are relatively smaller in size, but they are widespread across various sections of the highland landscape layer (Fig. 6.3.3). One of the most significant centres of such drying is situated in the upper reaches of the Hoverla River basin to the west of Hoverla Mountain, specifically within the tract of the ravine slopes on the southern exposure. This area spans approximately 100 square metres (Karabiniuk, 2020b). The progression of biotic processes in the alpine landscape tier of the Ukrainian Carpathians can be attributed to the prevailing conditions, including rising air temperatures, reduced summer precipitation, and the ongoing anthropogenic impact on alpine landscape complexes.

Fig. 6.3.3. Continuous drying of Siberian juniper (Juniperus sibirica Burgsd.) in the highlands of Chornohora in the tract of raked slopes of the southern exposure (west of Hoverla) (Photo by the author)

Significant environmental threats to the landscape complexes of the subalpine and alpine highlands of the Ukrainian Carpathians are intrinsically linked to the long-standing economic pressures placed upon this region. Historically, the primary economic activity in the highlands revolved around mountain meadow farming, particularly in the form of nomadic livestock practices (Karabiniuk, 2021a). This economic complex flourished in Zakarpattia Region, driven by the widespread availability of natural highland meadows and the rapid regeneration of vegetation cover, typical of the highland landscape tier, owing to ample rainfall and solar radiation. Consequently, robust mountain meadows have developed in various mountain ranges of Zakarpattia Region, such as Chornohora, Svydovets, Borzhava, among others. These meadows are exclusively utilised for grazing purposes, predominantly for sheep and cattle. For instance, within the Chornohora massif alone, there are currently around 20 substantial meadows where more than 3,500 cattle graze annually (Karabiniuk, 2020a).

One distinguishing feature of the highlands in Zakarpattia Region is the presence of expansive meadows, typically spanning an average of 300 to 400 hectares each. These meadows, such as Shumnieska, Harmaneska, Kozmieska, and Hropa, primarily serve as centres for sheep farming or adopt a combined approach, which involves both cattle and sheep grazing (Karabiniuk, 2020a). The specialisation of these meadows, along with the total number of livestock they support, significantly influences their impact on the highland landscape complexes. Over 83 % of the livestock primarily consists of sheep, necessitating extensive pasture areas for grazing (Karabiniuk, 2021a; Karabiniuk et al., 2022b). Consequently, the largest meadows can sometimes exceed 800 to 900 hectares in size, while approximately 17 % of the total livestock is dedicated to cattle grazing in the high mountain meadows of the region.

Long-term and intensive grazing in high mountain meadows and the surrounding areas has a profound impact on the vegetation cover of the subalpine and alpine highlands in the Ukrainian Carpathians. It adversely affects soil development, accelerates erosion processes, and contributes to the overall degradation of the ecological condition of highland landscape complexes. Consequently, due to continuous pasture pressure, low-productivity ecosystems such as sytnyk-bilobus, bilobus-bush, and bilobus wastelands have become prevalent, displacing the native meadow and shrub vegetation that once characterised these areas, and which were known for their high biodiversity (Malynovskyi, 2003; Karabiniuk, 2020a). Systematic livestock grazing in the high mountain pastures of Chornohora, Svydovets, and other mountainous landscapes in Zakarpattia Region has resulted in a noticeable reduction of biomass due to consumption, trampling, and removal from the biological cycle. This, in turn, affects the input of nutrients into the soil and alters the soil formation processes (Barannyk, 2018). Particularly in regions experiencing the highest economic pressures and where livestock grazing is constant, the ground cover is significantly impacted. A network of pathways, riddled with potholes and micro-disturbances, forms in these areas. Soil compaction becomes evident, and erosion processes intensify, contributing to the fragmentation of slopes and the degradation of already damaged vegetation.

In addition to the proliferation of low-yielding bromegrasses and Vorian bindweed within the herbaceous vegetation of the subalpine and alpine zones in the Ukrainian Carpathians, the historical management of meadows has resulted in the degradation of significant portions of the subalpine crooked forest and a retreat of the natural forest boundary (Krabiniuk, 2020a). In the past, shrubbery was cleared to make room for the expansion of mountain pastures, essential for poloninas. Consequently, this has led to significant disturbances in the structure and altitudinal positioning of plant belts in the meadows and adjacent regions. In certain highland areas, such as the vicinity of Rognieska, Sheshul, Konets meadows, and others, the original mountain pine (*Pinus mugo* Turra) and Siberian juniper (*Juniperus sibirica* Burgsd.) forests are no longer present. This, in turn, intensifies erosion and landslide processes in the highlands while destabilising mudflows at lower elevations within the mid-mountain landscape tier of the upper Tisza River basin.

Recreational and tourist activities represent a primary and progressively growing use of the landscape complexes in the subalpine and alpine highlands of the Ukrainian Carpathians, particularly in Zakarpattia. The rich landscape diversity, the aesthetics of glacial landforms, panoramic vistas, and the presence of unique natural recreational assets such as peaks, lakes, caves, and more, all contribute to the development of recreation and tourism in these highlands. However, it's essential to recognize that the mismanagement of this sector can significantly impact the ecological state of these landscape complexes. The highlands feature an extensive network of tourist routes and paths that traverse the watersheds of the highest mountain ranges, primarily leading to the main tourist attractions.

In the alpine landscape tier of the Ukrainian Carpathians, the most popular natural recreational sites, including the highest peaks and relict glacial lakes, face significant recreational and tourist pressure (Rozhko, 2000; Karabiniuk et al., 2020; 2021). The most visited site is Mount Hoverla, attracting over 15 000 to 20 000 visitors annually (Karabiniuk, 2020a). In general, the highlands of the Chornohora massif receive between 25 000 and 45 000 to 48 000 visitors each year. Over 75 % of them choose to explore the highlands during the summer, particularly in July and August. This concentrated influx of recreationists and tourists in a relatively short timeframe, especially in the most attractive highland areas, has a detrimental impact on the ecological condition of the landscape complexes. Hiking routes and trails bear the brunt of this pressure.

Field research conducted on tourist routes in Chornohora, specifically those leading to peaks like Hoverla, Petros, and Pip-Ivan, has revealed significant degradation due to the high number of summer climbers on these routes. The most popular hiking paths within the alpine landscape layer have reached the final (fifth) stage of degradation, characterised by the complete destruction of vegetation, the intensified development of erosion gullies, and the exposure of the mineral soil layer (Karabiniuk, 2020a). This degradation is primarily driven by the disruption of the natural processes within highland landscape complexes. Moreover, it exacerbates erosion processes, particularly in areas with a geological base of mudstones and surface slopes exceeding 9-12°.

Unauthorised overnight stays and prolonged visits by tourists exert a significant adverse influence on the environmental conditions within the highlands of the Ukrainian Carpathians. Of particular concern are the unique alpine lakes that originated during the final glacial deglaciation phase and now constitute prominent attractions within the highland landscape of the Ukrainian Carpathians. These lakes represent relics from ancient stages of mountain landscape evolution. However, the present recreational and tourist activities pose a potential threat to several of these lakes, especially those located along well-trodden tourist routes, in proximity to resorts or recreational centres, and amidst established tourist infrastructure.

Within the Zakarpattia Region, alpine glacial lakes are situated in the highlands of the Chornohora and Svydovets massifs at elevations exceeding 1450 metres. It was at these altitudes that the snow line extended during the Pleistocene glaciations. These lakes exhibit notable variations in terms of size, depth, and other morphometric characteristics (as shown in Table 6.3.1). The largest among these alpine lakes are Heresaska and Apshynets, boasting a water surface area of 1.2 hectares each. The substantial recreational and tourist activities in proximity to the lakes and their surrounding areas significantly heighten environmental threats. Such activities often result in littering, the cutting of shrubs, and various other unlawful actions by visitors to the highlands.

Table 6.3.1.

Morphometric parameters of alpine glacial lakes in the Zakarpattia Oblast (Mykytchak and others, 2010; Karpenko, 2006; Hera and Kysheliuk, 2013)

Lake Name	Absolute Lake Height, m	Water Mirror Area, ha	Length, m	Width, m	Maximum Depth, m
Chornohora Mountain Range					
Brebeneskul	1791	0,61	146,8	67,1	3,0
Bretskul	1739	0,1	39,1	12,0	1,4
Verkhnie Ozirne	1637	0,24	122,2	24,7	3,2
Nyzhnie Ozirne	1507	0,13	60,2	29,0	2,0
Svydovets Mountain Range					
Drahobratske	1600	0,12	55	24	1,2
Hereshaska	1577	1,2	125	110	1,2
Apshynets	1487	1,2	126	100	3,3
Vorozheska (Verkhnyie and Nyzhnie)	1460	0,7	95	95	4,5
	1445	0,2	76	28	1,9

Particularly noteworthy is Lake Brebeneskul, situated at an elevation of 1791 metres, making it the highest lake in Ukraine (Ecosystems of the Lentic..., 2014). It stands as one of the most precious natural recreational sites within the Chornohora massif's highlands and holds the distinction of being a hydrological natural monument. Nestled at the base of a deeply incised cirque of the southwestern slope, near the summit of Hutyn Tomnatyk (2016.4 metres), in the upper region of the Brebeneskul basin, this area is encompassed by the Carpathian Biosphere Reserve, a dedicated nature conservation zone. Nevertheless, insufficient regulation of recreational and tourist activities in the Chornohora, unmonitored overnight camping and prolonged stays, a lack of essential hiking equipment such as stoves, and the relatively low eco-consciousness of tourists and recreationalists all contribute to adverse impacts on these invaluable landscape complexes.

To assess the adverse environmental impacts of unregulated recreational and tourist activities in the highlands of the Ukrainian Carpathians, we conducted field surveys of the landscape complexes near Lake Brebeneskul (Karabiniuk et al., 2020). Our surveys revealed nine extensive areas with evidence of cutting, primarily affecting mountain pine (Pinus mugo Turra), as well as significant instances of littering. Moreover, we identified four sizable areas showing signs of trampling, with a combined area of approximately 2 hectares (Karabiniuk et al., 2020). Utilising ArcGIS 10.4.1 software tools, we generated a landscape map at a scale of 1:10,000, which delineates the primary degradation areas within highland natural territorial complexes resulting from intensive recreational and tourist activities (see Figure 6.3.4).

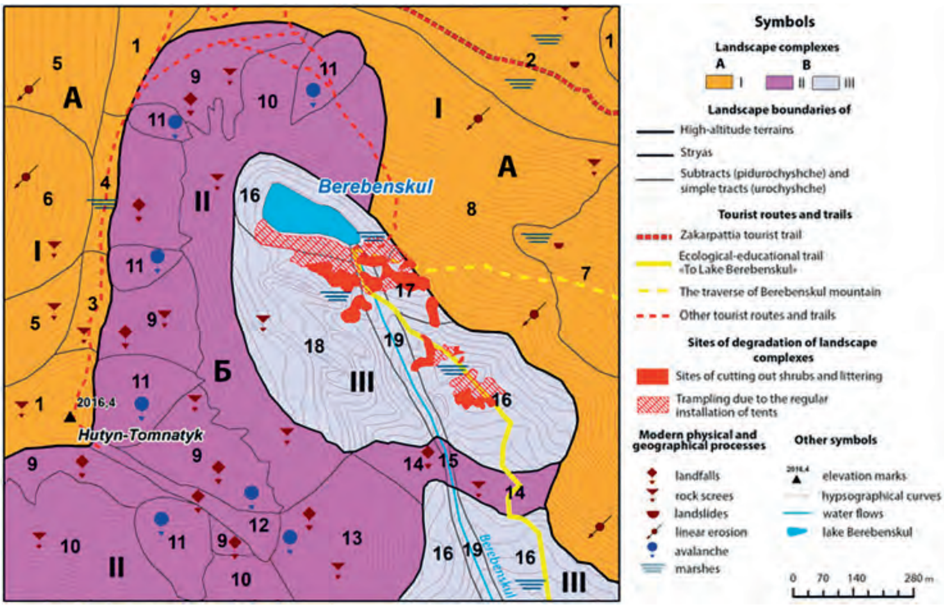

Fig. 6.3.4. Sites of degradation of natural territorial complexes of the subalpine and alpine highlands of Chornohora in the vicinity of Lake Brebeneskul (Karabiniuk et al., 2020).

The most significant environmental issue in the landscape complexes surrounding Lake Brebeneskul is the extensive cutting of mountain pine (*Pinus mugo* Turra) on an area of approximately 0.8 hectares (Karabiniuk et al., 2020). These activities result from the systematic cutting of shrubs, primarily for creating fires for cooking and heating in the absence of burners and other essential hiking equipment. During the field survey of the area, numerous pits were identified and mapped, with most measuring between 6×13 and 10×14 metres. Approximately 35% of these continuous cutting centres are concentrated within the sub-tract of the strongly sloping wavy section of the pit floor (see Fig. 6.3.5). The largest areas of mountain pine (*Pinus mugo* Turra) cutting, exceeding 10×18 metres in size, were observed in the tract of bedrock outcrops and the strongly sloping wavy section of the Brebeneskul cirque floor (refer to Fig. 6.3.6).

Figure 6.3.5. Cutting of mountain pine (Pinus mugo Turra) in the subtract of a strongly sloping wavy section of the Brebeneskul cirque floor (photo by the author)

Fig. 6.3.6. Cutting of mountain pine (Pinus mugo Turra) in a simple tract of bedrock outcrops in the bottom of the Brebeneskul cirque (photo by the author)

The environmental condition of the area around glacial Lake Brebeneskul is adversely affected by littering with household waste, including plastic and glass. This not only pollutes the environment but also poses dangers to tourists and recreationalists. The anthropogenization of the highland landscape complexes in the vicinity of the village of Brebeneskul in Chornohora is also experiencing intense trampling, resulting in the formation of a complex network of small trails. In areas with concentrated foot traffic, meadow and shrub vegetation are damaged, and various erosional processes occur. The cutting of mountain pine (*Pinus mugo* Turra) and other shrubs, along with trampling and the progression of trail degradation, leads to changes in soil moisture and structure. These activities affect the accumulation and erosion of snow under precipitation and impair the overall functioning and restorative properties of alpine landscape complexes (Karabiniuk et al., 2020).

To mitigate the recreational and tourist impact and anthropogenization of the highland landscape complexes in the Ukrainian Carpathians, it is advisable to establish designated recreation and rest areas for tourists along popular tourist routes. This will significantly reduce the ad hoc placement of tents. Additionally, it is crucial to establish restrictions on the maximum capacity of the main tourist routes and recreational facilities and regulate the number of visitors in accordance with established guidelines. An essential measure in organising recreational and tourist activities in highlands includes verifying whether tourists possess burners and cylinders and implementing modern video surveillance or photographic documentation of any violations, among other steps. Another vital action for improving the ecological condition of high mountain areas is the implementation of systematic cleaning and geo-environmental monitoring.

References:

1. Baitsar A. L. Verkhnia mezha lisu v landshaftnykh kompleksakh Ukrainskykh Karpat : avtoref. dys. na zdobuttia nauk. stupenia kand. heohr. nauk. : 11.00.01. [The Upper Boundary of the Forest in the Landscape Complexes of the Ukrainian Carpathians: PhD Thesis for the Degree of Candidate of Geographical Sciences: 11.00.01.] Kyiv, 1994. 21 s.
2. Barannyk A. V. Hirsko-luchno-burozemni hrunty Svydovetskoho i Chornohirskoho masyviv Ukrainskykh Karpat [Mountain-Meadow-Brown Soils of Svydovets and Chornohora Massifs of the Ukrainian Carpathians: PhD Thesis for the Degree of Candidate of Geographical Sciences]: avtoref. dys. na zdobuttia nauk. stupenia kand. heohr. nauk : Lviv, 2018. 20 s.
3. Hera Y. B., Kysheliuk A. V. Morfometrychni osoblyvosti ozernykh ulohovyn Chornohirsko-Svydovetskoho masyvu Ukrainskykh Karpat. Realii, problemy ta perspektyvy rozvytku heohrafii v Ukraini : Materialy Kh-IV-oi 199 studentskoi naukovoi konferentsii (m. Lviv, 24 kvitnia 2013 r.). [Morphometric Features of the Lake Basins of the Chornohora-Svydovets Massif of the Ukrainian Carpathians. Realities, Problems and Prospects for the Development of Geography in Ukraine: Proceedings of the XIVth 199th Student Scientific Conference] Lviv : LNU imeni Ivana Franka. 2013. C.165–175.
4. Ekosystemy lentychnykh vodoim Chornohory (Ukrainski Karpaty) [Ecosystems of Lentic Reservoirs of Chornohora (Ukrainian Carpathians)] / za red. T.I. Mykitchaka. Lviv: ZUKTs, 2014. 288 s.
5. Karabiniuk M. M., Kalynych I. V., Peresoliak V. Yu. Morfometrychni osoblyvosti reliefu landshaftiv Chornohora i Svydovets v mezhakh Zakarpatskoi oblasti. Naukovi zapysky Ternopilskoho natsionalnoho pedahohichnoho universytetu imeni Volodymyra Hnatiuka. [Morphometric Features of the Landscape Relief of Chornohora and Svydovets within the Zakarpattia Oblast.] Ser. Heohrafiia. 2017. Vyp. 43 (2). S. 10–19.
6. Karabiniuk M. M. Landshaftna dyferentsiatsiia nehatyvnykh fizyko-heohrafichnykh protsesiv u subalpiiskomu i alpiiskomu vysokohiri Chornohory (dilianka “Sheshul-Petros”). Fizychna heohrafiia i heomorfolohiia. [Landscape Differentiation of Negative Physical and Geographical Processes in the Subalpine and Alpine Highlands of Chornohora (Sheshul-Petros Area). Physical Geography and Geomorphology.] 2019a. Vyp. 3 (93). S. 7–17. DOI: https://doi.org/10.17721/phgg.2019.3.01
7. Karabiniuk M. M. Do pytannia zledeninnia landshaftu Chornohora v Ukrainskykh Kaparatakh (istorychnyi aspekt). Dovhoterminovi

sposterezhennia dovkillia : dosvid, problemy, perspektyvy : materialy Mizhnarodnoho naukovoho seminaru, prysviachenoho 75-richchiu z dnia narodzhennia B. P. Mukhy i 50-richchiu roboty Roztotskoho landshaftno-heofizychnoho statsionaru Lvivskoho natsionalnoho universytetu imeni Ivana Franka (Lviv-Briukhovychi, 10‒12 travnia 2019 r.). [To the Issue of Glaciation of the Chornohora Landscape in the Ukrainian Carpathians (Historical Aspect). Long-term Observations of the Environment: Experience, Problems, Prospects: Proceedings of the International Scientific Seminar dedicated to the 75th anniversary of B. P. Mukha and the 50th anniversary of the Roztotskyi Landscape and Geophysical Station of Ivan Franko National University of Lviv] Lviv : LNU imeni Ivana Franka, 2019b. S. 84–88.

8. Karabiniuk M. M., Shuber P. M. Zminy klimatychnykh umov u lisystomu serednohiri pivnichno-skhidnoho sektoru landshaftu Chornohora. Dovhoterminovi sposterezhennia dovkillia : dosvid, problemy, perspektyvy : materialy Mizhnarodnoho naukovoho seminaru, prysviachenoho 75-richchiu z dnia narodzhennia B. P. Mukhy i 50-richchiu roboty Roztotskoho landshaftno-heofizychnoho statsionaru Lvivskoho natsionalnoho universytetu imeni Ivana Franka (Lviv-Briukhovychi, 10‒12 travnia 2019 r.). [Changes in Climate Conditions in the Forested Middle Mountains of the North-Eastern Sector of the Chornohora Landscape. Long-term Observations of the Environment: Experience, Problems, Prospects: Proceedings of the International Scientific Seminar dedicated to the 75th anniversary of B.P. Mukha and the 50th anniversary of the Roztotskyi Landscape and Geophysical Station of Ivan Franko National University of Lviv] Lviv : LNU imeni Ivana Franka, 2019. S. 88–93.
9. Karabiniuk M. M. Pryrodni terytorialni kompleksy subalpiiskoho i alpiiskoho vysokohiria Chornohirskoho masyvu Ukrainskykh Karpat [Natural Territorial Complexes of the Subalpine and Alpine Highlands of the Chornohora Massif of the Ukrainian Carpathians: PhD Thesis for the Degree of Candidate of Geographical Sciences: 11.00.01.]: avtoref. dys. na zdobuttia nauk. stupenia kand. heohr. nauk : 11.00.01. Kyiv, 2020a. 21 s.
10. Karabiniuk M. M. Problema vsykhannia chaharnykiv ta yii vplyv na ekolohichnyi stan pryrodnykh terytorialnykh kompleksiv subalpiiskoho y alpiiskoho vysokohiria Chornohory. Konstruktyvna heohrafiia i kartohrafiia: stan, problemy, perspektyvy : materialy mizhnarodnoi naukovo-praktychnoi onlain-konferentsii, prysviachenoi 20-richchiu kafedry konstruktyvnoi heohrafii i kartohrafii Lvivskoho natsionalnoho universytetu imeni Ivana Franka (Ukraina, m. Lviv, 1‒3 zhovtnia 2020 r.). [The Problem of Shrubs Drying Out and Its Impact on the Ecological Status of Natural Territorial Complexes of the Subalpine and Alpine Highlands of Chornohora. Constructive Geography and Cartography: State, Problems, Prospects: Proceedings of the International Scientific and Practical Online Conference dedicated to the 20th anniversary of the Department of Constructive Geography and Cartography of Ivan Franko National University of Lviv] Lviv: Prostir-M, 2020b. S. 217–2020.

11. Karabiniuk M. M., Hnatiak I. S., Markanych Ya. V. Antropizatsiia tsinnykh pryrodnykh terytorialnykh kompleksiv subalpiiskoho y alpiiskoho vysokohiria Chornohory pid vplyvom rekreatsiino-turystychnoi diialnosti v okolytsiakh ozera Brebeneskul (Ukrainski Karpaty). Fizychna heohrafiia ta heomorfolohiia. 2020. [Anthropisation of Valuable Natural Territorial Complexes of the Subalpine and Alpine Highlands of Chornohora under the Influence of Recreational and Tourist Activities in the Vicinity of Lake Brebeneskul (Ukrainian Carpathians). Physical Geography and Geomorphology.] Vyp. 1-2 (99-100). S. 13–25. DOI: https://doi.org/10.17721/phgg.2020.1-2.02
12. Karabiniuk M. M., Markanych Ya. V. Dynamichnist klimatychnykh umov ta suchasni tendentsii yikhnikh zmin u pivnichno-skhidnomu sektori landshaftu Chornohora (Ukrainski Karpaty). Pryroda Karpat: naukovyi shchorichnyk Karpatskoho biosfernoho zapovidnyka ta Instytutu ekolohii Karpat NAN Ukrainy. [Dynamism of Climate Conditions and Current Trends of Their Changes in the North-Eastern Sector of the Chornohora Landscape (Ukrainian Carpathians). Nature of the Carpathians: Scientific Yearbook of the Carpathian Biosphere Reserve and the Institute of Ecology of the Carpathians of the National Academy of Sciences of Ukraine.] 2020. Vyp. №1(5) S. 58–70.
13. Karabiniuk M. M. Polonynske hospodarstvo u subalpiiskomu y alpiiskomu vysokohiri Chornohory: suchasnyi stan ta orhanizatsiia // Stiikyi rozvytok silskykh terytorii u konteksti realizatsii derzhavnoi ekolohichnoi polityky ta enerhozberezhennia : kol. monohrafiia [Polonyna Farming in the Subalpine and Alpine Highlands of Chornohora: Current Status and Organisation // Sustainable Development of Rural Areas in the Context of Implementation of State Environmental Policy and Energy Saving: a Collective Monograph] / za red. T. O. Chaika. Poltava : Vyd-vo PP «Astraia», 2021a. S. 203–2016.
14. Karabiniuk M. M. Rozvytok pryrodnykh terytorialnykh kompleksiv subalpiiskoho y alpiiskoho vysokohiria Chornohory u holotseni ta yikh suchasna struktura. Pryroda Karpat: naukovyi shchorichnyk Karpatskoho biosfernoho zapovidnyka ta Instytutu ekolohii Karpat NAN Ukrainy. [Development of Natural Territorial Complexes of the Subalpine and Alpine Highlands of Chornohora in the Holocene and Their Modern Structure. Nature of the Carpathians: Scientific Yearbook of the Carpathian Biosphere Reserve and the Institute of Ecology of the Carpathians of the National Academy of Sciences of Ukraine.] 2021b. Vyp. №1(6). S. 57–73.
15. Karabiniuk M. M., Burianyk O. O., Roman L., Karabiniuk Ya. V. Rekreatsiino-turystychna diialnist u Karpatskomu biosfernomu zapovidnyku: dynamika, suchasnyi stan ta problemy rozvytku. Liudyna ta dovkillia. Problemy neoekolohii. [Recreational and Tourist Activity in the Carpathian Biosphere Reserve: Dynamics, Current Status and Development Problems. Man and the Environment. Problems of Neoecology.] 2021. № 35. S.115–130. DOI: https://doi.org/10.26565/1992-4224-2021-35-11
16. Karpenko N. Osoblyvosti poshyrennia ozer v Ukrainskykh Karpatakh. Problemy heomorfolohii i paleoheohrafii Ukrainskykh Karpat i pryle-

hlykh terytorii. [Features of the Distribution of Lakes in the Ukrainian Carpathians. Problems of Geomorphology and Paleogeography of the Ukrainian Carpathians and Adjacent Territories.]2006. C. 82−87.

17. Kovaliukh N. N., Petrenko L. V., Tretiak P. R. Heokhronolohyia nyvalno-hliatsyalnыkh otlozhenyi srednehoria Ukraynskykh Karpat. Biuro komys. po yzuchenyiu chetvertychnoho peryoda. [Geochronology of Nival-Glacial Deposits of the Middle Carpathian Middle Range. Bureau of the Commission for the Study of the Quaternary Period.]1985. № 54. S. 113–118.
18. Kravchuk Ya. S. Alpiiskyi relief Ukrainskykh Karpat. Problemy heomorfolohii i paleoheohrafii Ukrainskykh Karpat i prylehlykh terytorii : Zbirnyk naukovykh prats, 2006.[Alpine Relief of the Ukrainian Carpathians. Problems of Geomorphology and Paleogeography of the Ukrainian Carpathians and Adjoining Territories: Collection of Scientific Papers] S. 3–18.
19. Malynovskyi K. A. Karpatski polonyny i polonynske hospodarstvo. Pratsi naukovoho tovarystva im. Shevchenka. Ekolohichnyi zbirnyk "Ekolohichni problemy Karpatskoho rehionu". [Carpathian Meadows and the Meadow Economy. Works of the Shevchenko Scientific Society. Ecological collection "Ecological Issues of the Carpathian Region".] 2003. S. 293–309.
20. Melnyk A. V. Ukrainski Karpaty: ekoloho-landshaftoznavche doslidzhennia: monohrafiia. [Ukrainian Carpathians: Ecological and Landscape Studies: a Monograph.] Lviv, 1999. 286 s.
21. Melnyk A. V., Karabiniuk M. M., Kostiv L. Ya., Senychak D. V., Yaskiv B. V. Pryrodni terytorialni kompleksy verkhivia baseinu richky Lazeshchyna v mezhakh Chornohory. Fizychna heohrafiia ta heomorfolohiia. [Natural Territorial Complexes of the Upper Lazeshchyna River Basin within Chornohora. Physical Geography and Geomorphology.] 2018. Vyp. 90 (2). S. 5–24. DOI: https://doi.org/10.17721/phgg.2018.2.01
22. Melnyk A. V., Karabiniuk M. M. Chynnyky formuvannia ta kryterii vydilennia vysokohirnoho landshaftnoho yarusu v Chornohori (Ukrainski Karpaty). Problemy heomorfolohii i paleoheohrafii Ukrainskykh Karpat i prylehlykh terytorii : zbirnyk naukovykh prats. [Factors of Formation and Criteria for the Allocation of the Highland Landscape Layer in Chornohora (Ukrainian Carpathians). Issues of Geomorphology and Paleogeography of the Ukrainian Carpathians and Adjoining Territories: a Collection of Scientific Papers.]2018. Vyp. 8. S. 24–41. DOI: http://dx.doi.org/10.30970/gpc.2018.08.2012
23. Mykitchak T. I., Rozhko I. M., Lenko O. V. Fizyko-heohrafichna ta hidrokhimichna kharakterystyka ozer ta ozerets masyvu Chornohora (Ukrainski Karpaty). Nauk. pratsi UkrNDHMI. [Physical, Geographical and Hydrochemical Characteristics of Lakes and Lakes of the Chornohora Massif (Ukrainian Carpathians). Scientific Works of UkrNDGMI.] 2010. Vyp. 259. C.231−244.
24. Miller H. P., Fedirko O. M. Karpaty Ukrainski. Heohrafichna entsyklopediia Ukrainy. [Ukrainian Carpathians. Geographical Encyclopedia of Ukraine.] Kyiv : Holovna red. URE im. P. M. Bazhana, 1990. T.2. C. 113–114.

25. Miller H. P., Fedirko O. M., Brusak V. P. Landshaftna dyferentsiatsiia terytorii KBZ. Bioriznomanittia Karpatskoho biosfernoho zapovidnyka. [Landscape Differentiation of the CBR Territory. Biodiversity of the Carpathian Biosphere Reserve.] Kyiv : InterEkoTsentr, 1997. S. 96–113.
26. Rozhko I. M. Rekreatsiina otsinka hirskykh pryrodno-terytorialnykh kompleksiv dlia potreb turyzmu (na prykladi Ukrainskykh Karpat) : avtoref. dys. na zdobuttia nauk. stupenia kand. heohr. nauk : 11.00.11 [Recreational Assessment of Mountain Natural and Territorial Complexes for Tourism Needs (On the Example of the Ukrainian Carpathians): PhD Thesis for the Degree of Candidate of Geographical Sciences: 11.00.11] Lviv, 2000. 22 s.
27. Stadnytskyi D. H., Kravchuk Ya. S. Heoloho-heohrafichni peredumovy rozvytku i poshyrennia suchasnykh stykhiinykh protsesiv v Ukrainskykh Karpatakh. Heohr. problemy Ukrainskykh Karpat i Podillia [Geological and Geographical Preconditions for the Development and Spread of Modern Natural Processes in the Ukrainian Carpathians. Geogr. Issues of the Ukrainian Carpathians and Podillia] : II zizd Heohr. t-va. URSR. Kyiv, 1970. S. 70–81.
28. Tykhanovych Ye. Ye. Poshyrennia i dynamika lavynnykh pryrodnykh terytorialnykh kompleksiv v Ukrainskykh Karpatakh : avtoref. dys. na zdobuttia nauk. stupenia kand. heohr. nauk : 11.00.01. [Distribution and Dynamics of Avalanche Natural Territorial Complexes in the Ukrainian Carpathians: PhD Thesis for the Degree of Candidate of Geographical Sciences: 11.00.01.] Kyiv, 2016. 20 s.
29. Karabiniuk M., Markanych Y., Burianyk O., Hnatiak I., Gostiuk Z. Methodical aspects of geoinformation analysis of landscape differentiation of modern negative geological and geomorphological processes in natural territorial complexes of the highlands of Chornohora (Ukrainian Carpathians). *International Conference of Young Professionals, GeoTerrace 2020* (December 7-9, 2020. Lviv, Ukraine). Lviv, 2020. Vol. 2020, P.1–5. DOI: https://doi.org/10.3997/2214-4609.20205709
30. Karabiniuk M., Kalynych I., Leta V., Mykyta M., Melnychuk V. Geological conditions of development and landscape differentiation of modern geological and geomorphological processes in the highlands of the Chornohora massif (Ukrainian Carpathians). *Geodynamics.* 2022a. Vol. 1(32). P. 64–79. DOI: https://doi.org/10.23939/jgd2022.02.064
31. Karabiniuk M., Melnychuk V., Romanko V., Radysh I., Kachailo, M. Pasture farming and its impact on the geoecological situation in the Rakhiv District of Transcarpathian Region. *16th International Conference Monitoring of Geological Processes and Ecological Condition of the Environment.* 2022b. Vol. 2022. pp. 1-5. DOI: https://doi.org/10.3997/2214-4609.2022580156
32. Karabiniuk M., Hostiuk Z., Burianyk O., Leta V., Terletska Ya. Mapping and geoinformation analysis of snow avalanche processes in geocomplexes of the subalpine and alpine highlands of the Chornohora (Ukrainian Carpathians). *International Conference of Young Professionals, GeoTerrace 2022.* 2022c. Vol. 2022. pp.1–5. DOI: https://doi.org/10.3997/2214-4609.2022590019

Environmental Issues of Zakarpattia. Manual / N. Kablak, Ya. Hasynets,
E 45 L. Felbaba-Klushyna, V. Mirutenko and others; Gen. Ed. prof. N. Kablak and prof. L Felbaba-Klushyna. – Uzhhorod : RIK-U, 2023. – 324+356 p.

ISBN 978-617-8276-79-9

The manual contains scientific materials devoted to the coverage of contemporary environmental issues of Zakarpattia. Considerable attention is paid to the peculiarities of its natural conditions. Emphasis is placed on the preservation of biodiversity in the face of climate change. While devising this textbook, the authors resorted to the analysis of literary sources as well as the findings of their own research. It will benefit school teachers, students and postgraduates of higher educational institutions majoring in natural sciences, employees of the nature reserve fund, and representatives of the authorities.

This manual was produced with the financial support of the European Union within the project HUSKROUA/1901/6.1/0075 "Environment for the Future by Scientific Education" (EFFUSE) of ENI CBC Programme Hungary-Slovakia-Romania-Ukraine 2014-2020. Its contents are the sole responsibility of NGO "Institute of Development of Carpathian Region" and do not necessarily reflect the views of the European Union.

UDC 502+504(477.87)

ENVIRONMENTAL ISSUES OF ZAKARPATTIA

Manual

Team of authors:

N. Kablak, Ya. Hasynets, L. Felbaba-Klushyna, V. Mirutenko, M. Vakerych, M. Balazh, I. Besehanych, A. Hiurtler, V. Leta, I. Kalynych, M. Karabiniuk, R. Kish, V. Klushyn, N. Kryvtsova, F. Kurtiak, O. Mateleshko, L. Miklovsh, M. Nychvyd, R. Ozymko, H. Popovych, V. Sabadosh, M. Savenko, Yu. Shpontak, O. Stankevych-Volosianchuk, Ya. Syvokhop, D. Tomenchuk

Author's correction

Font: Noto Serif. Offset paper. Offset printing. Format: 70x100/16.
Conditional printed sheets: 55,3. Order: No 156K. Circulation: 1000 copies.

The original layout was made and printed
by RIK-U LLC, 88006, Uzhhorod, 36 Karpatskoyi Ukrainy st.
Certificate of the subject of the publishing business:
DK No. 5040 dated January 21, 2016.