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PARTNERSHIP
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ENVIRONMENTAL ISSUES OF ZAKARPATTIA

Manual

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Manual

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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

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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.

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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/

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INTRODUCTION

The quality of life human beings have is closely related to the environment in which they live. The negative impact of the anthropogenic factor on the state of the environment in view of contemporary scientific and technological advancements, is significant and is constantly increasing. In some cases the scale of this impact exceeds the consequences of the largest disasters of natural origin. Such a reckless consumerist strategy, which society adheres to, results in a catastrophic environmental situation in all corners of the globe. Global environmental problems, the reduction of the regenerating capacity of renewable natural resources – all these stimulate the rapid mindset change of the world community, the formation of the environmental consciousness and environmental culture. In this regard, environmental education is becoming the new priority area of scientifically grounded education.

Among the mechanisms for achieving the ultimate goal – the formation of an environmentally aware citizen, educated in view of sustainable development principles, is the implementation of scientific projects aimed at shaping an ecumenical worldview. One of these is the scientific project implemented within the framework of the Joint Operational Program Hungary-Slovakia-Romania-Ukraine 2014-2020 «Environment For the Future by Scientific Education» – EFFUSE. The project represents a joint Slovak-Ukrainian environmental and educational campaign focused on highlighting the state of the environment (in particular, the water pollution growth rates) and the need to protect water resources in the border regions (Slovakia-Ukraine). The partners of the project are Pavol Jozef Šafárik University in Košice, (Košice, Slovakia), State University «Uzhhorod National University» (Uzhhorod, Ukraine) and the non-governmental organisation «The Institute of Development of the Carpathian Region» (Uzhhorod, Ukraine). The aim of the project is to raise the level of environmental awareness of young people (schoolchildren, students) and the public by creating and distributing eco-educational materials and organising eco-educational activities.

The experience of the countries of the European Union proves that the state of the environment can be improved based on the principles of the country's environmental policy, a high level of environmental culture and an active position of society in nature conservation activities. However, a high level of environmental culture is not possible without an appropriate level of environmental education, which must be carried out on the grounds of comprehensiveness and continuity. Raising the level of society's education based on the integration of knowledge and modernization of the entire educational space with elements of sustainable development is vitally important.

Chapter 1.

GEOGRAPHICAL LOCATION: FEATURES AND NATURAL CONDITIONS OF ZAKARPATTIA

1.1. OROGRAPHIC AND HYDROGRAPHIC FEATURES *(V. Sabadosh)*

The territory of Zakarpattia Oblast covers 12.8 thousand km^2, which accounts for approximately 2% of Ukraine’s total land area. As of January 2022, the region's population was estimated to be around 1,244,000 people, constituting roughly 3% of Ukraine's total population (Chyselnist naselennia…,.2022). With a population density indicator exceeding 97 people per 1 km^2, the region is considered densely populated.

To characterise the relief, hydrography, weather and climate conditions, and soils of the Zakarpattia oblast, information from several publications has been used (Anuchin, 1956; Nature of the Ukrainian Carpathians, 1968; Nature of Zakarpattia Oblast, 1981; Natural ..., 1987; Ukrainian ..., 1988; Geographical ..., 1990; Ecological ..., 2022).

Relief

There are two types of relief within Zakarpattia Oblast: mountainous and lowland. The majority of the region (approximately 80% of the territory) is occupied by mountain ranges, intermountain valleys, and valleys, and belongs to the Carpathian mountain country. Around 20% of Zakarpattia's territory lies within the Middle Danube lowland (this portion of the region is referred to as the Transcarpathian plain or the Transcarpathian or Prytysian lowland in various literary sources).

The Carpathian mountain country, as a well-defined natural region of the Earth's surface, is commonly divided orographically into three parts: the Western Carpathians, the Eastern (or Forested) Carpathians, and the Southern Carpathians (or Transylvanian Alps). The term "Ukrainian Carpathians" is used to denote the part of the Eastern Carpathians that lies within the territory of Ukraine.

The Carpathian arc extends from the Morava River in the Czech Republic and Slovakia (in the west) to the Iron Gate Gorge on the Danube River, located at the border of Serbia and Romania (the gorge separates the Southern Carpathians from the northwestern foothills of the Balkan Mountains). The length of the entire mountain system is about 1500 km, with its width varying significantly in different areas: in the northwest, it measures 240-250 km, in the central part, it spans 100-120 km, and in the southeast, it extends to 350-430 km (Fig. 1.1.1). The highest mountain massifs are the High Tatras (Slovakia, with Gerlachovski Štit at 2655 m above sea level) and the Fegerash Mountains (Romania, with Moldovianu at 2543 m above sea level). Hoverla stands as the highest point in the Ukrainian part of the Carpathians, reaching 2061 m above sea level.

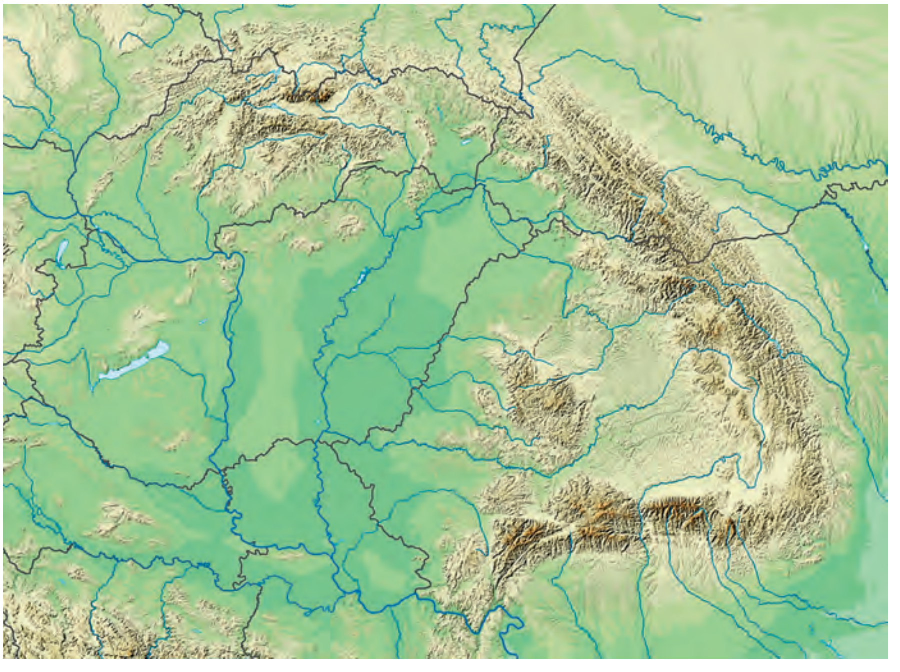

Fig. 1.1.1. Relief of the Carpathians
(Carpathian relief location map. Source: Wikipedia)

The Ukrainian Carpathians, in terms of their spatial arrangement, extend from the northwest to the southeast. Within Zakarpattia, they consist of three longitudinal strands of mountain ranges and a separate mountain group in the southeast. The main geomorphological units in this region are the Watershed Range (Watershed Carpathians), the Polonyna Range (Polonyna Carpathians), the Vihorlat-Hutyn Range (Volcanic Carpathians), the Chornohora Massif (Chornohora, with Hoverla being the highest peak at 1,936 m above sea level), and the Rakhiv (or Marmaro) Massif (also known as Rakhiv Mountains or Hutsul Alps, with the highest peak being Pip Ivan Marmarosky at 1,936 m above sea level).

Additionally, smaller-scale elements of the region's relief include volcanic island mountains such as Chorna Hora (located near the town of Vynohradovo at 568 m above sea level), Shalanka (372 m above sea level), a mountain range near the town of Berehove (Berehove Dribnohirya) reaching 350 m above sea level, and another near the village of Kosyno at 200 m above sea level. The watershed Carpathians are formed by the Verkhovyna watershed ridge and the Watershed Gorgans. The Gorgan ridges are highly fragmented, narrow, and characterised by steep slopes and rocky ridges. In the western part of Gorgans, several mountain ranges are distinguished, including Smerek (1,425 m above sea level), Ozerna (1,500 m above sea level), Kamianka (1,579 m above sea level), Kanch (1,583 m above sea level), and Strymba (1,723 m above sea level), which are intersected by the headwaters of the Tereblia, Rika, and Mokryanka rivers. The eastern Gorgans are higher in elevation compared to the western ones. Among them, the following peaks stand out: Popadia (1,742 m above sea level), Chorna Kleva (1,723 m above sea level), and Bushtul (1,693 m above sea level).

River valleys divide the strands of the Polonyna and Vyhorlat-Hutyn ridges into separate massifs. As parts of the Polonyna ridge, the massifs of Rivna (with a peak at 1478 m above sea level), Borzhava (Stiy mountain, 1777 m above sea level), Krasna (Syhlansky mountain, 1560 m above sea level), and Svydovets (Blyznytsia mountain, 1880 m above sea level) are distinguished. The Vyhorlat-Hutyn Range is divided into the Makovytsa massif (at 976 m above sea level), Syniak (1018 m above sea level), Velykyi Dil (Buzhora mountain – 1085 m above sea level), Tupyi (Velykyi Sholes, 878 m above sea level), and Hutyn (within the borders of Ukraine, the section of this massif is also called the Shayan or Avash mountains; the height here is about 900 m above sea level). The Vyhorlat-Hutyn ridge represents a strand of extinct volcanoes with remnants of volcanic cones. The southern slopes of these mountains gradually give way to a strip of foothills that converge towards the Zakarpattia lowland .

Important elements of the relief of Zakarpattia Oblast are the valleys and canyons of an almost plain character between the ranges of mountain massifs. The valley of Volovets-Mizhhiria Verkhovyna separates the Watershed Carpathians from those of the Polonyna Carpathians. The Yasinia basin lies between the Chornohora and the Vododil, as well as the Polonyna ridges. These two areas of lower relief are part of the so-called Central Carpathian lowering, which covers the adjacent regions of Ukraine.The Berezne-Lypchansk (also known as Tsyrok-Borzhavska, Turyanska, Zavyhorlatska) valley of the Inner Carpathian lowering separates the Polonyna Range from the Vyhorlat-Hutynsk. Three basins are distinguished here: Perechyn, Svaliava, and Khust. The vast Irshava basin is located between the bend of the Vyhorlat-Hutyn ridge and its southern spurs (the Hat volcanic chain). Intermountain lowerings are connected to the lowland of Zakarpattia by river valleys.

The Zakarpattia lowland is divided into two parts. The western part, which is larger in area (also known as the Chop-Mukachevo lowland), has elevations ranging from 100 to 160 m above sea level. The eastern part (Solotvyno, or Khust-Solotvyno, or Verkhnia Tysa basin, located east of the city of Khust) in the plain area has elevations ranging from 150 to 300 m above sea level.

Hydrography

The Ukrainian Carpathians are situated on the Main European Watershed, where rivers flow into the Baltic and Black Seas. The river network of Zakarpattia Oblast belongs to the Tysa basin, one of the largest tributaries of the Danube, which carries its waters into the Black Sea. Only the upper reaches of the Tysa River basin is located within the territory of Zakarpattia; here, its right-bank tributaries predominantly flow from the northeast to the southwest.

Zakarpattia Oblast possesses a dense river network, with more than 9,000 rivers spanning a total length of almost 20,000 km. The average density of rivers in the region (over 1.5 km/ km^2) is the highest in Ukraine. Only four rivers in the region are more than 100 km long – Tysa, Latorytsia, Uzh and Borzhava. Additionally, there are 152 rivers over 10 km in length. The combined area of water bodies, including rivers, canals, lakes, and ponds, exceeds 15 thousand hectares.

According to their regime, the rivers of the region are divided into two groups: mountain (their catchment area covers 75% of the territory of the region) and foothill-plain. The mountain regime is characteristic mainly for the upper and middle sections of the larger rivers in the region. For instance, the Black Tisza and Bila Tisza are completely mountainous, while the Tysa itself remains only in the section up to the village of Velykiy Bychkiv. The Kosivska and Shopurka rivers are entirely mountainous, whereas the Teresva is only up to the village of Dubove, the Tereblia up to the village of Drahovo, the Rika up to the village of Berezovo, the Borzhava up to the village of Dovhe, the Latorytsia up to the city of Svaliava, and the Uzh up to the city of Uzhhorod. The lower reaches of most rivers, as they flow through the Zakarpattia lowland, exhibit a foothill-plain hydrological regime.

The river runoff constitutes the primary component of the region's water resources. Approximately 60% of the precipitation contributes to the formation of river runoff, while the remainder evaporates. In an average water year, about 8 km^3 of water flow from the territory of the region.

The rivers of the region have a mixed nature of nutrition – the largest share falls on rainwater (about 40% of the annual flow), and snow and soil nutrition account for approximately 30% each. The water content of rivers varies significantly throughout the year. In summer, rainfall prevails, in autumn – rain and soil, in winter – meltwater, and in spring – snow and rain. A characteristic feature of the distribution of runoff is the presence of river floods during most of the year and a vague spring flood (flooding). Throughout the year, up to 20 or more peaks of water level rise are possible, with the largest occurring in spring due to melting snow and in June during periods of heavy rains. On average, 8-10 floods are observed per year, with up to 4 resulting in flooding of the floodplain. During these floods, the water level rises by 1-2 m, and the water rushes from the mountains to the plains with great speed, carrying pebbles and even large stones with it.

The surface runoff on the territory of the flat Zakarpattia lowland is slowed down due to small differences in elevations and the insignificant depth of river valleys, which leads to waterlogging. Spills are accompanied by an increase in the groundwater level.

During the flood period, 50-70% of the river flow is formed. In the dry season, even the largest rivers of Zakarpattia become very thin (up to a depth of 0.8-1.2 m) and narrow, and lowland rivers have a very slow current.

For comparison, we present the survey characteristics of three large rivers of the region. A tributary of the Tysa, **the Tereblia River** originates on the slopes of Horhan at an altitude of 1,080 m above sea level. The length of the river is 91 km, and the catchment area is 750 km^2. In the upper part, it flows from north to south in a very narrow and deep valley. Near the village of Synevyr, the Tereblya river turns southeastward, and its 10-kilometer section in the Central Carpathian Depression extends to the village of Kolochava. The river valley in this part is up to 1 km wide and narrows to 0.3 km downstream. Only below the village of Dragovo and up to its confluence with the Tysa, the Tereblia Valley in the Solotvyno Basin expands to 2-3 km. The main tributaries of the Tereblya are Ozeryanka, Sukhar, and Velyka Uholka.

Latorytsia is the largest river in the western part of Zakarpattia. It originates on the slopes of the Verkhovyna watershed ridge near the Veretsky Pass at an altitude of about 800 m above sea level. The length of Latorytsia within the region is 144 km (total length – 191 km; near Chop, the river crosses the border with Slovakia and flows into the Bodrog River – the right tributary of the Tysa). The catchment area is 4,900 km^2 (the total catchment area is 7,860 km^2).

Above the town of Svaliava, the valley of Latorytsia cuts across the Polonyna Carpathians, and here it is narrow (up to 1 km). Just below the village of Chynadiyevo, the river valley widens to 2-2.5 km, reaching the Zakarpattia lowland. Most of the tributaries fall on the upper and middle reaches of the Latorytsia. The largest of them are Vicha, Svalyavka, Pynia, Vyzhnytsia, and Stara.

The **Uzh River** flows in the northwestern part of Zakarpattia Oblast. It originates on the Vododilnyi Ridge near the Uzhotsky Pass with two sources (Uzh and Uzhok) at altitudes of 1,250 and 1,000 m above sea level. The length of the river within the region is 107 km (the total length of the Uzh is 23.7 km). Here, the continental climate is most pronounced. In the mountain basins, where the summer is colder due to the altitude and the north-easterly winds, the expression of continentality of the climate is slightly weaker.

The territory of Zakarpattia has sufficient moisture, with even the driest places in the region receiving an average annual precipitation of not less than 530-640 mm. In areas of the greatest moisture, precipitation levels reach 1400-1600 mm in the mountains, 800-1000 mm in the foothills, and 620-700 mm in the lowlands. The western slopes are particularly well-moistened.

The Uzh River flows for a distance of 133 km within the region (total length – 2010 km, it crosses the border with Slovakia near the city of Uzhhorod, and there it flows into the Laborets river – the right tributary of the Latorytsia River). The catchment area is 2010 km^2 (total catchment area – 2750 km^2). In the upper reaches, up to the village of Velykyi Bereznyi, the Uzh valley is very narrow with high steep slopes, and the banks are covered with boulders. Between Velykyi Bereznyi and Perechyn, the mountains decrease in height, and the river valley widens to 0.8-1.2 km. Below, in the Volcanic Carpathians, the Uzh river resumes the characteristics of a mountain river, and only near Uzhhorod, upon reaching the Zakarpattia lowland, does its valley expand to 2-3 km.

In the southeastern part of the region, in the ancient glacial kares (cup-shaped relief forms on the slopes near the tops of the mountains) on Svydivka and Chornohora, there are also several small high-altitude lakes, namely Apshynets, Hereshaska, Nesamovyte, Brebenjeskul, and Maricheyka.

Weather and Climate Conditions

The climate of the Zakarpattia Oblast is moderately continental, softened by the influence of the Atlantic Ocean. The Carpathians create obstacles to the movement of air masses, strengthen continentality, contributing to greater warming of the air in summer and greater cooling in winter. The mountainous relief determines and forms a very colorful mosaic of local climates. Often, two points located only a few kilometers from each other have quite different weather and climate conditions. The region is characterized by mountain and valley winds with daily periodicity. At night, when the peaks cool faster than the lower slopes and foothills, cold air rushes into the valleys. Therefore, even on the hottest summer days, there are almost never stuffy nights here. As the sun rises, the air in the valleys becomes lighter due to heating, as a result of which there is a daily upward movement of air. Mountain-valley winds are especially noticeable in the valleys of the Uzh and Latoritsa rivers.

In the annual course of temperatures in the region, the minimum is everywhere in January, and the maximum is in July. With the rise in the mountains, the climate becomes harsher. The warm season in the mountains is 2 months shorter than in the lowlands. The average annual temperature in the city of Uzhhorod is 9.3°C, and in the mountains, it is only 3°C (Turbat). An annual isotherm of 8.5°C separates the lowland and the strip of the southern foothills from the colder mountainous regions. The mountainous part of Zakarpattia is divided by the temperature conditions along the Rika river into approximately two equal parts: western and eastern. The western part of the region is warmer; here, the average annual temperatures range from 8.5 to 4.5°C. The eastern part is colder, with average annual temperatures ranging from 6.5 to 3.0°C. The annual amplitude of average monthly temperatures reaches its greatest range in the Transcarpathian lowland, with Khust experiencing a difference of 25.1°C. Most of the rainfall occurs in the summer, accounting for more than 60% of the total precipitation, particularly in June. Conversely, in the mountains, the peak of rainfall is observed in July. During the winter months, precipitation is limited, ranging from 40 to 90 mm per month. On the plain, approximately half of the December precipitation falls as rain, with winter conditions typically setting in only in January. Snow cover on the plain rarely persists for more than one month. It is not uncommon for snowfall to occur and subsequently melt four to five times during the winter, with each snowfall lasting approximately 10 to 12 days. In the mountains, snowfall can occasionally occur in June, and at higher altitudes, it may persist even into July.

Informative indicators of the agroclimatic features of a specific territory encompass the sum of active temperatures (SAT) and the quantity of moisture supply during the period characterized by an average daily temperature exceeding 10°C. Based on the interplay of these parameters, the region reveals a clear distinction into three distinct districts.

The lowland area encompasses the entirety of the Transcarpathian lowland, representing a notably warm region within the larger area. The sum of active temperatures (SAT) in this area ranges from 3000-3020°C, with some locations experiencing values as high as 3600°C. The warmest locality is the district of Vynohradovo, which boasts a significantly elevated level of heat supply. In Muzhievo of Berehovo district, SAT values range between 3500-3550°C.

The duration of the period with temperatures exceeding 10°C spans 180-195 days, while temperatures surpassing 15°C persist for 120-140 days. The frost-free period, contingent on topography, spans between 170-190 days. Moisture levels vary across the district, with the northern areas experiencing sufficient moisture, moderate levels in the south, and intermittent droughts in some years. Precipitation during the period with an average daily temperature above 10°C ranges from 380-460 mm, with a yearly total of 530-700 mm.

The foothills area encompasses the entire foothills region, the southern section of the Vyhorlat-Hutyn ridge, as well as the Irshava and Khust valleys. Due to the diverse terrain within this area, climatic conditions exhibit a notable degree of diversity. In general, it represents a warm region, with temperatures ranging from 2700-3000°C. However, the thermal regime of the Irshava and Khust basins exhibits more pronounced continental characteristics compared to the foothills. The duration of the period with an average daily air temperature above 10°C in the foothills extends for 180-185 days, and temperatures exceeding 15°C persist for 115-130 days. The frost-free period spans an average of 170-175 days. Furthermore, the foothill area is classified within the zone of excessive moisture.

The mountain area encompasses the largest portion of the region's territory, spanning almost the entire Vyhorlat-Hutyn ridge, excluding its southwestern part, as well as all other mountainous areas situated to the northeast of it. Climatic conditions in the mountainous region undergo significant changes with increasing altitude above sea level. In January, there is a decrease in air temperature by 0.4°C for every 100 meters of vertical elevation, and in July, a decrease of 0.7°C occurs. Valleys represent the warmest locations within the mountainous region. In specific valleys, particularly those situated on the bottom, southern, and western slopes, the sum of active temperatures (SAT) ranges from 2400-2470°C. The annual atmospheric precipitation in the mountainous area totals approximately 1000 mm on open slopes and up to 800 mm in valleys. The climate of the middle zone is characterized as moderately cold, with temperatures spanning between 1000-1600°C, and a period of active vegetation lasting 90-100 days. In the upper zone, the climate is cold, with a period featuring temperatures exceeding 10°C lasting only 60-88 days, with temperatures in this period ranging from 600-1000°C. The average annual rainfall in the upper zone reaches 1500 mm.

1.2. NATURAL CONDITIONS AND ANTHROPOGENIC FACTORS AFFECTING THE HYDROECOLOGICAL STATE OF THE UPPER REACHES OF TISZA RIVER BASIN *(V. Leta, M. Karabiniuk)*

The Tisza River is the main watercourse of Zakarpattia Region and the largest tributary of the Danube (Fig. 1.2.1). The total length of the river is 966 km, of which 2658 km is within Ukraine (Zakarpattia Region). The total area of the Tisza basin is 157.2 thousand km^2, including 13.8 thousand km^2 within Ukraine. The basin is formed on the territory of five countries: Serbia, Slovakia, Hungary, Romania and Ukraine. Within Ukraine, the Tisza basin occupies the administrative boundaries of Zakarpattia Region, which makes the basin unique and its borders with neighboring countries transboundary (NPMTRB, 2012).

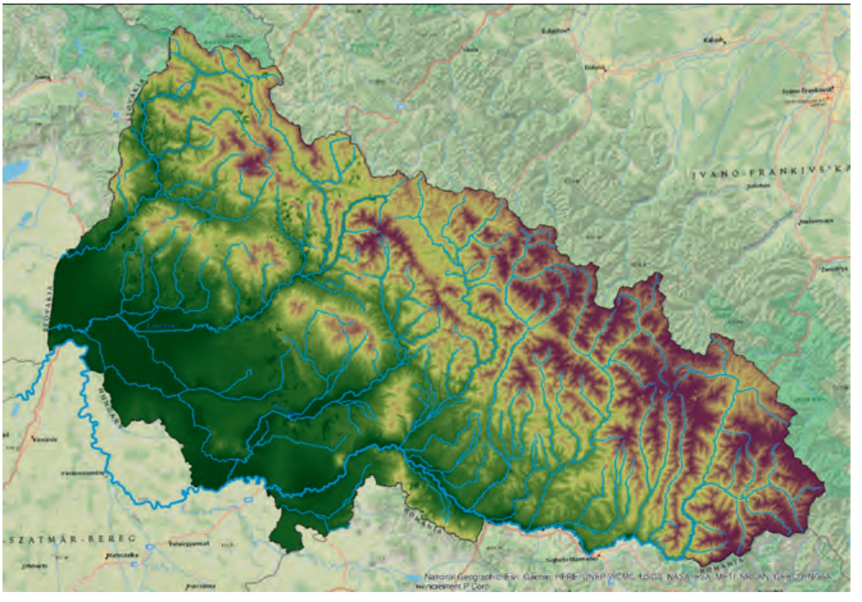

Figure 1.2.1. River Network of Zakarpattia Region (compiled by the author)

The peculiarity of the Ukrainian part of the Tisza basin is that it is located in the headwaters, where both the flow and the chemical composition of the water are formed. These factors are important to consider when conducting various studies, both within Ukraine and downstream of the Tisza. In particular, it is necessary to account for the flood regime of the waters of the Tisza River and its tributaries within Zakarpattia Region. Additionally, the presence of volcanogenic deposits in the explored polymetallic deposits and ore occurrences in this region, owing to the high solubility of sulfate compounds of heavy metals (such as chromium, cadmium, copper, etc.), is one of the reasons for the increased concentrations of these elements in the surface waters of the Tisza river basin system within Ukraine.

Surface runoff within Zakarpattia Region is formed by the following right tributaries of the Tisza River: Teresva, Tereblia, Rika, Borzhava, which flow into the Tisza river, as well as the Uzh and Latorytsia rivers. The latter flow into the Laborec and Bodrog rivers in the Slovak Republic, and then into the Tisza River in Hungary.

Transit surface runoff comes from Romania, the main rivers Viseu and Iza (flowing into the Tisza river above the Tyachiv city) and from Slovakia, the Ulichka and Ubl'a rivers (flowing into the Uzh river above the Zarichevo village).

In the Tisza basin of Zakarpattia Region, there are approximately 9,426 rivers and streams with a total length exceeding 16.1 thousand km, and the river network density averages 1.7 km/km^2. Most watercourses in the region have an average length of about 2 km and a catchment area of 1.2 km^2. Only 152 rivers are longer than 10 km, of which 4 exceed 100 km in length: Tisza, Latorytsia, Uzh, and Borzhava (NPMTRB, 2012).

The Ukrainian part of the Tisza basin includes both the Upper Tisza (from the source of the Black Tisza to the village of Badalovo, 7 km downstream from the mouth of the Borzhava) and the Middle Tisza (the basins of the Latorytsia, Uzh, and Tisza rivers from the village of Solovka to the village of Solomonovo). From its source to its outlet on the territory of Hungary, the Tisza River either flows entirely through Ukraine or forms the state border with Romania.

The total length of the Tisza River in Ukraine is 265 km. From the source of the Black Tisza to the village of Dilove in the Rakhiv district, the Tisza flows through the territory of Ukraine and then forms the state border between Ukraine and Romania for 61 km. Below the town of Tyachiv the river flows through Ukraine again to the village of Vylok. Downstream, the river forms the state border between Ukraine and Hungary for 25 km, and below the village of Badalovo, the Tisza flows through Hungarian territory for 77 km. From the village of Solovka to the villages of Solomonovo and Zahony, the Tisza serves as a border. The length of this section is 19 km. Downstream, the river forms the state border between two European countries – Slovakia (right bank) and Ukraine, with a total length of about 5 km. The river then flows through the territory of Hungary and Serbia.

The results of the water quality analysis and assessment presented below pertain to the surface waters of the Upper Tisza River basin, encompassing the transboundary section of the Tisza River, commencing at the confluence with the Romanian tributary of the Tisza, the Viseu River, and extending from the village of Dilove in Rakhiv district. The transboundary section of the Tisza River traverses the Ukrainian-Romanian border in Rakhiv and Tyachiv districts, spanning a total length of 64 km (NPMTRB, 2012).

Within Ukraine, the tributaries of Tisza in the border area consist of the following rivers: Kosivska and Shopurka in the Rakhiv district, and Apshytsia, Teresva, and Tyachivskyi in the Tyachiv district. The Romanian tributaries of the Tisza, on the other hand, include the rivers Viseu, Iza, and Sepince. The identification of the surface water massif was undertaken by Ukrainian and Romanian hydrological experts as part of international cooperation between the water management basin authorities of Ukraine and Romania. This collaborative effort resulted in the determination of the average length of the cross-border section of the Tisza River, which currently stands at 64 km.

The Tisza River originates at an altitude of approximately 460 m due to the confluence of two mountain rivers, namely the Black Tisza and the White Tisza (Table 1.2.1). These headwaters of the Tisza are situated in close proximity to Rakhiv, the highest mountain town in Ukraine. The Tisza basin encompasses a total area of 157,186 km², constituting 19.2% of the Danube basin, rendering it the largest tributary in this regard. The primary focus of our study pertains to the upper reaches of Tisza region, which encompasses the cross-border area within the Rakhiv district, extending from the upper reaches of the Black Tisza river basin to Velykyi Bychkiv.

The study area encompasses the entirety of Rakhiv district and a substantial portion of the Tyachiv district within Zakarpattia Region, Ukraine. This region's intricate morphometry is characterised by the presence of the Chornohora and Svydovets mountain ranges, as well as a segment of the Marmarosh massif, encompassing the Yasinia and Solotvyno depressions. The topographical complexity of this mountainous terrain also exerts an influence on the density of the river network, prominently featuring the Black Tisza and White Tisza Rivers. These two rivers converge near the town of Rakhiv, situated at an elevation of 460 m, giving rise to the Tisza River. Additionally, a multitude of tributaries, including the significant Kosivska, Shopurka, Apshytsia, Teresva, and others, contribute to the Tisza's flow. The degree of relief fragmentation diminishes downstream from the origin point of the Black Tisza. The study area covers approximately 3420 km², and the Tisza River section stretching from Rakhiv to Tyachiv spans 80 km, with around 60 km forming the state border between Ukraine and Romania.

Table 1.2.1.

The main morphometric parameters of the rivers studied in the upper reaches of the Tisza within Ukraine (compiled from data provided by the Zakarpattia Regional Hydrometeorological Centre).

River	Length, km	Area, km²	Slope, m/km
Black Tisza	49	567	19
White Tisza	28	489	10
Tisza	80/265	3420/12777*	3.6/1.4*

Notes. * – within the study area / within the entire Zakarpattia Region of Ukraine

The territory of the studied upper reaches of the Tisza river basin area is characterised by a significant distribution of aquifers within the structure of Paleogene sediments in the Ukrainian structural-folding system. Sandstone aquifers are also prevalent within shale strata, providing water for domestic and drinking water purposes. In relatively developed alluvial complexes, hydrocarbonate waters are concentrated in river valleys, which contribute to river flow during low water periods and serve various economic needs.The hydrogeological conditions of the area are marked by the presence of a single quaternary aquifer, composed of hard sandy loam with up to 40 % gravel and pebbles. Groundwater is free water (gravitational water) and is replenished by the infiltration of precipitation. Groundwater levels in this aquifer vary from 0.5 m to 4.0 m (NPMTRB, 2012).

In the context of climate change, the examination of the current state and alterations in the quality of surface waters holds considerable significance. This is due to the profound modifications in the characteristics of the natural environment, which, in turn, engender changes in the broader framework of environmental protection, the resilience of natural resources to anthropogenic exploitation, conservation principles, and more. Within the Tisza river basin, there is a notable prevalence of intensive developments related to a complex of contemporary physiographic processes. The manifestations and extents of these developments may undergo alterations in the face of climate change. Similarly, the upper Tisza river basin region is marked by the vigorous evolution of a complex of contemporary physiographic processes, the appearances and scopes of which could also shift in response to climate change. Concerning the environmental scenario and surface water contamination, processes such as landslides, mudflows, floods, and others exert the most significant impact on water quality and its primary hydrochemical parameters. These processes contribute to substantial quantities of solid runoff (soil) enriched with elements such as iron (Fe), manganese (Mn), and heavy metals including copper (Cu), zinc (Zn), chromium (Cr), and lead (Pb). Furthermore, these processes influence turbidity, water transparency, nutrient levels, and the oxygen regime of the surface water in the studied rivers.

The hydrological regime of the rivers within the upper reaches of the Tisza basin

The Tisza River is recognized as the source of the Black Tisza, which boasts a greater length and catchment area in comparison to the White Tisza (see Table 1.2.2). The river basin is entirely situated within the southwestern macro-slope of the Ukrainian Carpathians. Upon the confluence of the Black Tisza and White Tisza rivers above the city of Rakhiv, the water content of the Tisza increases, and its narrow river valley takes a southward orientation towards the Romanian border. Subsequently, below the village of Dilove, located at the border with Romania, the river alters its course from the left bank of the Viseu River and flows through a narrow gorge in a northwesterly direction, eventually reaching the village of Velykyi Bychkiv.

Table 1.2.2.

Hydrographic characteristics of the main rivers in the Tisza River basin (compiled from the data provided by the Tisza River Basin Water Resources Management).

River Name	Falls into	Distance from the mouth of the main river, km	River Length, km		Catchment Area, km^2	
			Entire	within Ukraine	Entire	within Ukraine
Tisza (with Black Tisza)	Danube	1218	966	265	157186	12777
Black Tisza	Tisza	913.5	50	50	567	567
Bila Tisza	Tisza	913,5	26	26	489	489
Viseu	Tisza	886,1	79,1	0	1580	0
Kosivska	Tisza	876,6	43,1	43,1	157	157
Shopurkra	Tisza	871,9	41,4	41,4	286	286
Iza	Tisza	856,5	80,0	0	1300	0
Sepyntsya	Tisza	838,5	18,0	0	149	0
Teresva	Tisza	835,4	56	56	1220	1220
Tereblya	Tisza	818,1	91	91	750	750
Rika	Tisza	793,0	92	92	1240	1240
Borzhava	Tisza	729,3	106	106	1360	1360
Latorytsya	Bodroh	90	191	144	7860	2900
Uzh	Laborets	-	133	106	2750	2010

The Black Tisza stands as one of the primary watercourses in the Rakhiv district, and it serves as the source of the Tisza river near the city of Rakhiv. Given the mountainous terrain that encompasses the entire Black Tisza basin, commencing with its origin in the Svydovets mountain range, the river valley exhibits a distinctly mountainous regime and structure. The elevation drop from the source to the mouth amounts to 800 m, resulting in the presence of rapids and waterfalls throughout the entire course of the Black Tisza. The river also maintains a rapid flow, particularly registering speeds of up to 1.5 m per second during low-water periods and up to 4.5 m per second during floods. Characterized by a V-shaped valley, the river valley width varies from 50 m in the upper reaches to 300 m downstream, accompanied by steep and at times precipitous banks, which can reach heights of up to 10 m (Khilchevskyi, 2016).

The subsequent major tributary of the Tisza within the Rakhiv district is the White Tisza. This river originates on the slopes of Chornohora, where the Stohivets and Balzatul Rivers converge. Similar to the Black Tisza, the White Tisza exemplifies a characteristic mountain river, measuring a mere 28 km in length and featuring a narrow, gently winding V-shaped valley. The river's channel seldom widens beyond 20 m. Owing to its swift flow, the elevated banks are frequently subjected to erosion, necessitating additional measures for reinforcement (Khilchevskyi, 2017).

The Shopurka River serves as a right tributary of the Tisza River and is formed through the confluence of the Mala Shopurka and the Serednya Rika. The Shopurka stands out from other Tisza tributaries due to the unique characteristics of its lower valley, which can extend to a width of up to 300 m, featuring a meandering and branching channel that, in certain sections, reaches up to 40 m in width. The slopes exhibit steep gradients of 20-40 degrees in the upper reaches, gradually lessening downstream. Along the course of the Shopurka, one can frequently encounter rapids and islands. Notably, the Shopurka basin encompasses the villages of Kobyletska Poliana and Velykyi Bychkiv, which, in comparison to other settlements in the Rakhiv raion, have shown more advanced economic activities (Leta, 2016).

The Kosivska (Kisva) river also serves as a right tributary of the Tisza River. It runs parallel to the Shopurka River and originates on the slopes of Svydovets, which, in turn, defines the mountainous characteristics of the river’s hydrological regime and the morphometric parameters of its basin. The river valley exhibits a slightly winding course, resembling a gorge in some sections with a width of up to 4 m. The floodplain of the Kosivska River is present only in specific areas along its course (Leta, 2019).

The Lazeshchyna river originates in the Petros and Hoverla intermountain area and represents a left tributary of the Black Tisza. Similar to previous instances, the hydrological regime and the V-shaped valley structure classify this river as a mountain river, characterized by extremely steep slopes and a rapid flow. The Lazeshchyna's channel features slight meandering, branching, and rapids, with a floodplain primarily observed in the lower reaches of the river (Leta et al., 2019).

The Tisza river serves as the primary body of surface water within the Rakhiv district and is partitioned into two segments, distinguished by variations in the river valley's characteristics and the river's water regime parameters. The first segment commences at the confluence of the Black Tisza and the White Tisza, terminating at the village of Velykyi Bychkiv. In this segment, the Tisza River exhibits hydrological and morphometric characteristics typical of mountainous regions. Here, the Tisza courses through a narrow and deep valley, flowing southward until it meets the Romanian tributary, Viseu, near the village of Dilove. Beyond this point, the river undergoes a transformation, unveiling a broad floodplain, extending up to 500 m in width, and changing its course to the northwest. The Tisza riverbed is slightly sinuous, sometimes empties, and occasionally forms islands, while the banks rise to heights of up to 6 m. The river itself reaches widths of up to 40 m. Notably, the river's depth increases significantly downstream, ranging from 0.5 m on the rifts in the upper reaches to 5 m within the backwaters. Additionally, it's of significance that the border demarcating Romania and Ukraine originates in the village of Dilove, near the confluence of the Viseu, following the course of the Tisza River. This aspect enhances the scientific appeal of any studies related to the Tisza including those focusing on hydroecology (Leta, 2017; NPMTRB, 2012; Technical Report, 2009).

Table 1.2.3.

Information on the composition of observations at hydrological stations within Rakhiv district (compiled by the Zakarpattia Regional Hydrometeorological Centre)

№	The river is a hydropost	Periods for which data on the main elements of the water body regime are provided			Catchment area, km²	Mark "0" of the post schedule, m BS
		characteristic water levels	characteristic water discharge rates	characteristic sediment flow rates		
1	Black Tisza – Yasinia	1947-2018	1956-2018	-	194	648,5
2	Black Tisza – Bilyn	1946-1988	1946-1988	1968-1988	540	492,12
3	White Tisza – Lugy	1947-2018	1955-2018	-	189	602,05
4	White Tisza– Roztoky	1955-1988	1955-1988	1968-1988	473	482,93
5	Tisza – Rakhiv	1946-2018	1947-2018	1951-2017	1070	431,73
6	Tisza – Dilove	1946-1988 2010-2018	1956-1988	-	1190	345,96
7	Kosivska – Kosivska Polyana	1963-2018	1963-2018	-	122	406,77
8	Shopurka – Kobyletska Polyana	1947-2018	1954-2010 2017-2018	-	240	389,06
9	Tisza – Velykyi Bychkiv	1946-2018	2017-2018	-	1700	294,78

In the mountainous terrain of Rakhiv and Tyachiv districts, several factors, including the amount of precipitation, geological structure (characterised by a lack of aged aquifers, high rock fracture, rock infiltration capacity, substantial debris, and limited soil cover), surface fragmentation, steep slope gradients, and the low catchment accumulation capacity, play a decisive role in shaping the river runoff of the Tisza and its tributaries (Lukianets, 2004). According to Lukianets' research, the average annual runoff has been increasing over the past decades (Lukianets, 2004).

The Tisza river and its tributaries in the mountainous part of Zakarpattia Region are characterised by a pronounced flood regime. The most powerful floods in the region are triggered by intense (heavy) rains between May and October, as well as during the winter snowmelt, brought on by warm Atlantic air masses and thaws. Flooding can also result from a substantial overall rise in springtime air temperatures and accelerated snowmelt, further exacerbated by significant rainfall (Vyshnevsky, 2003; Water Fund, 2007; Schwebs, 2003).

Nevertheless, determining the time interval of spring floods in the upper Tisza River's rivers is challenging due to significant variations in the hydrological regime and meteorological features from year to year. An analysis of the period 1981-2016 reveals distinct patterns, with some years characterised by clear high spring floods and low floods (1986, 2000, 2002, 2013), others marked by low floods and sharp fluctuations (1997, 1998, 2001, 2008, 2014, 2015), and still others showing alternating high floods throughout the year (1985, 1987, 2004, 2011, 2016) (refer to Figures 1.2.2 to 1.2.4) (Leta, 2021).

The hydrological regime of the rivers, which includes spring floods, summer-autumn low water, and winter low water, significantly influences the sources of river feeding, resulting in variations in the chemical composition of water. In essence, the hydrological regime plays a crucial role in shaping the hydrochemical regime.

The rivers in the upper reaches of the Tisza are characterised by flooding resulting from snowmelt during winter thaws, frequent spring rains, and intense precipitation in the summer and autumn (May-October). At the Tisza-Rakhiv hydrological station, covering a catchment area of 1070 km^2, the average long-term water discharge is 25.4 m^3/s. The highest recorded water discharge was 938 m^3/s on 5th March 2001, while the lowest was 1.14 m^3/s on 2nd February 1963 (Leta, 2021).

During periods of low summer and autumn water levels, as well as low spring floods, the Tisza River experiences minimal water levels. Paradoxically, the most catastrophic floods also transpire in the summer and autumn, primarily driven by intense rainfall. It's worth noting that the amplitude of level fluctuations can vary from 3.1 m to 6.8 m (Leta, 2021). In contrast, water levels in the Tisza River and its tributaries exhibit instability during the winter period due to frequent thaws and rains.

The mountainous region of Zakarpattia Region experiences intensive snowmelt, often accompanied by periodic rains, resulting in elevated river water levels. Consequently, spring flooding typically occurs during the latter half of March and early April, sometimes unfolding in multiple stages. During high floods, water levels can surge by 150-200 cm per day, while low floods lead to more gradual increases of 5-15 cm per day (Zakarpattia Regional Hydrometeorological Centre). At the Tisza River hydrological station in Rakhiv, the highest recorded water level during the period from 1950 to 2016 was 575 cm, observed on 5th March 2001 (Zakarpattia Regional Hydrometeorological Centre). Notably, even in years with average water conditions, the spring season consistently witnesses elevated water levels (Leta, 2021).

Floods in the basin's rivers primarily result from frequent precipitation events (165-175 days annually). However, flood formation typically commences when daily precipitation exceeds 20 mm. During exceptionally heavy downpours, characterised by rainfall exceeding 100 mm, floods reach catastrophic levels. In such instances, water levels surge in mountainous areas by 2-4 m, in foothill regions by 5-6 m, and in the Tisza River, by 6.5-9.5 m. Consequently, floodwaters rapidly drain from mountain watercourses into river valleys, leading to extensive flooding. This inundation spans a 15-60 m width in the mountainous zone, 115-500 m in the foothill zone, and extends to 2500 m in the plains. The steep terrain profiles contribute to flash floods, during which water levels can elevate by 1.5-2.5 m within just 3-4 hours (Leta, 2021).

An analysis of long-term data on precipitation and the hydrological regime in the Tisza River basin reveals that the most significant increases in water levels and flows are characteristic of autumn and winter floods (refer to Figures 1.2.2 to 1.2.4). These floods, which typically constitute 20-30% of the total annual flood count, have a mixed origin and primarily occur during the colder months. In addition to these cold-season floods, there are warm-season floods, spanning from April to November, resulting from sudden heavy rainfall.

Minimum water flows occur in both warm and cold seasons. The first minimum typically transpires in September-October and is linked to a significant reduction in precipitation. The second minimum emerges in January-February when surface runoff is absent, and groundwater reserves are depleted. In mountain rivers across the basin, stable summer low water conditions are observed in 20% of cases, while stable winter low water conditions prevail in 40% of cases. The summer low water phase commences in June and July and extends into early November, lasting on average for 100-160 days. On the other hand, the winter low water phase concludes in February-March, with an average duration of 45 to 80 days.

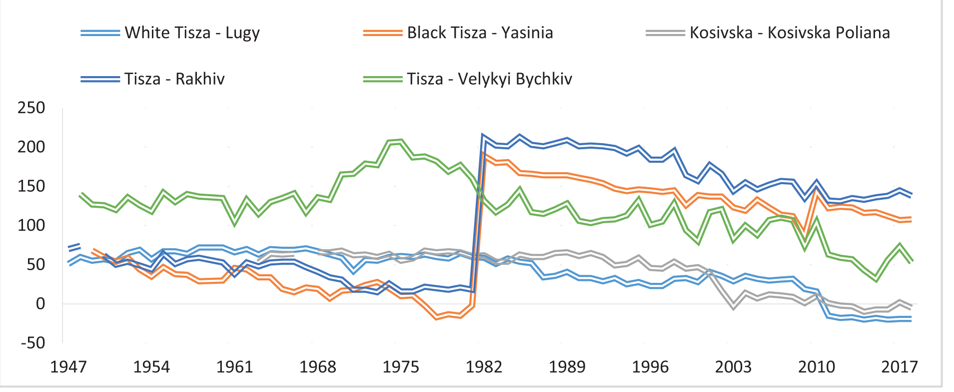

Fig. 1.2.2. Dynamics of water levels by annual averages, cm (compiled by the Zakarpattia Regional Hydrometeorological Centre)

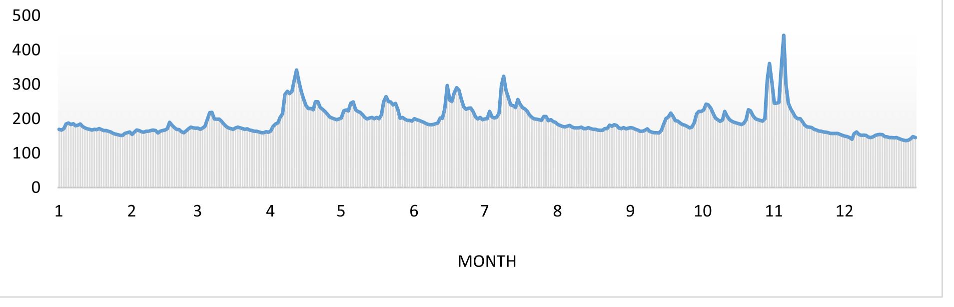

Fig. 1.2.3. Dynamics of water levels in the Tisza River (Rakhiv) during 1998 (high-water year), cm (compiled by the Zakarpattia Regional Hydrometeorological Centre)

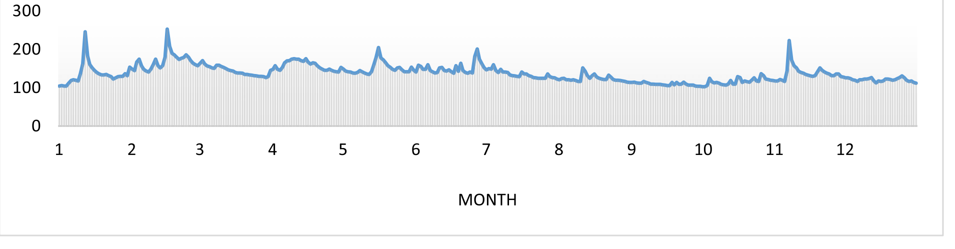

Fig. 1.2.4. Dynamics of water levels in the Tisza river (Rakhiv) during 2016 (average water year), cm (compiled from the materials of the Zakarpattia Regional Hydrometeorological Centre)

The minimum flow characteristics are the average monthly flow (30-day periods with the lowest flow) and the minimum average daily flow in summer, autumn and winter. The minimum average monthly flows of 95%

availability are mainly used as a reference for the design of hydroelectric power plants, reservoirs, and ponds, and the minimum average daily flows of 95% availability are used for the design of water supply facilities for settlements and industrial enterprises.

Similar to the water level indicator, water discharge exhibits a consistent pattern in the observation series (see Figure 1.2.5). Minor variations can be attributed to differences in precipitation, topographic characteristics, and underlying surface conditions. Over the period spanning 1946-2017, the highest water discharge was documented during the March 2001 flood, reaching a peak of 938 m^3/s, while the average long-term discharge remained at 25.4 m^3/s.

The highest average long-term runoff levels in the studied part of the Tisza basin for the period 1981-2017 are observed in the Kosivska river (Kosivska Poliana village) and the Shopurka river (Kobyletska Polyana village). This can be attributed to elevated precipitation levels and the catchment area's height. It's also noteworthy that there has been an increase in the average long-term values of water discharge and the water flow module compared to previous studies (NPMTRB, 2012; Obodovsky, 2017). The only exceptions are the data from the hydrological stations on the Black Tisza river (Yasinia village) and the Kosivska river (Kosivska Poliana village), which indicate a slight decrease in average annual water discharge and runoff module over the past decades.

Table 1.2.4.

Average flow characteristics of the rivers in the upper reaches of the Tisza river basin (for the period 1981-2017) (compiled from the materials of the Zakarpattia Regional Hydrometeorological Centre)

№	River – Hydropost	Average long-term values	
		$Q_{average}$ m^3/s	$M_{average}$ $l/s\ km^2$
1	Black Tisza – urban-type village Yasinia	4,68	24,14
2	Black Tisza – village Bilyn*	13,1	24,3
3	White Tisza – village Lugy	5,25	27,8
4	White Tisza – village Roztoky*	14,5	30,7
5	Tisza – city of Rakhiv	26,06	24,35
6	Tisza – village Dilove*	32,7	27,5
7	Kosivska – village Kosivska Polyana	4,59	37,65
8	Shopurka – village Kobyletska Polyana*	8,51	35,5

*-1981-1988 pp.

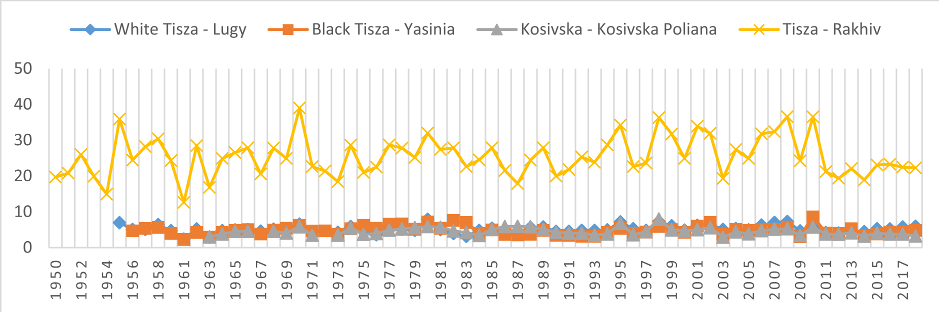

Fig. 1.2.5. Dynamics of water discharge by annual average, m³/s (compiled from the materials of the Zakarpattia Regional Hydrometeorological Centre)

In the high-water year of 1998, except for the White Tisza River (Lugy village), autumn runoff predominated, with maximum values occurring in November. Conversely, in 2016, the influence of spring flooding on the flow distribution is notably evident. The allocation of runoff between warm and cold periods also exhibits variations. For instance, the mild winter and April floods in 2016 resulted in a prevalence of runoff during the cold season. In 1998, the period of the lowest winter low water mark with the least runoff was distinctly discernible, whereas in 2016, we observe a more balanced intra-annual distribution of runoff (refer to Tables 1.2.5 to 1.2.6).

Table 1.2.5.

Intra-annual distribution of runoff (by months of 1998) in the Tisza basin rivers, % (compiled from the materials of the Zakarpattia Regional Hydrometeorological Centre)

River – Hydropost	Months											
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Tisza – city of Rakhiv	3,43	2,76	4,57	15,50	11,22	11,66	12,58	4,08	4,93	12,19	14,24	2,85
Black Tisza – village Yasinia	2,04	2,09	2,36	16,33	13,31	11,72	11,09	5,30	7,26	12,35	13,76	2,40
White Tisza – village Lugy	3,20	3,21	3,58	16,08	14,71	12,60	14,55	3,57	4,31	8,27	12,60	3,33
Kosivska – village Kosivska Polyana	3,36	2,88	5,09	15,24	8,82	8,26	8,95	3,40	5,15	11,53	24,43	2,89

Table 1.2.6.

Intra-annual distribution of runoff (by months and seasons in 2016) in the rivers of the Tisza basin, % (compiled from the materials of the Zakarpattia Regional Hydrometeorological Centre)

River – Hydropost	Months											
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Tisza – city of Rakhiv	7,93	15,97	9,72	13,03	11,44	11,19	7,43	5,11	2,67	3,83	8,46	3,22
Black Tisza – urban-type village Yasinia	7,79	13,93	8,69	12,89	12,95	13,94	8,58	4,72	2,58	3,40	8,39	2,15
White Tisza – village Lugy	5,08	12,13	9,15	15,24	11,93	12,47	7,68	5,85	3,50	5,03	8,07	3,87
Kosivska – village Kosivska Poliana	9,21	17,03	10,84	15,51	12,04	10,51	5,46	3,91	2,04	2,36	7,55	3,54

Riverbed processes and deformations

An essential aspect of river network functioning and development, under the influence of varying external environmental factors, including climate, involves riverbed processes such as erosion, sediment transport, and accumulation. The vigorous evolution of these processes in different parts of the river valley leads to modifications in the river channel's configuration, resulting in alterations to its morphology and morphometric parameters. Riverbed processes in the mountain river basins of Zakarpattia Region exhibit unique manifestations, which arise from the complex geological and geomorphological characteristics of the region, as well as the distinctive features of the hydrological regime, river feeding, and other natural and anthropogenic factors (Hydrometeorological conditions, 2005).

The primary driver behind the occurrence and progression of riverbed deformations is the dynamic structure of water flow, which induces riverbed erosion, sediment transport, and accumulation (Hydrometeorological conditions, 2005). The water content of the stream and its carrying capacity are contingent on the moisture regime of the area. In certain mountainous of the Zakarpattia Region, annual precipitation surpasses 2,000 mm. Moreover, during cyclonic periods, a two-month rainfall equivalent can precipitate in a single day, with up to 200 mm of rainfall occurring within 2-3 days. This gives rise to rapid and destructive floods, which, in plains, result in inundations causing substantial harm to the local population and accumulating significant quantities of river material. During severe floods, the riverbanks undergo active erosion, leading to profound channel deformities and the transportation of substantial alluvial sediments to lower hypsometric levels of the river network. These processes coincide with the degradation of hydraulic structures, road infrastructure, residential buildings, communications, and more.

The most severe floods in Zakarpattia Region occurred in 1998 and 2001, resulting in the destruction of numerous bridges, deforestation, disruption of power lines, and washouts in some of the region's mountain rivers. Beyond inflicting significant economic damage on the region's economic infrastructure and exacerbating the overall geo-environmental situation in Zakarpattia Region, these high floods pose a threat to the population. They also contribute to an increase in water flow capacity, accompanied by bank and riverbed erosion, as well as overall deformations (Karabiniuk, 2021; Obodovskyi et al., 2002).

Riverbed processes and deformations are also influenced by the orographic characteristics of the region, where steep mountain slopes contribute to rapid runoff and the formation of high floods. Sudden shifts in the configuration of river valleys and the presence of erosion-resistant rocks, including sandstones, gneisses, and shales, lead to the creation of specific rapids within river channels. These natural transverse barriers impact the dynamics and progression of riverbed processes. The manifestation of riverbed processes is significantly influenced by the outcrops of metamorphic rocks on the riverbed surface, which greatly enhance the riverbed's resistance to deformation. Such outcrops of hard bedrock are observed in Zakarpattia Region, particularly in the channels of the Black Tisza, Shopurka, Kosivska, and others. Rock formations traversing the riverbed can alter the kinematic forces of the flow during floods, giving rise to supports and hydraulic jumps (Hydrometeorological conditions, 2005; Obodovsky et al., 2002).

Generally, the sediment transport pattern in the mountain rivers of Zakarpattia Region follows the following sequence (Obodovsky and others, 2002):

✓ in the upper reaches, there is active erosion and sediment transport.

✓ in the middle reaches, a combination of erosion and accumulation processes occurs alongside sediment transport.

✓ in the lower reaches, accumulative processes and meandering become prominent.

Within the complex river network of Zakarpattia Region, sediments prevail in various sections of the riverbed-floodplain complex.

Under the influence of water runoff, alluvial sediments accumulate in widening areas of river valleys, with the accumulation intensity increasing downstream. In these locations, the riverbed consists of pebble, pebble-boulder sediments, mixed with gravel, sand, and clay, and may branch out when the channel's stability against scour is poor (Hydrometeorological Conditions, 2005). This phenomenon of river valley expansion and alluvium accumulation is most commonly observed in the mountainous rivers of Zakarpattia Region, particularly in regions with a concave topography and a geological base of mudstone flysch, which is susceptible to erosion by water. For instance, within the Jasinia Basin in the Black Tisza River valley, pebble-boulder alluvial deposits accumulate along a substantial portion of the river's course, flowing through the Krosnenska geological zone predominantly composed of argillites (Figure 1.2.6). As the river exits the Yasinia Basin, the Tisza river channel significantly narrows and cuts through the hard sandstone rocks of the Porkulets Cover, resulting in reduced sediment accumulation and a riverbed marked by rapids often devoid of alluvial deposits.

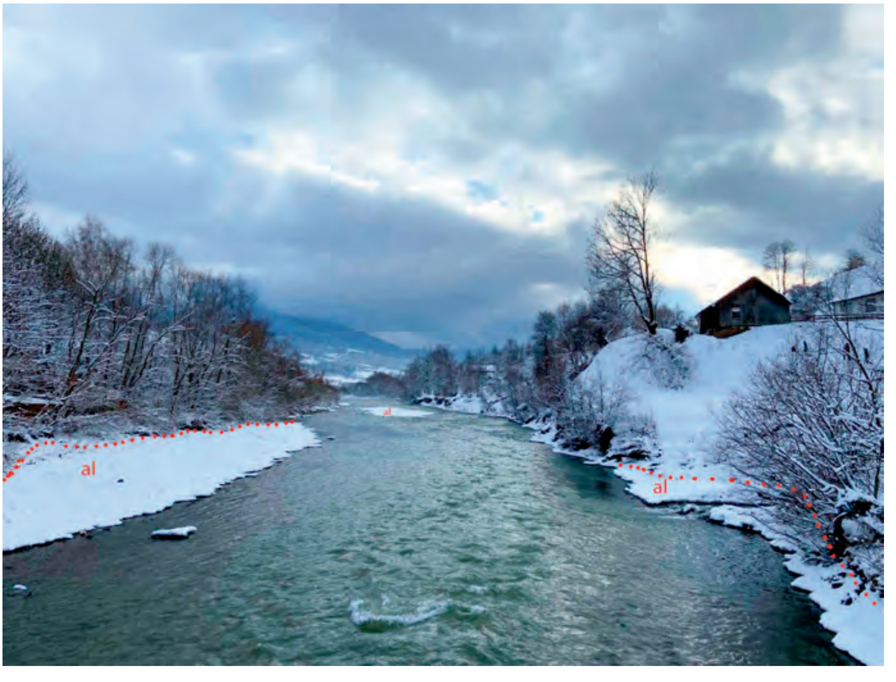

Fig. 1.2.6. Accumulation of alluvial sediments in winter in the Black Tisza riverbed within Yasinia, 2021 (Photo by the author)

The manifestation of riverbed deformations in the mountainous areas of Zakarpattia Region is characterised by the predominance of deep erosion, resulting in the active incision of riverbeds. This is evident in several basins, including Black Tisza, Shopurka, Kosivska, Latorytsia, and others, where narrow river valleys lack terraced sides and feature straight stony channels with multiple rapids. In areas where the river valley widens and the drop in the riverbed decreases, weakly sinuous meanders form. The most significant lowering of water levels is observed after destructive floods, leading to the transportation of a substantial amount of sediment and the development of deep erosion (Hydrometeorological Conditions, 2005; Leta et al., 2019).

Other significant factors influencing the development of riverbed processes in Zakarpattia Region include the ongoing anthropogenic impacts, such as excessive ploughing of catchment surfaces, unauthorised riverbed quarrying and pebble mining, expansion of development into floodplain and water protection zones, and the construction of hydraulic structures.

Based on its genesis, the river valley comprises several sections, with the riverbed and the first floodplain terraces being the most dynamic (Obodovskyi, 2013). Geometric features of the riverbed, such as its tortuosity and width, influence the river's flow characteristics. We conducted in-depth studies of channel processes and deformations in the mountainous region of Zakarpattia Region, using the Black Tisza river as an example, known for its dynamic flood regime. The Black Tisza River crosses significantly different geological areas along its course, impacting the morphology of the riverbed and the feasibility of hydrotechnical structures. Within the Yasinia Basin, the widest segment of the river valley exhibits pronounced meandering and minimal transformation of the main riverbed. This area has experienced the most substantial anthropogenic impact on the riverbed, particularly in the Jasinia settlement. In the early 21st century, the Black Tisza river was dammed along a significant portion of its length within the central part of the settlement. Special attention was also given to fortifying the section where the Black Tisza river meets its tributary, the Lazeshchyna river.

Downstream of the Black Tisza River, the orographic features of the terrain, coupled with the steep spurs of the Chornohora and Svydovets massifs, have given rise to the formation of an exceedingly narrow river valley, extending from the village of Keveliv to its confluence with the White Tisza River near Rakhiv. The anthropogenic impact on this stretch of the river valley, including the floodplain, has experienced a significant upsurge. This escalation can be attributed to the presence of the nationally important motorway H09, which has witnessed the construction of numerous engineering bank protection structures along the Black Tisza river valley in recent years. These constructions have had notable effects on riverbed processes and riverbed deformation (refer to Figure 1.2.7).

Figure 1.2.7. Anthropogenic pressure on the valley and riverbed of the Black Tisza river in the area from the village of Kvasy to the village of Yasinia (fragment of Google Earth image)

Active bank protection structures on the Black Tisza river perform the main function of protecting the banks from active erosion processes that disrupt the landscaping of the territory, destroy infrastructure, and contribute to the development of slopes and landslides in mountainous terrain (Fig. 1.2.8). In practice, river dams and riverbed transformation often reduce the natural tortuosity of the river, which creates optimal conditions for increasing the speed of river masses during periods of rising river water levels. This results in a greater potential destructive capacity of water masses, which is associated with changes in the characteristics of solid material transport, development of channel deformations, etc. Engineering unjustified construction within floodplains contributes to artificially induced accumulation of alluvial sediments, riverbed deformation and further changes in river flow.

Figure 1.2.8. Dumping and development of low terraces in the Black Tisza river valley within the village of Kvasy (fragment of Google Earth image)

To regulate floods and mitigate flood risks, a considerable 14.6 km of dams and nearly 18 km of bank protection were constructed in the Rakhiv raion, as reported by Leta in 2021. However, this extent of hydraulic infrastructure falls short in providing sufficient protection to the local population against the ramifications of hydrological hazards and the progression of riverbed deformations. In the Zakarpattia Region, the majority of river basins fail to meet the stipulated criteria for coastal protection zones within river valleys, and related standards.

The ecological well-being of rivers and the morphology of riverbeds within the Zakarpattia Region is imperiled by the obstruction of river channels with solid household waste. A substantial number of spontaneous dumpsites are observed in this area. Notably, within the Black Tisza river basin, the authorized landfill near the town of Rakhiv raises the greatest concern, with the garbage layer attaining heights of up to 10 m (Leta, 2021). The lack of proper waste segregation results in the contamination of water bodies with municipal solid waste (MSW), with quantities during flood events in the Tisza river reaching hundreds per minute, including waste products and household chemicals, among others. A similar situation is observed with unauthorized dumpsites located along the banks of rivers such as Lazeshchyna, Borzhava, Latorytsia, Teresva, and more (Leta, 2021; Obodovsky, 2013). Conversely, the prevalent illicit gravel extraction practices in Zakarpattia Region's rivers lead to the formation of unnatural depressions and riverbed deformations, thereby disrupting the natural cycle of erosion and sediment accumulation processes within the riverine system.

Economic activity affect on surface waters

Economic activity in the upper Tisza basin has experienced profound transformations over the past centuries, manifesting in the region's socio-economic development and environmental conditions. This encompasses the rapid growth of mining and manufacturing industries, light industry, food processing, transportation and social infrastructure, agriculture, among other sectors. It is inherent that economic activity within the Tisza basin yields not only economic but also environmental repercussions, one of which pertains to its influence on the hydroecological conditions of watercourses.

The analysis of economic activity as a factor impacting the hydroecological state of rivers entails an examination of the territorial and sectoral composition of the industry. Distinctive natural conditions and substantial natural resource potential have fostered the growth of the wood processing industry, construction materials sector, and food industry. At certain points in time, the Rakhiv district witnessed active development in timber and chemical, pulp and paper, as well as light and metal processing industries. Following the disintegration of the Soviet Union, major industrial establishments experienced a decline and eventually ceased their operations, with the proliferation of small and medium-sized private enterprises.

Routine surveys of the Black Tisza, White Tisza, and Tisza Rivers along the Ukrainian-Romanian border have enabled the identification of the impact of agriculture, household waste and wastewater, illegal landfills, manure storage facilities, and summer animal camps within the coastal protection zones and floodplains on river water quality.

The analysis of economic activity within Rakhiv and Tyachiv districts has revealed a list of primary enterprises and institutions whose activities during the study period presented a direct or indirect threat of polluting the waters of the Tisza River or its tributaries. These include municipal enterprises in Rakhiv, Kobyletska Polyana, Solotvyno, and Tyachiv; marble mining operations in Trybushany and Bilkam; wood processing facilities such as VGSM, Karpaty, Velykyi Bychkiv Timber and Chemical Plant, and Rakhiv Cardboard Factory; in addition to Kozmeschyk tourist resort, Dragobrat resort, and Hirska Tisza sanatorium (Rakhiv District State Administration). It is noteworthy to emphasize the risk of water pollution in the Tisza River area downstream from Rakhiv, resulting from solid household waste, organic and synthetic substances that emanate from the landfill situated directly on the left bank of the river.

The popularity of Rakhiv and Tyachiv districts in the tourism sector has been steadily increasing year by year, evident from the rise in direct railway connections with other regions of Ukraine. This growth holds particular significance for the development of both domestic and international tourism. However, tourist and recreational facilities, including those situated in the upper reaches of the Tisza River basin, represent a direct threat to surface water quality. Foremost among these threats is the absence of a centralized water supply and sewerage system, a consequence of the uncoordinated expansion of recreational complexes and the absence of effective water usage monitoring.

Forest management indirectly poses a threat to the deterioration of surface water quality, specifically in relation to water turbidity and the presence of specific heavy metals. An instance of this is observed in the upper reaches of the Tisza river basin, where clearcutting leads to accelerated runoff during heavy rainfall, subsequently resulting in a swift escalation of floodwater levels in the Tisza river and its tributaries within the study area.

Figure 1.2.9. Deforestation in the Black Tisza River Basin

Fig. 1.2.10. Deforestation in the Lazeshchyna River Basin

The orographic and climatic conditions in the Rakhiv and Tyachiv districts, combined with distinctive features of economic development and a range of historical factors, have fostered a particular form of subsistence farming characterized by cattle breeding (dairy and meat), sheep farming, poultry husbandry, and various other agricultural activities. These practices significantly dominate over crop production, the expansion of which is predominantly constrained by specific natural and geophysical conditions.

Private subsidiary plots and farms account for more than 95 % of livestock production in Rakhiv district. In particular, there are 19,800 private subsidiary plots and 55 farms within the raion (Rakhiv District State Administration). The functioning and efficiency of these entities are directly related to the level of sales and market demand for their products, which is associated with the level of trade relations between territorial communities at the Raion and Oblast levels. The main livestock products in this region include meat, milk, eggs, and cheese. An analysis of the number of livestock indicates a decline in livestock numbers and a general decline in agriculture, primarily attributed to lower production costs and intense competition in the market for inexpensive factory food. The absence of systematic state support in the form of programs, limited awareness among the population regarding the opportunities and procedures for receiving subsidies, and other factors also negatively impact the economy.

Among the agricultural products, potatoes and vegetables are most commonly cultivated in limited quantities, providing the annual required amount for a portion of the local population. At the hypsometrically lowest levels of the study area, there is limited cultivation of crops such as corn, barley, and legumes. The flat south-western part of the raion, known as the Solotvyno Plain, is most suitable for gardening and horticulture. In the Tisza River valley near Velykyi Bychkiv and the villages of Luh and Bila Tserkva, collective farms used to be prevalent in the past, but now they primarily focus on cultivating technical grape varieties. The development of viticulture in the mountainous part of the study basin is hindered by unfavorable climatic conditions and low grape yields (Leta, 2021).

Given the limited availability of land in Rakhiv district, the cultivation of sloping and steep slopes in narrow river valleys and along riverbanks is prevalent. The use of organic fertilizers and pesticides on arable land, combined with intensive surface runoff in conditions of ample precipitation, heightens the risk of surface water pollution and the development of erosion, among other processes, especially during floods (Leta, 2021). Consequently, agriculture is characterized by its impact on surface water and its quality in the upper reaches of the Tisza river region. This impact is notably associated with:

- the application of organic and mineral fertilizers in arable land cultivation; the utilization of coastal strips and river floodplains for agricultural purposes;
- the construction of manure storage facilities and summer livestock camps in close proximity to rivers;
- the discharge of water from fish farm ponds into rivers; the absence of sewage treatment facilities and centralized water disposal at livestock facilities and enterprises.

An important factor influencing the quality of surface water in the cross-border section of the Tisza River is the water usage within Rakhiv and Tyachiv districts. This usage has undergone several structural changes, which, in turn, have impacted specific quantitative indicators. Over the analysed period from 1990 to 2019, a 20-fold reduction in the volume of water withdrawn can be observed. This reduction is primarily attributed to the decline of water-intensive industries, including those related to chemicals, forestry, food production, and more. It is worth noting that the ratio between water abstraction from surface and groundwater sources has also shifted, contingent on the purpose of water usage. In recent years, a preeminence of water withdrawal for drinking and sanitary purposes has been noted, thus making groundwater abstraction the predominant source.

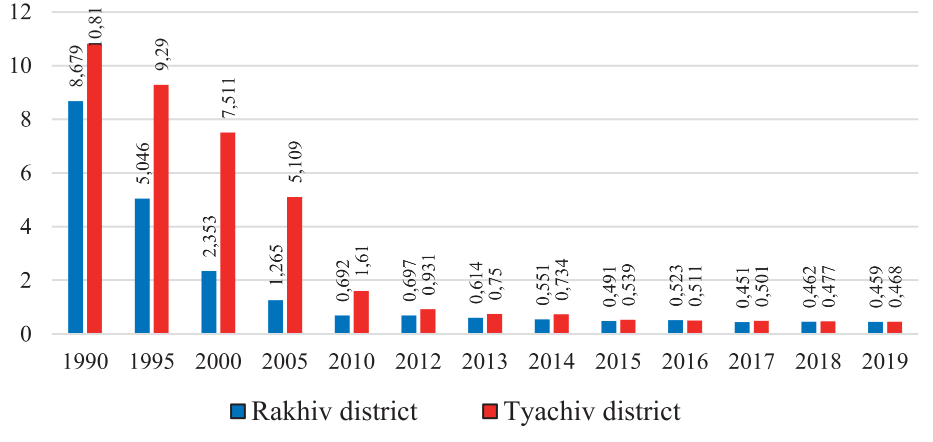

Fig. 1.2.11. Dynamics of Water Intake in 1990-2019, Million m³, Rakhiv district Tyachiv district (compiled by the Tisza River Basin Water Resources Management Authority)

The reduction in water withdrawal also leads to a decrease in wastewater volumes, thus impacting the hydroecological status of the Tisza (Figure 1.2.12). For instance, as a result of structural changes in water usage, the volume of industrial wastewater from enterprises within the Tisza study area's sub-basin decreased by a factor of 15. In recent years, municipal wastewater has come to dominate, leading to organic pollution of the Tisza river waters.

The greatest threat of pollution in the transboundary section of the Tisza River is posed by biogenic nitrogen-containing substances (ammonium, nitrite, nitrate) and phosphates, as well as synthetic detergents, which serve as a source of synthetic surfactants in the river. Another concerning source of pollution is associated with wastewater treatment plants, particularly due to their inadequate condition, outdated equipment, and limited treatment capacity. For instance, mechanical treatment methods tend to prevail over biological treatment at wastewater treatment plants in Rakhiv and Tyachiv districts, resulting in an increase in chemical water quality indicators such as BOD_5, ammonium nitrogen, nitrite nitrogen, nitrate nitrogen, COD, and so forth. It is crucial to note that in recent years, the category of “polluted” water, or at the very least "insufficiently treated" water, has become predominant among the classifications of wastewater discharged into the riverbed.

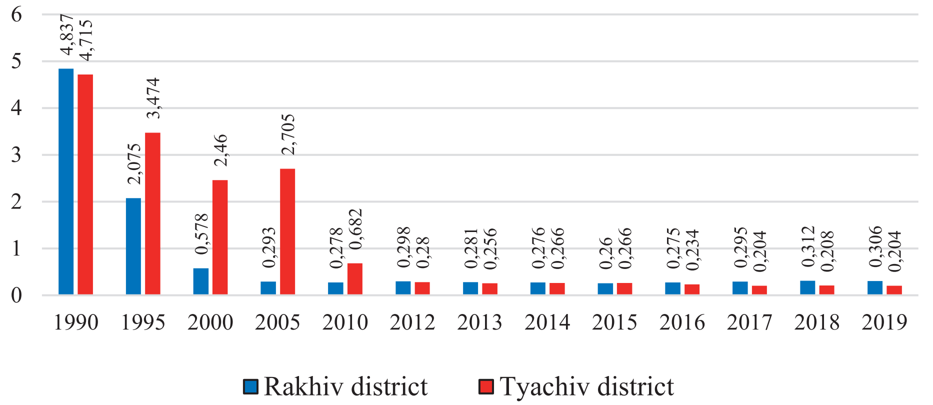

Fig. 1.2.12. Dynamics of wastewater discharge in 1990-2019, million m³, Rakhiv district, Tyachiv district (compiled by the Tisza River Basin Water Resources Management Authority)

Fig. 1.2.13. Sewage Treatment Facilities in Tyachiv

The most substantial water users and consequently the primary sources of pollution in the transboundary section of the Tisza River include the extractive industry enterprises located in Dilove village, such as Trybushany Marble Quarry PJSC, Sauliak LLC, Bilkam LLC. Additionally, woodworking enterprises in Velyky Bychkiv, namely VGSM LLC and Karpaty LLC, as well as food processing companies like Canning Plant ALC, and municipal enterprises in Solotvyno and Tyachiv, significantly contribute to water pollution. For instance, in 2018, 20% of the abstracted water was allocated for production needs, marking a twofold increase compared to previous years. However, it's important to note that the volume of water utilized for production purposes in 2018 was 50 times less than in 1990. Presently, wastewater from industrial enterprises primarily consists of treated drinking and sanitary water after undergoing biological treatment.

1.3. HYDROECOLOGICAL STATE OF THE UPPER REACHES OF THE TISZA RIVER BASIN *(V. Leta)*

The hydroecological state represents a spatiotemporal combination of quantitative hydrological, hydrochemical, and physical characteristics that provide insights into the regime, water quality, and the degree of pollution within a surface water body or its segments. It also elucidates the interplay with the environment and the impact of economic activities (Leta, 2021). The dynamics and variability of hydroecological conditions in river waters can be examined through data collected from a single river reach, specific points, surface water bodies (river sections), or an entire basin, spanning various timeframes (such as a day, month, season, year, or long-term period) (Leta, 2021). The study of hydroecological conditions in rivers serves the following purposes:

- analysis of the anthropogenic load on the aquatic geosystem;
- hydroecological monitoring of surface waters;
- development of management decisions;
- forecasting environmental changes due to the impact of anthropogenic activities;
- development of plans and schemes for integrated use and protection of water resources;
- optimisation of the water management complex;
- development of recommendations for the preservation of the ecological balance of hydrogeosystems (Leta, 2021).

There are numerous methods available for determining and classifying the hydroecological conditions of surface waters. Within the Ukrainian scientific geographical community, the most commonly employed methods include the Comprehensive Water Pollution Index (CWPI) and the Integral Environmental Index (I_E).

To ascertain the hydroecological states of waters, their seasonal variations, and long-term dynamics, it is essential to consider the relationship between hydrological aspects (as detailed by Leta, 2021) as a governing factor within the abiotic environment and the hydrochemical indicators. Among the hydrological indicators, it is imperative to analyze, at the very least, the level regime, the feeding regime, the distribution of water flow, and discharge patterns over the course of a year and across multiple years. Hydrochemical indicators should be meticulously selected to delineate the hydro-ecological conditions of the water, while accounting for a wide array of natural and anthropogenic influences.

The evaluation of Tisza river's water quality, as determined by the comprehensive hydrochemical index for water pollution, involves the comparison of average annual nutrient levels (nitrite, nitrate, and ammonium), phosphate concentrations, as well as indicators of the oxygen regime (dissolved oxygen and biochemical oxygen demand over five days, BOD_5) in surface waters with the maximum permissible concentrations of these substances in fishery waters.

During the period of 2008-2018, the WPI exhibited a dynamic range from 0.32 to 0.48, aligning with the second category of water quality, which signifies "clean water." Notably, there is a discernible upward trend in the index values both downstream and over the duration of the study period. Downstream indices witness an increase following the confluence of the Romanian tributary of the Tisza, the Viseu river. There is a slight reduction in the water pollution index from Velykyi Bychkiv village, Rakhiv district, to Solotvyno village, Tyachiv district, due to the augmented water content in the Tisza river and inherent self-purification processes. Conversely, the WPI registers an increase at the cross-border section's terminus, specifically in Tyachiv, primarily attributable to the influence of municipal wastewater.

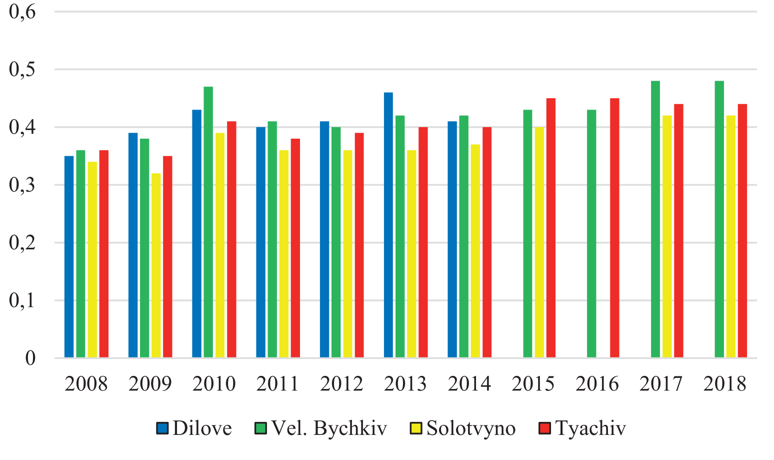

Figure 1.3.1. Dynamics of the WPI values during 2008-2018 (compiled from the Tisza River Basin Water Resources Management)

The analysis of the annual average values employed in the computation of the Water Pollution Index (WPI) for Black Tisza (Bilyn village) and White Tisza (Roztoky village) reveals an escalating impact of parameters such as BOD_5, COD, and dissolved oxygen on the index value, thereby influencing the classification of water quality (Leta, 2021). As an illustration, the WPI of Black Tisza River (Bilyn village) in the year 2011 was determined as follows:

(0,18 NH4 + 1 BOD5+0,35 NO2+0,5 O2+0.54 COD+0,11 petroleum products)/6=0,44

which indicates the crucial role of oxygen regime indicators in the calculation of the Black Tisza River WPI. The results of the calculations of the WPI of the White Tisza River (Roztoky village) for 2011 are similar:

(0,1 NH4 + 0,9 BOD5+0,13 NO2+0,5 O2+0,42 COD+0,1 petroleum products)/6=0,36

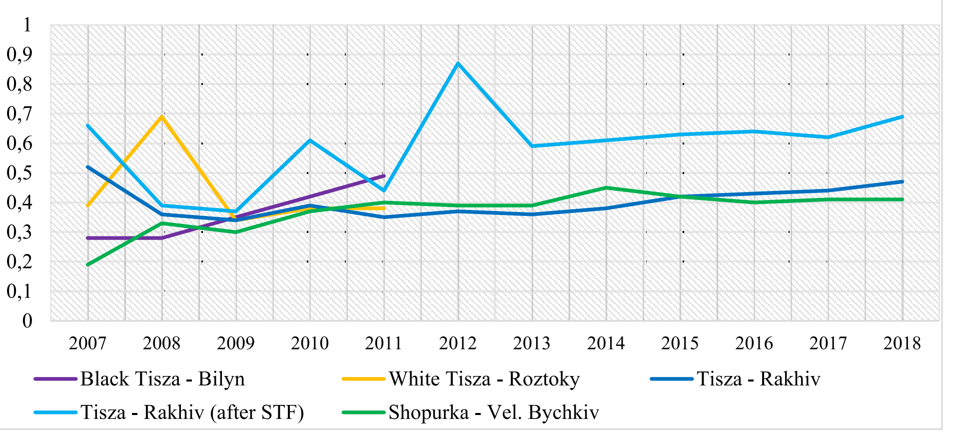

Figure 1.3.2. Dynamics of the WPI for the period 2007-2018.
(compiled by the Tisza River Basin Water Resources Management Authority)

By analogy, the 2018 WPI of the Shopurka River (Velykyi Bychkiv) was also calculated:

(0,14 NH4 + 0,72 BOD5+0,5 NO2+0,55 O2+0,37 COD+0,2 petroleum products)/6=0,41

Tisza River (Rakhiv):

(0,28 NH4 + 0,87 BOD5+0,5 NO2+0,53 O2+0,41 COD+0,2 petroleum products)/6=0,47

Tisza River (Rakhiv, below the STF):

(0,54 NH4 + 1,1 BOD5+0,75 NO2+0,55 O2+0,48 COD+0,2 petroleum products)/6=0,6

As a consequence, there is an evident augmentation in the contribution of nitrite within the computation of the Shopurka River's Water Pollution Index (WPI), and an increased significance of both nitrite and ammonium in the WPI of the Tisza River. This is based on the annual average indicators for the year 2018. The rise in the downstream WPI of the Tisza River observed during the 2007-2018 period, attributed to ammonium, nitrite, BOD_5, and COD, signifies a heightened presence of organic matter in surface waters following the discharge from Rakhiv's sewage treatment plants.

The most pronounced character of seasonal variability is observed in the nutrient content values. However, the mass fraction of the Water Pollution Index (WPI) is significantly higher in the oxygen regime. This observation raises concerns regarding the potential pollution threat of the Tisza River with organic substances, particularly during the spring and summer. The concentration of biogenic substances in the WPI experiences the most substantial growth in the Tisza River section downstream of Velykyi Bychkiv. This increase can be attributed to the expansion of the river valley and the utilisation of land for agriculture, especially within the floodplain, which serves as a source of nitrogen-containing substances in the river's waters. The annual average nutrient content has never exceeded the Fisheries Maximum Allowable Concentration (MAC) but remains notably high for a river with a mountainous course, extending up to Velykyi Bychkiv. This is corroborated by the values of the oxygen regime in the Tisza River, specifically the parameters BOD_5 and dissolved oxygen content.

The Integral Environmental Index (I_E) is a block indicator of surface water quality, which includes: a block of indicators of salt composition (I_1), a block of environmental and sanitary indicators of water (I_2) and a block of indicators of specific substances of toxic effect (I_3) (Leta, 2021). The algorithm for the environmental classification of water quality includes the determination of block indices (I_1, I_2, I_3) and the calculation of the environmental index (I_E).

The methodology employed in this paper for the environmental assessment of surface water quality according to relevant categories yields results indicating the assignment of the second category within the 2nd class of water quality (characterised as clean water), aligning with a state of good environmental health. Notably, in contrast to the Water Pollution Index (WPI), the Integrated Environmental Index (I_E) exhibits far less variation downstream. This divergence can be attributed to the higher number of indicators encompassed by the index, comprising 20 indicators divided into 3 block indices, a significantly larger set compared to the WPI's 6 indicators. The expanded indicator count within the block indices serves to mitigate deviations in normalised values across multiple pollutants, given that the core methodology aims to establish the arithmetic mean value of the integral index. Based on the data from the study period, discernible trends emerge within the block indices:

✓ The block index for salinity indicators consistently maintains a value of 1, aligning with the I category of the 1st class of water quality, denoting an excellent condition characterised by water safety in terms of mineralization.

✓ Within the integrated environmental index, the highest mass fraction is attributed to the specific toxic substances index (I_3), encompassing heavy metals and synthetic pollutants. Notably, the values of this index, in certain instances, surpass the threshold for achieving good ecological water status.

✓ Between 2010 and 2018, akin to the trends observed in the WPI, the values of the IE index display a progressive increase year by year. This trend underscores a growing anthropogenic impact on the quality of surface waters in the transboundary segment of the Tisza River.

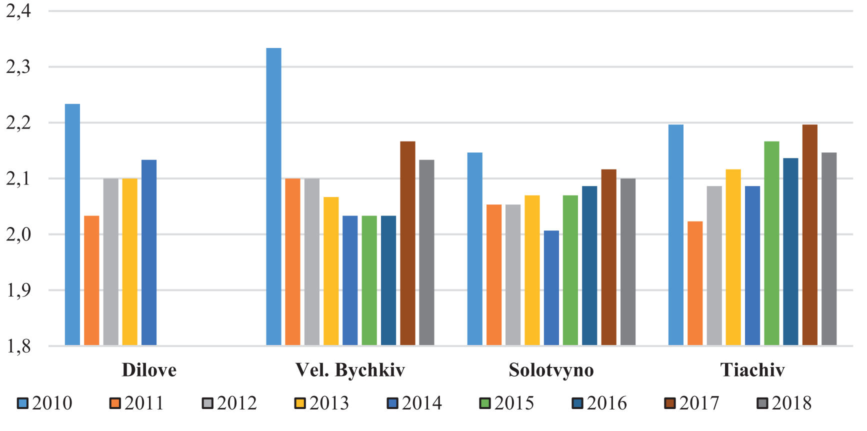

Fig. 1.3.3. Dynamics of the integrated environmental index values in 2010-2018 (compiled from the Tisza River Basin Water Resources Management)

The section of the Tisza river located within Rakhiv and Tyachiv districts serves as the state border separating Ukraine and Romania. Therefore, it is prudent to evaluate the hydroecological status of the Tisza waters using the classification established by the International Commission for the Protection of the Danube River (ICPDR). This classification encompasses five distinct water quality classes, with class II serving as the reference point, as class I characterises conditions under natural reference parameters.

The assessment of water quality, in accordance with the criteria set forth by the International Commission for the Protection of the Danube River (ICPDR), adopted as a representative example of European water quality evaluation standards for the transboundary Tisza River segment, yields a nuanced outcome. Consequently, it is evident that between 2008 and 2018, the ecological state of the waters transitioned from good to satisfactory, thus evolving from the category of clean to conditionally clean waters. Consistent with domestic methodologies, the classification in alignment with ICPDR requirements affirms the mounting influence of anthropogenic factors in recent years.

In contrast to domestic methodologies, the classification of water quality as per the requirements of the International Commission for the Protection of the Danube River (ICPDR) entails the determination of the water quality class and ecological status based on the most adverse value. This value is then compared with each of the five classes and five ecological statuses (in contrast to domestic methods which comprise seven categories, five classes, and five statuses). Consequently, the environmental status determined by the most unfavourable value of a specific pollutant offers a more objective reflection of the actual state of affairs. While domestic methods mitigate the surpassing of the Fisheries Maximum Allowable Concentration (MAC) for parameters like total iron, manganese, and heavy metals such as copper and zinc through the utilisation of 20 indicators in the denominator, international standards employ an absolute criterion of 90% coverage from a minimum of 11 samples throughout a year for the purpose of classification.

The study encompasses a comparative analysis of the outcomes obtained from classifying water quality and associated hydroecological conditions through the utilisation of two national methods in conjunction with the criteria set forth by the ICPDR. This comparison reveals that both national methods for establishing integral indices yield similar results, characterising the water quality as falling within the II category of the 2nd class, denoting clean water and a state of good condition. The key determinants for this classification are the indicators related to nutrient content and the oxygen regime. Additionally, the IE index incorporates parameters such as iron, copper, and manganese. Conversely, the classification as per the ICPDR requirements points to pollution in the transboundary segment of the Tisza River. Specifically, heavy metals like copper and zinc are implicated, along with some concerns regarding the oxygen content in the river waters, particularly in the vicinity of Solotvyno.

The comparison of water quality assessment methods in the Tisza River (Tyachiv) based on both national methodologies and European standards reveals commonalities and distinctions:

✓ Domestic methodologies for water quality assessment through integral indicators, specifically the WPI and the IE index, ultimately yield nearly identical results, signifying a good ecological status of the water.

✓ In both national methods, the most significant weighting factors used for determining the indices are BOD_5 and NO_{2-}.

✓ The water quality assessment framework in accordance with the stipulations of the ICPDR suggests that Tisza River waters are subject to contamination from heavy metals.

Table 1.3.1.

Comparative analysis of water quality assessment methods on the example of the Tisza River in Tyachiv (compiled from the materials of the Tisza River Basin Water Resources Management)

Methods	WPI (2008–2018)	I_E (2010–2018)	ICPDR (2008–2018)
Water Quality Class	II	II	2/3
Ecological Status	good	good	good/ satisfactory
Defining Indicators	BOD_5, NO_2–	Fe, Mn, Cu, BOD_5, NO_{2-}, transparentness	BOD_5, Zn, Cu

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1.4. CHARACTERISTICS OF CURRENT CLIMATIC CONDITIONS AND CLIMATE CHANGE MANIFESTATIONS *(R. Ozymko, M. Karabiniuk)*

The climate is a long-term weather pattern derived from extended meteorological observations and serves as a fundamental geographical characteristic of a specific region (International Meteorological..., 1992). The climate of the Zakarpattia Region, akin to any other part of the planet, arises through the intricate interplay of factors such as radiation conditions, atmospheric circulation, and the underlying surface.

In accordance with one of the most widely employed Köppen-Geiger climate classification systems, Zakarpattia is categorised as Dfb (indicating a humid temperate continental climate with warm summers) (Fig. 1.4.1) (Peel et al..., 2007).

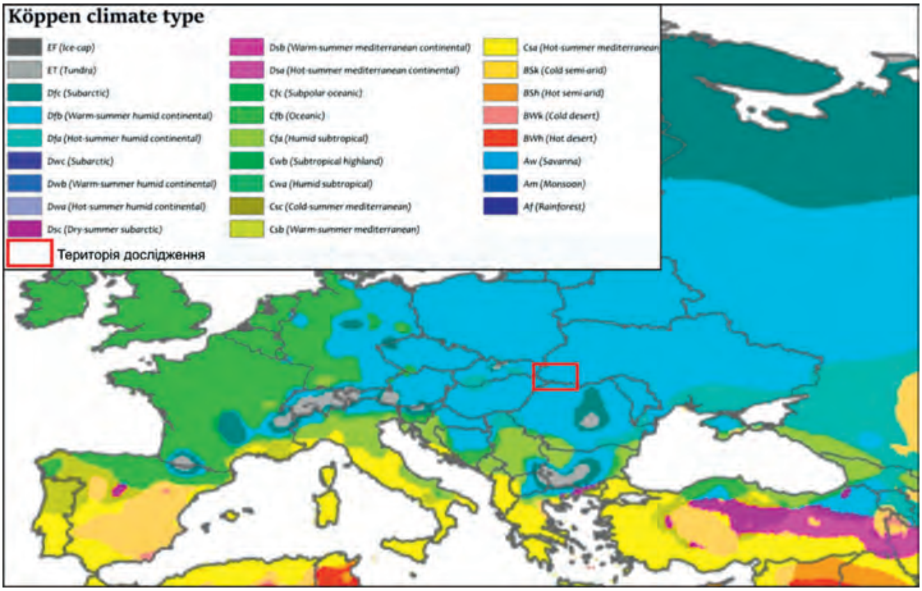

Fig. 1.4.1. Distribution of Europe's Territory According to Köppen-Geiger Climate Classification (Peel et al..., 2007)

The climate of Zakarpattia Region shares many similarities with that of Hungary, Slovakia, Romania, Poland, the Czech Republic, and the northern part of the Balkan Peninsula, and this resemblance is primarily shaped by the overarching atmospheric circulation patterns across Europe. The meteorological dynamics over the territory of Zakarpattia Region are generally influenced by atmospheric processes originating from the Atlantic and Eurasian regions. The key climatological centres of atmospheric influence (Stepanenko et al., 2015) that dictate this circulation include:

1. The Icelandic baric depression.
2. The Arctic anticyclone.
3. The Mediterranean baric depression.
4. The Azores anticyclone.

The Siberian winter anticyclone, with its extensions occasionally reaching the lowlands of Zakarpattia Region.

The interplay between these baric centres induces the transformation of air masses. During the winter season, the majority of cyclones originate from the Atlantic and Mediterranean regions and advance towards Zakarpattia Region. These cyclones tend to be deep and frequently bring about conditions such as ice, thaws, snowmelt, heavy rains, and often lead to winter floods in Zakarpattia and neighbouring areas (National Report..., 2012).

Another notable winter-related process is the eastern influence associated with the reinforcement of the anticyclone situated in the eastern part of the Eastern European Plain. On occasion, Zakarpattia Region experiences the impact of polar-origin anticyclones, which introduce cold air masses from the Arctic. The intrusion of Arctic air masses typically occurs in the rear section of cyclones, where intermediate or ultimate anticyclones take form. Such occurrences are associated with severe winters, which have become increasingly rare over the past two decades.

In spring, the Azores anticyclone gains strength as its extensions and cores reach Europe. This period witnesses a reduction in the frequency of western cyclones, with southern and southwestern cyclones making their way towards Poland or Belarus (Climate of Ukraine..., 2003). As summer arrives, advective processes weaken, while the significance of radiation and local factors grows. The Azores anticyclone experiences significant development, gradually expanding eastward. This influx of tropical air masses results in hot and dry weather conditions within the core of the Azores High. By autumn, the Azores anticyclone weakens, still retaining some influence during the early part of the season. Eventually, it diminishes, giving way to the growing impact of the Siberian High. This transition is accompanied by an upsurge in the frequency of western and southern cyclones (Sakali et al., 1985).

In summary, the weather patterns in Zakarpattia Region are predominantly shaped by the alternating effects of the Azores and Siberian anticyclones, along with the movement of cyclones from the Atlantic and Mediterranean regions. Despite the frequent presence of anticyclones and the associated continental influences, Zakarpattia's climate is milder compared to central and eastern Ukraine. This can be attributed to the fact that Zakarpattia Oblast is exclusively situated on the southwestern macro-slope of the Ukrainian Carpathians, whose watershed ridges provide a protective barrier against the incursion of cold and dry Arctic air masses from the north during winter. The climate of Zakarpattia Region displays remarkable diversity, characterised by warm, protracted summers and mild winters with frequent thaw periods.

Another highly significant factor in shaping the climate is the land surface, encompassing the Earth's surface composed of soil, water, snow, and artificially created surfaces. This land surface engages in interactions with the atmosphere, influencing the exchange of heat and moisture and serving as a source of dust and condensation nuclei for the atmosphere. The attribute describing the unevenness of the underlying surface and its impact on the movement of air in the surface layer is referred to as "roughness" (International Meteorological..., 1992). The Carpathian Mountains wield a substantial influence over the climate in the Zakarpattia Region. This mountain range serves to weaken and alter the direction of air mass movement, simultaneously effecting transformations in the primary climatic characteristics of these air masses (Climate of Uzhhorod..., 1991). The prevailing wind patterns are contingent on the intricacies of the orography, river valley orientations, and mountain ranges. Consequently, mountain-valley winds are quite distinct in Zakarpattia, particularly during the warmer months. In addition to these, the region experiences föhn winds, though they are less prominent. These winds periodically move from the ridges to the valleys, ascending to higher altitudes where they cool and subsequently descend as heavier air masses, warming up considerably as they travel down the slopes towards the valleys. This results in the occurrence of a dry, warm wind (Ukrainian Carpathians..., 1988).

The Carpathians also exert a substantial influence on cyclogenesis, thus impacting the regional climate. As a cyclone approaches the mountain range, primarily its frontal section, there is an increase in atmospheric pressure due to flow convergence within the foothill areas. Subsequently, as the cyclone proceeds, concurrently with the rise in pressure on the windward side of the ridge, there is a decrease on the leeward side. This leads to the formation of two centres of reduced pressure, one on the windward macroslope and the other on the leeward side. The centre on the windward macroslope gradually fills, while the one on the leeward slope deepens and shifts eastward. This phenomenon in the evolution of cyclones is termed "segmentation" (Sakali et al., 1985).

Roughly one third of cyclones traversing the Carpathians from the western and southwestern directions undergo segmentation, with younger cyclones being particularly susceptible. This segmentation process, attributed to the mountain's impeding influence, is a primary reason Transcarpathia receives a notable amount of precipitation in comparison to other regions of Ukraine. Cyclones arriving from the west and southwest essentially discharge their precipitation, moisture, and heat over the region, contributing to the comparatively milder climate of Zakarpattia. This phenomenon stands in contrast to the region's high occurrence of anticyclones and the resultant continental influence (Climate of Ukraine..., 2003).

The intricate orography of the Zakarpattia Region gives rise to a "mosaic" climate, or topoclimates (mesoclimates), which are climates shaped by local factors such as relief, vegetation, water conditions, and others (International Meteorological..., 1992). The fundamental characteristics of the region's climate are dictated by the distinct patterns in the annual course of the primary meteorological elements, including temperature, precipitation, atmospheric pressure, wind, and more, and their spatial distribution.

The temperature regime takes shape under the influence of various factors, including the radiation regime, atmospheric circulation, and the characteristics of the underlying surface. Within the region, a complex distribution of air temperatures prevails, largely attributable to the challenging orographic conditions. In the mountainous segment of the region, air temperature changes are observed as altitude increases, with an average annual vertical temperature gradient ranging from 0.76 to 0.86 °C per 100 m of elevation. The altitudinal zonation of climatic conditions exhibits significant variations during different periods and seasons. Consequently, in winter, the temperature gradient is within the range of 0.4 to 0.7 °C, while in summer, it is notably higher, spanning from 1.0 to 1.1 °C (Climate of Ukraine..., 2003). As a result of the active inflow of cold air masses into river valleys and hollows from mountain peaks and ridges, the temperatures in these elevated areas can surpass those at lower hypsometric levels. These temperature inversions can persist for several days and are a characteristic feature during the winter period.

One of the primary indicators of the thermal regime is the average monthly air temperature, which is the arithmetic mean of the air temperature for the month, derived from the average daily values (International Meteorological..., 1992). Data regarding the average monthly air temperature regime serves as a valuable tool for addressing a wide range of practical and theoretical challenges. The annual fluctuations in the average monthly temperature closely align with the annual fluctuations in solar radiation.

The average temperature in January varies from -0.7 °C (Berehove) in the lowlands to -6.1 °C (Plai) in the mountains. In March, the average temperature turns positive in the foothill and lowland regions, ranging from +3.8 to +5.9 °C, while in the mountains, it varies from +0.6 to +2.8 °C, and in the highlands, it remains negative at -2.8 °C. During April and May, there is a significant increase in temperature: in the lowlands, temperatures range from +11.5 to +16.6 °C, and in the highlands, they range from +3.1 to +8.1 °C. The highest average monthly temperatures are experienced in

July and August: in the lowlands, temperatures reach +21.0 to +21.9 °C, in the mountains, they range from +16.2 to +18.6 °C, and in the highlands, temperatures hover between +13.2 and +13.4 °C (Fig. 1.4.2). Starting in September, a decline in air temperature is observed. The winter regime takes hold in lowland areas during the second decade of December and in the mountains, it sets in during the third decade of November (Climatological Standard Norms..., 2021).

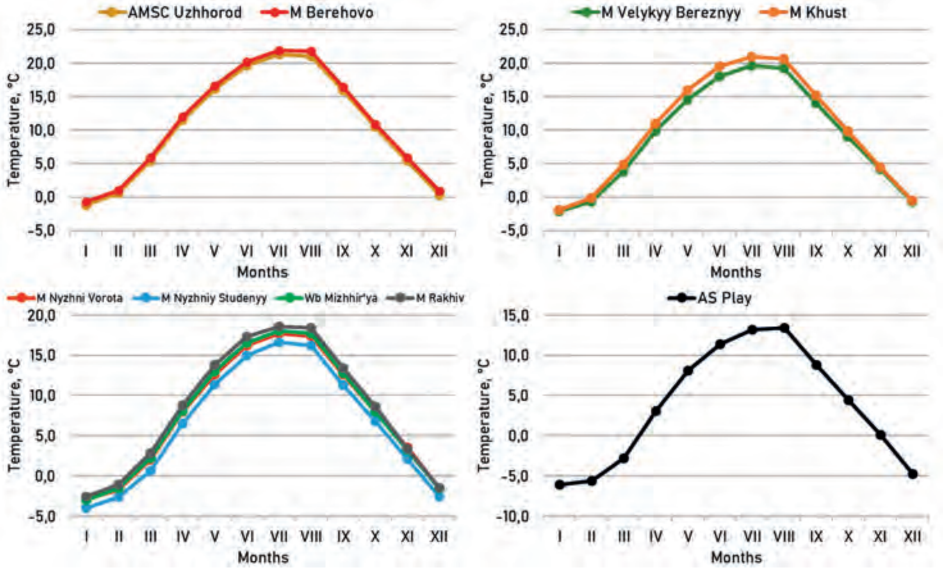

Fig. 1.4.2. Graphs of average monthly air temperatures according to weather stations in Zakarpattia Region during 1991-2020. (compiled by the authors based on data from the B. Sreznevsky Central Geophysical Observatory)

In the foothill and lowland regions of the area, the average annual temperatures are relatively high, ranging from +9.1 to +11.1 °C, while in the mountains, they range from +6.4 to +8.3 °C. On the exposed peaks at elevations of 1200-1400 metres above sea level, the average annual temperature is approximately +3.6 °C. The absolute maximum air temperature recorded in lowland and foothill areas stands at +38.6 °C (Berehove and Uzhhorod), in the mountains, it reaches +36.3 °C (Rakhiv), and in the highlands, it is +26.9°C (Plai). On the other end of the spectrum, the absolute minimum air temperature noted in lowland and foothill regions is -32.5 °C (Berehove), in the mountains, it drops to -31.6 °C (Nyzhni Vorota), and in the highlands, it registers at -27.6 °C (Climatological Standard Norms..., 2021).

In the lowland areas of Zakarpattia Region, the average daily temperature reaches +15 to +20 °C for 80 days per year. For a period of more than 1 to 1.5 months annually, temperatures surpass +20 to +25°C. In the mountainous region, these average daily temperatures are experienced for only 1 to 2 days during the summer. In the mountains, average daily temperatures ranging from +10 to +15 °C are recorded for 83 days each year (Climatological Standard Norms..., 2021).

The growing season, defined by average daily air temperatures at or above +5 °C, extends for 229-241 days in lowland and foothill regions, typically commencing between 17-25 March and concluding between 9-14 November. In mountain valleys, the growing season spans 198-219 days, typically starting from 29 March to 11 April and ending between 26 October to 3 November. The cumulative positive air temperatures above +5 °C during this period range from 3100 °C in the foothills to 3640 °C in the lowlands, and from 2340 to 2880 °C in mountainous areas (Agricultural Climate Handbook..., 2013).

The period of active crop vegetation, characterised by average daily air temperatures of +10 °C and above, typically lasts for 174-192 days in lowland and foothill regions, with a usual onset between 13-18 April and termination between 9-13 November. In mountainous areas, this period spans 140-170 days, commencing from 24 April to 8 May and ending between 25 September to 11 October. The sum of positive air temperatures above +10 °C during this period ranges from 2700 °C in the foothills to 3240 °C in the lowlands, and from 1920 °C to 2540 °C in mountainous areas (Agricultural and Climatic Handbook..., 2013).

The second most critical climatic characteristic is precipitation. The annual average precipitation in Zakarpattia Region varies significantly, ranging from 650 to 1500 mm. This considerable discrepancy can be attributed to the presence of mountains, which induce orographic uplift of air masses leading to subsequent cloud formation. Precipitation is distributed quite unevenly across the region. In lowland areas, the average annual precipitation amounts to 650-750 mm, in foothill areas, it ranges from 850-1050 mm, and in high mountain ranges and mountain valleys, it can reach up to 1500 mm (Climatological Standard Norms..., 2021).

In general, the region receives 250-600 mm of precipitation during the cold season (November-March) and 400-900 mm during the warm season (April-October). The winter months exhibit minimal variation in terms of precipitation, with February predominantly registering the lowest amounts (45-100 mm) (Figure 1.4.3). In lowland and foothill areas, March experiences relatively low precipitation (40-75 mm). In April, there is the lowest amount of precipitation throughout the year, with 40-60 mm in lowland and foothill areas, 65-85 mm in the mountains, and 90 mm in the highlands (Plai). Precipitation then rapidly increases in May, reaching its peak in June and July (70-170 mm). In some years, this maximum occurs in other months. For instance, in June 1960, Uzhhorod recorded 242 mm of precipitation, and in October 1974, it reached 288 mm, which represents 355-480 % of the monthly precipitation norm. By August, the amount of precipitation decreases significantly to 55-100 mm and then experiences a slight increase towards the end of the year, ranging from 50-140 mm (Climatological Standard Norms..., 2021).

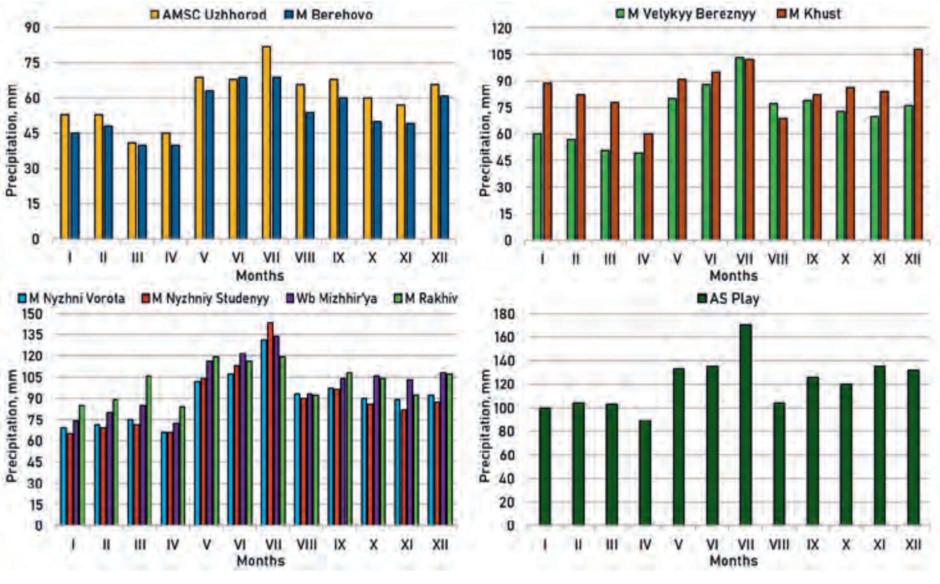

Fig. 1.4.3. Diagrams of the average monthly precipitation according to the data of meteorological stations in Zakarpattia Region during 1991-2020. (compiled by the authors based on data from the B. Sreznevsky Central Geophysical Observatory)

Significant fluctuations in precipitation are observed both between years and, in certain years, among months. On average, there are 135-154 days per year with precipitation of ≥0.1 mm in the lowland and foothill regions, 170-191 days in the mountains, and 194 days in the highlands. However, when considering a threshold of ≥5 mm of precipitation, the average annual number of days decreases markedly. In lowland and foothill areas, it amounts to 42-63 days, in the mountains it falls within the range of 66-73 days, and in the highlands, it reaches 86 days (Climatological Standard Norms..., 2021).

Another crucial climatic indicator is the daily precipitation, which provides insights into the soil's moisture saturation, the frequency of hazardous meteorological events related to precipitation, and more. Over the course of a year, the lowest average daily precipitation is typically observed in January, ranging from 3-6 mm. In contrast, the highest daily precipitation occurs in July and August during intense heavy rains, averaging between 7-11 mm (Fig. 1.4.4). To illustrate, on June 26, 2016, at the hydrological station Luhy in Rakhiv district, a remarkable 89.7 mm of rain fell within 1 hour and 30 minutes, equivalent to 77 % of Rakhiv's monthly precipitation norm. Similarly, at the avalanche station Play on August 12, 2014, 100.0 mm of rain was recorded over a 9-hour period, amounting to 96% of the monthly precipitation norm. The absolute daily maximum precipitation in Zakarpattia Region was documented from 1000 to 0600 UTC on November 4-5, 1998, in Ruska Mokra (Tiachiv raion), where an astounding 157 mm of rain fell (Climatological Standard Norms..., 2021).

Relative humidity, alongside temperature and precipitation, represents one of the fundamental climate attributes. It quantifies the degree of air moisture saturation at a given temperature, expressed as a percentage, making it a valuable indicator of climate "dryness" (International Meteorological..., 1992). The distinctive features of the region's physical and geographical positioning, its topography, a significant proportion of forested areas, and other contributing factors contribute to elevated air humidity in Zakarpattia Region (Fig. 1.4.5).

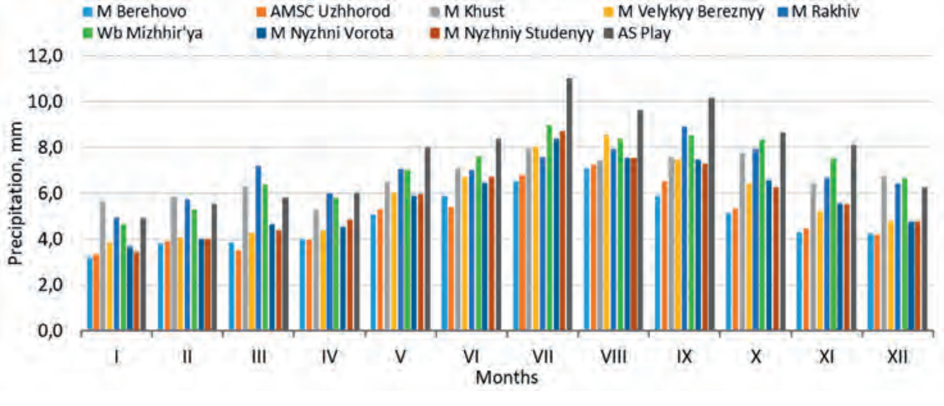

Fig. 1.4.4. Diagram of the average daily precipitation according to the data of weather stations in Zakarpattia Region during 1991-2020. (compiled by the authors based on data from the B. Sreznevsky Central Geophysical Observatory)

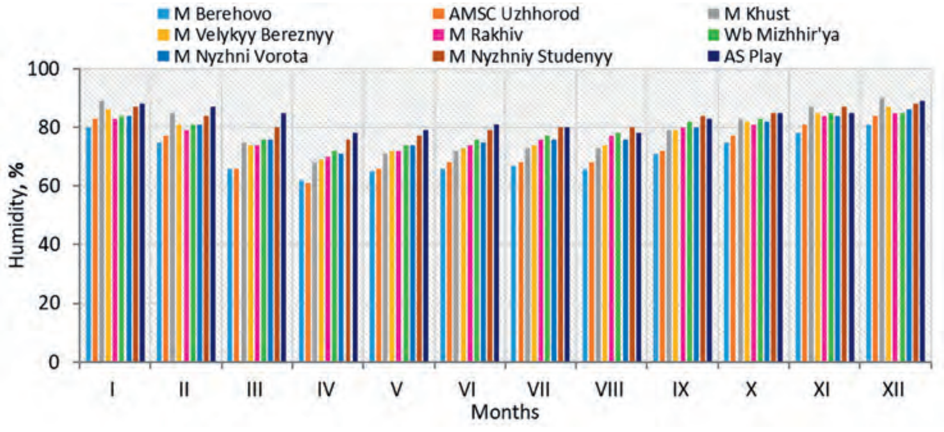

Fig. 1.4.5. Diagram of the average relative humidity according to the data of weather stations in Zakarpattia Region during 1991-2020. (compiled by the authors based on data from the B. Sreznevsky Central Geophysical Observatory)

The highest relative humidity levels (75-90 %) occur during winter, while the lowest (60-80 %) are experienced in spring. Throughout the year, relative humidity exhibits relatively consistent values without significant peaks or troughs. In the lowland regions of the area, the annual average relative humidity hovers around 70%, while in the mountains, it reaches approximately 80 %. Occasions when relative humidity falls to 30 % and below are classified as "dry days". On average, the region witnesses 10-12 such dry days annually. April sees the most dry days, typically numbering 3-4, followed by 1-2 dry days in May (Climatological Standard Norms..., 2021).

Wind represents the third primary climate attribute, following air temperature and precipitation. At meteorological stations, wind is characterised as the horizontal movement of air in relation to the earth's surface and is quantified in metres per second (m/s). Wind direction is determined using a 16-degree angular system spanning from 0 to 360°. The direction and speed of the wind are contingent on the seasonal dispersion of baric systems and the interplay between them. In the lowland regions of Zakarpattia Region, south and southeast winds prevail significantly, while in the foothills, north and northwest winds are dominant. In the mountains, north and south winds prevail, and on exposed summits, the southwest wind is prevalent (Fig. 1.4.6).

The wind regime is heavily influenced by the underlying surface, specifically the topography of the region, which significantly distorts the horizontal movement of air. Most meteorological stations are situated in deep, sheltered mountain valleys, and their data solely represent the local wind patterns, failing to provide a comprehensive overview of wind distribution across the region. For instance, in areas such as Mizhhiria, Nyzhni Vorota, and Nyzhniy Studenyi, the predominant north and south wind directions align with the meridional orientation of the valleys of the Rika, Studenyi, and Latorytsia rivers, where the meteorological stations are positioned.

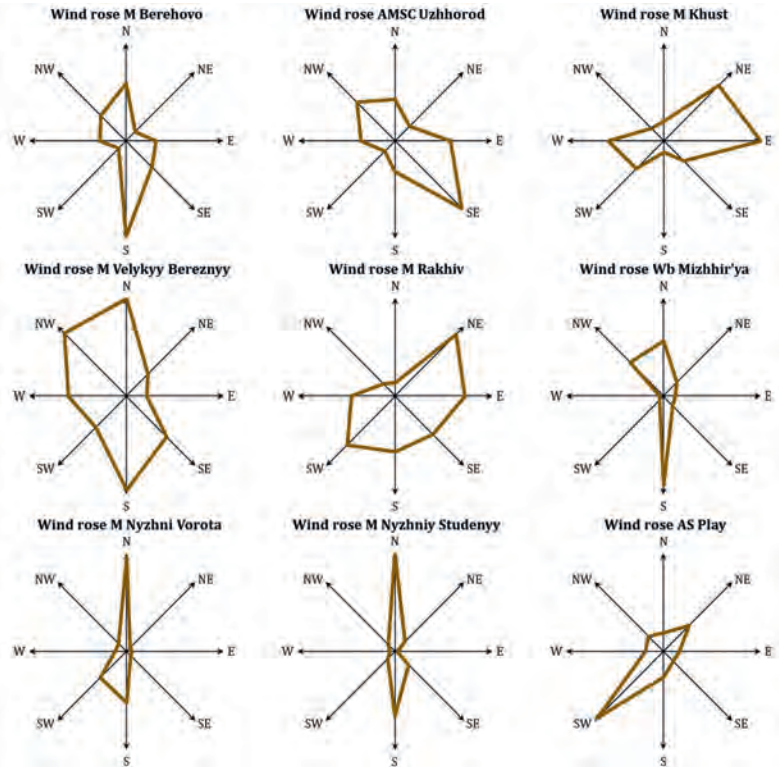

Fig. 1.4.6. Annual wind roses according to weather stations in Zakarpattia Region during 1991-2020 (compiled by the authors based on data from the B. Sreznevsky Central Geophysical Observatory)

The average annual wind speed across the region is 1.8 m/s. The highest recorded wind speed in the highlands of the region was 44 m/s on 13 October 1980 at Slipstream, while in the lowlands, it reached 30 m/s on 8 August 1978 at the Aviation Meteorological Station Uzhhorod (Civil) ("AMSC Uzhhorod") (Climatological Standard Norms..., 2021). In the highlands (St. Plymouth), winds of 40 m/s are most frequently observed from January to March. Winds with speeds of ≥15 m/s are most characteristic of winter and spring, resulting from the vigorous flow of cold air masses from the northeast through the mountain system of the Ukrainian Carpathians (Climatological standard norms..., 2021). Their occurrence diminishes significantly in the summer when they manifest as potent, short-term daytime squalls. These squalls are often accompanied by heavy rains, hail, and other perilous meteorological phenomena. Throughout the year, wind speeds of up to 5 m/s (16-46%) are most prevalent in lowland areas, while speeds of up to 3 m/s (15-72%) are common in mountain valleys (Climatological Standard Norms..., 2021).

The Zakarpattia Region is also characterised by the development of mountain-valley circulation, which is driven by heat radiation and the cooling of surface air layers. Mountain-valley winds follow a periodic pattern, blowing from the valleys towards the mountains during the day and reversing direction at night. These winds are particularly noticeable in the valleys of the Uzh, Latorytsia, Borzhava, Rika, Tereblya, and Teresva. Less frequently, foehn wind are observed in Zakarpattia Region – these are often strong and gusty winds characterised by high temperatures and low relative humidity, which can sometimes blow from the mountains to the valleys. They lead to accelerated snowmelt and, during the warm season, contribute to air drying (humidity dropping below 30 %), which can have a detrimental effect on vegetation.

Current Trends and Manifestations of Climate Change

Throughout Earth's history, the climate has undergone constant changes, giving us every reason to expect that this trend will persist. Scientific research of the Earth's surface and analysis of long-term instrumental observations confirm the fact of global climate change, with unique characteristics varying by region. This change affects the entire geographical shell in different ways, including increasing global temperatures, rising sea levels, warming of the world's oceans, melting glaciers, and more. Climate change, which has been taking place over the past decades, continues to be of interest to scientists, NGOs, and governments worldwide. As a result, methods for forecasting global climate change and its possible consequences are being increasingly actively developed, with mathematical methods of modelling atmospheric processes at the forefront (Fifth National..., 2009).

Climate change is having a multifaceted impact on various aspects of human existence and the environment. In recent decades, Europe has seen significant climate-related changes in the species composition, proportions, and habitats of animals, insects, birds, and plants. Extreme temperatures recorded in the first decade of the 2000s had a negative impact on human health, resulting in an increase in hospitalizations and heat-related deaths. Scientists estimate that, in Europe alone, the number of deaths due to record temperatures during the summer of 2003 exceeded 70,000. Climate change has also contributed, with a high degree of certainty, to the spread of infectious diseases among animals (Ukraine and Politics..., 2016).

In 1987-1988, the World Meteorological Organisation (WMO), together with the United Nations Environment Programme (UNEP), established the Intergovernmental Panel on Climate Change (IPCC), which laid the foundation for systematising knowledge in the field of climate change. According to the IPCC's guiding principles, the IPCC's work is "an assessment based on a complete, objective, and open basis of scientific, technical, and socio-economic information relevant to understanding the scientific basis of the risks of anthropogenic climate change, potential adverse impacts of climate change, and opportunities for adaptation and mitigation" (Manukalo and others, 2018).

In order to preserve the planet's climate and ensure human security, the Paris Agreement was signed in December 2015 to limit greenhouse gas emissions to avoid a 2 °C rise in the average global temperature compared to pre-industrial levels (currently, the temperature has risen by almost 1°C and the concentration of carbon dioxide in the atmosphere has reached 404 ppm). In addition to rising air temperatures, extreme natural events have become more frequent, causing significant damage to the economy and public health.

According to the IPCC forecasts, Europe is likely to experience an increase in average temperatures and temperature maximums, an increase in the uneven distribution of precipitation, with an increase in the uneven distribution of precipitation between Northern and Southern Europe. An analysis of precipitation patterns in the twentieth century in the Northern Hemisphere revealed a slight increase in precipitation – 0.5-1.0 % per decade – in most regions of high and middle latitudes, and in the second half of the century, the probability of heavy precipitation increased slightly. The number of daily heavy precipitation events leading to flooding has increased (Fifth National..., 2009; IPCC Climate.., 2014).

The territory of Zakarpattia Region is also affected by global climate change at the regional level. In the relatively recent past, it is worth noting the catastrophic consequences of the floods of 1992, 1998, 2001, 2008 and 2010 in the western regions of Ukraine, which demonstrated the urgent need to take measures to reduce the risks of natural disasters of hydrometeorological origin. It should also be taken into account that the economic losses caused by natural disasters significantly exceed those caused by man-made disasters.

When analysing climate change in the Zakarpattia Region, we will focus on two main climate characteristics: surface air temperature and precipitation. It is changes in the redistribution of heat and precipitation that lead to changes in all other components of the climate system. In order to objectively identify climatological changes in air temperature and precipitation, a comparative analysis of data from two consecutive standard climatological norms for the periods 1961-1990 and 1991-2020, approved by the WMO, was performed.

In winter, relatively warm and humid air masses from the North Atlantic often reach western Ukraine, resulting in consistently higher temperatures in Zakarpattia. Anticyclones from the east are relatively rare in the Carpathian region (Balabukh..., 2008). Consequently, during the period from 1991 to 2020, only January recorded negative average monthly air temperatures in the lowland part of Zakarpattia Region, with a value of -1.2 °C at the AMSC Uzhhorod (Fig. 1.4.7). In contrast, during the previous standard climatological period (1961-1990), negative average monthly air temperatures were observed throughout the entire winter.

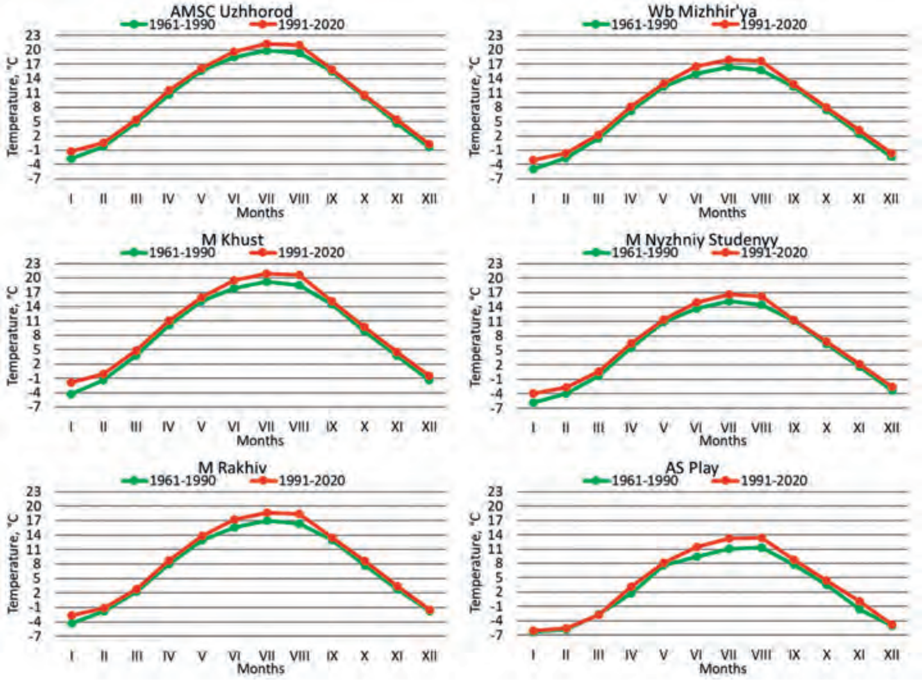

Fig. 1.4.7. Comparison of graphs of average monthly air temperatures according to weather stations in Zakarpattia Region during 1961-1990 and 1991-2020. (compiled by the authors according to the data of the Central Geophysical Observatory named after B. Sreznevsky Central Geophysical Observatory)

The annual variation of average monthly air temperatures in Zakarpattia Region over two consecutive climatological periods is depicted in Figure 1.4.7. Notably, for the past three decades, higher values of average monthly temperatures were recorded in every month compared to the 1961-1990 period. The most significant differences were observed in January and June to August (0.2-2.4 °C), while the smallest differences occurred in March to May (0.4-1.4 °C) and September to October (0.2-1.0 °C). The most substantial temperature contrasts were found in January. For example, in the city of Khust, the average air temperature in January increased by 2.4°C, and in the highlands of the region (Plai), it increased by 0.2 °C (Climatological Standard Norms..., 2021).These increases in average monthly temperatures in winter primarily result in reduced snow cover height and stability, while in summer, they lead to moisture deficits and droughts. Such changes have a direct impact on agriculture. The comparative analysis of average monthly temperatures undoubtedly confirms the phenomenon of global warming, which is also evident in Zakarpattia Oblast.

Throughout the entire period of instrumental meteorological observations in Zakarpattia, the lowest average monthly air temperature was recorded at Plai in February 1985 (-14.2 °C), and the highest was recorded at the AMSC Uzhhorod in August 1992 (+24.5 °C). On rare occasions, the lowest average monthly air temperature can be recorded not in winter, but in March (Balabukh..., 2013). February tends to be about 2 °C warmer than January, despite the similarities in atmospheric circulation and radiation conditions between these months. February experiences more dynamic changes in atmospheric processes, leading to faster air mass shifts and increased wind speeds. This, in turn, results in sharp fluctuations in air temperature. For instance, during the years 1964, 1966, 1968, 1969, 1972, 1974, 1980, 1987, 1990, 1995, 2000, 2002, 2012, 2016, and 2017, the average monthly temperature in January in the lowland part of the region was ≥5 °C lower than in February. In 1965 and 2012, it was ≥3 °C higher (Climatological Standard Norms..., 2021).

Over the past three decades, temperature contrasts between July and August have also decreased. For example, in the city of Khust, in 1961-1990, the difference in average monthly temperatures between July and August was 0.7 °C, and in 1991-2020, it was 0.3 °C. In general, August is closer to July in terms of temperature.

Calculations regarding the recurrence of changes in average air temperature between months have indicated that in the lowland part of the region, February was warmer than January in 68 % of all years, with only 31 % of the years being colder. The transition from January to February marks a sharp increase in average monthly temperatures. March typically sees an average temperature 3-6°C higher than in February. April, characterised by increased solar radiation, experiences the most significant temperature rise, with an upward difference of 5.9-6.2 °C between the average air temperatures in April and March. The steady rise in average air temperature continues into May, with May temperatures being 4.6-5.0 °C higher than in April. Meteorologically, May is a month that approaches summer. The increase in air temperature in summer is relatively gradual, amounting to 1.2-3.2 °C (Climatological Standard Norms..., 2021).

The increase in average monthly air temperatures and the rise in solar radiation inflow are nearly identical, but some differences exist (Adapting to Change..., 2015). The highest temperature values are most frequently recorded in July (56 % of cases), followed by August (35 % of cases), and rarely in June (9% of cases) (Climatological Standard Norms..., 2021). In August, as the length of daylight hours decreases, and the sun's height above the horizon diminishes, the average temperature begins to gradually decline (by 0.2-0.4 °C). However, in 27 % of cases, August exhibits higher temperatures than July. For instance, in 1962, 1971, 1974, 1979, 1984, 1986, 1992, 1993, 1996, 1997, 2000, 2011, 2015, 2017, 2018, 2019, and 2020, the average August temperature was 1-2°C higher than that of July. In September, a significant drop in air temperature commences. From August to September, it decreases by 4.7-5.4 °C, from September to October by 4.4-5.6 °C, from October to November by 4.3-5.3 °C, and from November to December by 4.7-5.1 °C (Climatological Standard Norms..., 2021).

During the modern climatological period, positive values of average monthly air temperatures are observed in the lowland part of the region from February to December (11 months), while in the previous period (1961-1990), it was only 9 months (from March to November). In the mountainous part of the region, positive values of average monthly temperatures persist from March to November, and in the highlands, from April to November. In the lowlands and foothills, temperatures exceed +15 °C from May to September (5 months) (Climatological Standard Norms..., 2021). In some years, average monthly air temperatures can deviate significantly from their long-term values and exhibit wide variations. In abnormally cold winter months, deviations can reach 7-8 °C, while in abnormally warm months, the deviations are 5-7 °C (Balabukh, Lukianets..., 2015).

An indicator of air temperature variability in the long-term context is its average annual value. The average annual air temperature is the arithmetic mean of the air temperature for the year, calculated using 12 monthly averages (Guidelines..., 2017).

To represent the long-term dynamics of average annual air temperatures, we selected data from the Uzhhorod Meteorological Centre, situated in the regional center of Zakarpattia Region – the city of Uzhhorod. Consequently, we calculated the average annual temperature values for each year within two consecutive 30-year observation periods (1961-1990 and 1991-2020) (Fig. 1.4.8). Upon analysis, it becomes evident that during the current climatological period, there is a marked upward trend in the average annual temperature values, as indicated by the increasing linear trend. In the preceding climatological period, such changes were absent, with the linear trend being nearly neutral (Ozymko..., 2020).

Figure 1.4.8 leads to the conclusion that in the Zakarpattia region, as well as globally, a persistent climate warming trend is observed. This trend has been particularly pronounced since the late 1990s. Such climate change is resulting in a shift in the seasonal boundaries, alterations in the biodiversity of ecosystems, and more. Changes in the thermal characteristics of the air also have adverse effects on human health, contributing to an increase in various chronic diseases and heightened meteorological sensitivity.

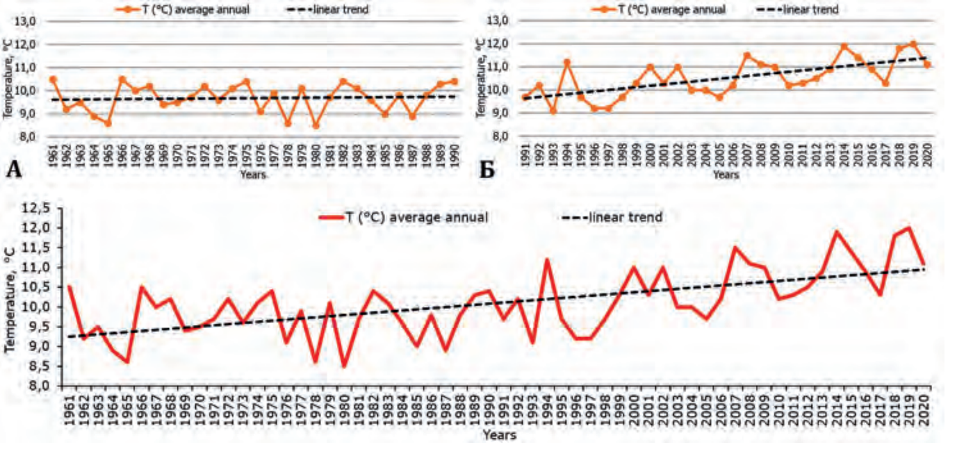

Fig. 1.4.8. Graphs of average annual air temperatures at the AMSC Uzhhorod during 1961-1990 (A) and 1991-2020 (B) (Ozymko..., 2020)

The annual variation of average monthly precipitation in Zakarpattia Region over two consecutive climatological periods is illustrated in Figure 1.4.9. Firstly, it is evident that during 1991-2020, there was a reduction in precipitation across the region during the summer months. The most significant changes occurred in June, with a decrease of 20-50 mm compared to the previous climatological period (1961-1990). In the annual precipitation pattern, the peak has shifted from June to July. Conversely, there was an increase in precipitation of 10-30 mm in September-October. The smallest changes in annual rainfall occurred during winter. In December-January, the average monthly precipitation decreased by 2-20 mm, while in February, it increased by 5-15 mm. Interestingly, the proportion of rainfall has increased during the winter months over the past three decades, which is atypical for Zakarpattia Region in the past. During spring, the amount of precipitation decreased by 9-15 mm. The most significant changes were observed in the highland zone of the region (Plai), where, in January, April, June, and August, the average monthly rainfall decreased by 25-50 mm (Climatological Standard Norms..., 2021).

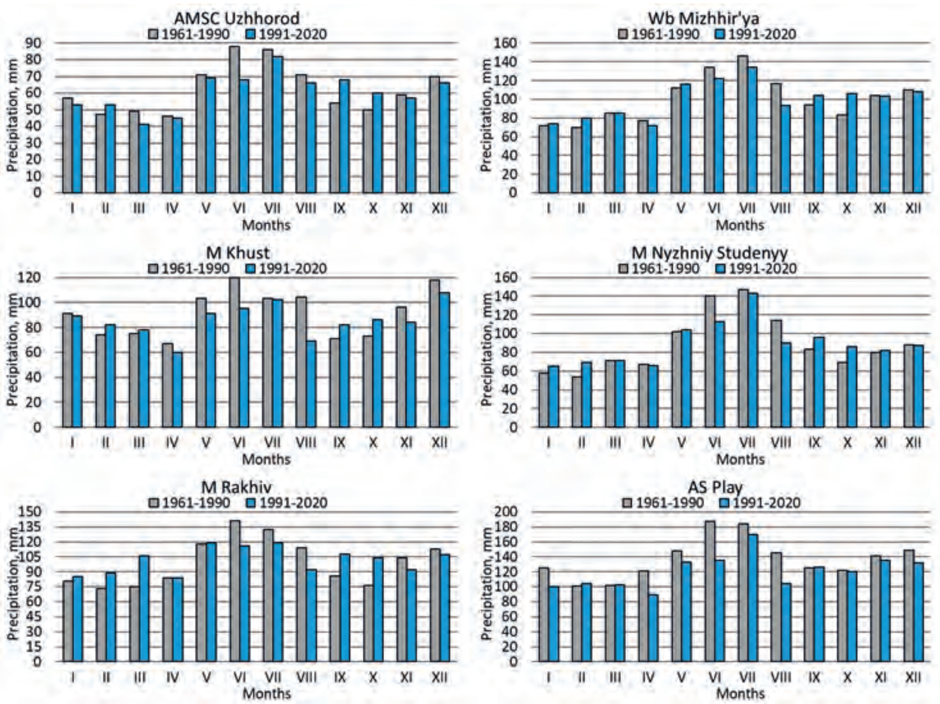

Fig. 1.4.9. Comparison of diagrams of average monthly precipitation according to meteorological stations in Zakarpattia Region during 1961-1990 and 1991-2020. (compiled by the authors according to the data of the Central Geophysical Observatory named after B. Sreznevsky)

Climatological changes in the precipitation regime across the region are considerably more intricate than those in air temperatures and are characterised by significant spatial and temporal disparities. Both positive and negative deviations in precipitation are observed during different seasons and months. The increase in the proportion of liquid precipitation during winter disrupts the stable snow cover and results in more frequent winter floods in the rivers of Zakarpattia Region. Such climatological shifts in the precipitation regime and phase state indicate a shift in the seasons and a transformation in the climate type, leading to alterations in vegetation and changes in agriculture, among other effects.

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1.5. SOILS AND VEGETATION COVER *(V. Sabadosh)*

Soils

Soil is a special natural formation emerging as a result of converting the upper layers of the lithosphere under the influence of water, air, climate factors and living organisms (in particular, under the influence of human-induced activities). Soil cover of the territory of Zakarpattia oblast formed in various conditions of relief, climate, moisture as well as vegetation cover and human-induced activities. Soil formation processes differ greatly in the mountainous and plain parts of the region. In the mountainous part of the region brown earth soil formation type is prevalent. The main factor here is the mountainous relief, which determines the spatial mosaic of vegetation cover and weather indicators. Brown mountain-forest, sod brown, mountain grassland brown soils prevail here.

Brown mountain-forest soils (brown soils) are the most common in the mountainous part of Zakarpattia, they cover mountain slopes within the forest belt from the foothills to heights of 1100-1200 m above sea level in the western and 1500-1550 m above sea level in the eastern parts of the oblast. The nature of brown soils is barely affected by the species composition of forests – the properties of the soil in beech, spruce and mixed forest stands differ little. Brown mountain-forest soils can have a high humus content, but this indicator fluctuates in a fairly wide range – under native forests it reaches 10-15%, under secondary grasslands it is up to 5-7%, and on arable lands it decreases to 3-5%. High acidity is typical of brown soils.

In the subalpine and alpine (high elevation) zones, mountain grassland brown soils of mountain valleys were formed under mountain meadows and high mountain open woodland. Soil formation takes place here in the conditions of low temperatures of the highlands very slowly due to the weakening of the processes of weathering of rocks and mineralization of organic remains. The humus content is 7-10%.

In the lower part of the forest belt of the Carpathians, on the gentler mountain slopes, medium and high terraces of mountain rivers, under oak and beech forests, sod brown soils were formed. The combination of the process of sod soil formation with the one of brown soil formation is caused by the presence of abundant herbage in broad-leaved forests, areas of open meadows and shrubs. Due to the aerobic decomposition of the remains of meadow vegetation, a distinct sod horizon was formed. The content of humus reaches 2.8-5.1%.

On the gentle slopes of the hills, at the foothills, on the high terraces of the rivers, brown podzolic soils are also common. In their formation, there was combined the brown process of soil formation under forest vegetation and the pseudopodzolic one, caused by excessive moisture and surface gleying. These soils have the humus content of 1-3%, significant acidity, and an unsatisfactory water-air regime.

In the mountainous part of the region, grassland brown soils are the best in terms of fertility, which are widespread on the alluvial floodplain of the lower terraces of mountain rivers in the foothills at altitudes above 250-300 m above sea level. They have a humus content of 1.7-3.5%, normal acidity and are well saturated with nutrients.

In the plain area of Zakarpattia soil is formed under different conditions – in warm and sufficiently humid climate, on ancient and modern deposits of mainly heavy mechanical composition: alluvial (sediments deposited by constant water flows), to a lesser extent deluvial (deposits of destroyed rocks formed at the foot of slopes as a result of being washed away from higher areas by rain flows and melted snow). The flatness of the relief and the shallow occurrence of ground water cause the significant gleying of the soil (gleying indicates overmoistening or waterlogging of the soil). The formation under the forest vegetation causes the soil to become podzolized. The sod process of soil formation in pre-agricultural times took place under the influence of the herbaceous vegetation of the forest-steppe, and during the last few millennia – under the influence of cultivated and grassland vegetation. As a consequence, the lowlands are dominated by varieties of sod-podzolic soils with varying degrees of podozolization and gleying. In general, they are low in humus (1.8-2.8%), structureless, acidic, more or less gleyed in the lower part. They are often poorly supplied with nutrients available to plants, and have an unsatisfactory water and air regime. By their physical properties, in the region, sod soils, formed in the floodplains of the Tysa and the Latorytsa on sandy and sandy-loamy well-drained river sediments, are the best. These soils have close to normal acidity, a lumpy-granular structure, good water permeability, and are easily cultivated.

Grassland and swamp soils on alluvium are common in floodplain depressions, on the territory of the former Black Swamp (the largest swamp of the Zakarpattia Lowland, which covered an area of more than 10,000 hectares; its intensive drainage began in 1878 and was completed in the middle of the 20th century), in other closed depressions of the lowland. They were formed under the influence of considerable surface wetting and shallow groundwater under herbacious grassland and swamp vegetation. Grassland soils have a lumpy-granular structure, with the humus content 4.1-7.6%; they are well supplied with nutrients. After drying, they are used as fodder grounds; less often – as arable land. Grassland-swamp soils lie in depressions with groundwater at a depth of 40-50 cm. Organic matter in the humus horizon is 9-13%, its content rapidly decreases with depth. The soils are highly acidic. Swamp soils, in fact, are not common in the lowlands.

Natural Zonation of the Territory Based on Vegetation Cover

The allocation of natural areas within a certain territory can be carried out according to various criteria. The geological-geomorphological approach, for example, operates on the characteristics of landscapes, morphostructural and morphosculptural differences. Zoning can reflect the specifics of weather and climate conditions, soil cover of various areas, etc. Let us consider in more detail the zoning of Zakarpattia oblast, which reflects the heterogeneity of the vegetation cover of its territory.

Although the area of Zakarpattia is only about 2% of the territory of Ukraine, more than 2 thousand species of vascular plants grow here (Fodor, 1974) – about half of the flora composition of Ukraine. The richness of the flora of the Zakarpattia Lowland is estimated at approximately 1,200 species (Pryhara, 1996). 214 species of vascular plants of the flora of Zakarpattia are included in the Red Book of Ukraine (2009).

The Carpathians form the Carpathian Subprovince of the Central European Province of the Circumboreal region, and the Zakarpattia Lowland is part of the Pannonian Subprovince of the Pannonian Province of the same Circumboreal region.

The vertical zonation of vegetation cover is well expressed on the territory of Zakarpattia Oblast. Five altitudinal vegetation zones are frequently identified within the oblast (Fodor, 1974):

1) **Zakarpattia Lowland** with forest-steppe vegetation – oak-hornbeam, oak-elm-hornbeam and oak-chestnut-linden forests;

2) **Foothill Belt** with a predominance of oak (a common and rock oak) and oak-beech forests;

3) **Lower Forest Belt** with broad-leaved (oak, beech, sycamore) and beech-fir (spruce) forests;

4) **Upper Forest Belt**, represented by dark coniferous spruce forests;

5) **High-altitude vegetation belt** with two zones – subalpine, where the transition of forests into high-altitude grasslands occurs, and alpine, represented by separate fragments of mossy, lichen and shrub vegetation on the highest peaks.

Schematically, changes in the vegetation cover of Zakarpattia against the altitudinal gradient can be presented as follows (The Nature of the Ukrainian Carpathians, 1968; Fodor, 1974; The Nature of Zakarpattia Oblast, 1981; The Ukrainian Carpathians, 1988).

In the Zakarpattia Lowland, forest areas now make up less than 10% of it. The forest-steppe character of this territory is considered to be the result of anthropogenic influence, therefore the grasslands here are mostly secondary, formed on the site of felled forests. Primary natural grasslands are probably only some floodplain grasslands of the lowlands. Authentic mesophytic grasslands prevail here, with a dominance of colonial bentgrass (*Agrostis tenuis*), meadow foxtail (*Alopecurus pratensis*), meadow fescue (*Festuca pratensis*), and velvet bentgrass (*Agrostis canina*). In marshy grasslands, there is a pronounced predominance of true fox sedge (*Carex vulpina*) and slender tufted-sedge (*C. gracilis*), great watergrass (*Gliceria maxima (=G. aquatica*)). Forest communities of the lowlands are represented through the combinations with the common oak (*Quercus robur*), namely, hornbeam-oak, ash-oak, alder-oak forests; willow forest plots of brittle (*Salix fragilis*) and white (*S. alba*) willows are presented in a fragmentary way.

The Volcanic Ridge is characterized by beech forests with the more thermophilic rock oak (*Quercus petraea*) as the main species. At altitudes of 400-500 m above sea level the beech (*Fagus sylvatica*) becomes a powerful competitor of the rock oak and in deep moist soils displaces it from forest stands. Oak trees can reach heights of 900-1000 m above sea level only on rocky, sunlit steep slopes.

Unlike oaks, beech trees form mainly monodominant communities. In such ecological conditions, where beech vitality is lower, mixed beech forest stands are formed – oak-beech, hornbeam-oak-beech, hornbeam-beech, hornbeam-fir-beech, sycamore-beech. As the altitude above sea level increases and temperatures decrease, beech trees form stands mixed with conifers – fir-beech, spruce-fir and fir-spruce forest stands. Where beech forest stands form the upper boundary of the forest belt, a kind of crooked beech forest is formed by low (3-5 m) trees, often with curved trunks.

Forests dominated by silver fir (*Abies alba*) – fir forests – used to be spread over larger areas in the past than they are today. After continuous felling, they were often replaced by forests of European spruce, or Norway spruce (*Picea abies*) – to designate such stands, the terms: fir forest, Norway spruce forest, or rámen (a dialectic name for a dense spruce forest) are used. The spruce forest belt is located in the cold climate zone and is identified in Gorgany, Chornohora, and the Marmara Massif at altitudes of 700-1,600 m above sea level. Similar to beech trees, spruce trees also form mainly monodominant stands (substantial admixtures of other tree species are noted in less favorable growth conditions for spruce). Beech-spruce and fir-beech-spruce forests are formed above the beech forest belt, and beech-fir-spruce forests are formed above areas of fir forests.

Researchers believe that the grassland communities on the slopes in the mountain forest belt (below 1500 m above sea level) have a secondary origin, emerging on the site of felled deciduous, coniferous or mixed forests. The most common here are mesophytic grasslands with a predominance of red and meadow fescue (*Festuca rubra, F. pratensis*), colonial bentgrass (*Agrostis tenuis*), quaking grass (*Briza media*), red clover (*Trifolium pratense*). The composition of the grasslands of the river terraces is more diverse, the dominant species here are tall oat-grass (*Arrhenatherum elatius*), meadow foxtail (*Alopecurus pratensis*), cocksfoot grass (*Dactylis glomerata*). In the spruce forests belt, there are grasslands with a predominance of tufted hairgrass (*Deschampsia cespitosa*), and on poorer soils – with a predominance of matgrass (*Nardus stricta*). Predominantly hygromezophyte and mezohygrophyte sedge, juncus, and rush grasslands, which do not occupy large areas, are considered to be primitive.

Above the continuous beech and spruce forests (in the western part of the oblast at an altitude of 1280, and in the eastern one – of 1500 to 1850 m above sea level) in the naturally forestless highlands, the subalpine belt of a crooked forest of mountain pine (*Pinus mugo*), green alder (*Duschekia viridis*), Siberian juniper (*Juniperus sibirica*) trees formed. The highlands are characterized by the spread over large areas of barren grasslands with a dominance of matgrass, colonial bentgrass, red fescue and painted fescue (*Festuca rubra, F. picta*). Dense thickets of Munk's rhubarb (*Rumex alpinum*) appear in places of overfertilization, where livestock stops. In the areas of the alpine belt, shrub wastelands with blueberry (*Vaccinium uliginosum*), Eastern Carpathian rhododendron, or red rue (*Rhododendron kotschyi (=Rh. myrtifolium)*), blueberry (*Vaccinium myrtillus*) and a continuous layer of moss and lichen are common. There are herbicious wastelands with three-leaved rush (*Juncus trifidus*).

An important component of the vegetation cover of the highlands of the Ukrainian Carpathians are swamp communities (although they do not occupy large areas). The formation of highland swamps is associated with areas of active glacial processes, terraces, basins, underground water exits to the surface (springs). Highland oligotrophic swamps (sedge-sphagnum and sedge-hypnot), being poor in minerals, feature particularly, such species as: silver sedge (*Carex canescens*), smooth black sedge (*C. nigra*), greater tussock-sedge (*C. paniculata*), bladder sedge (*C. vesicaria*), watercress (*Cardamine opicii*), common butterwort (*Pinquicula vulgaris*).

1.6. TERRITORIAL FAUNAL COMPLEXES *(V. Sabadosh)*

The richness and diversity of the animal world of Zakarpattia is determined by the mosaic of ecotopes of its territory. The estimated number of species of the jawless fish (Cyclostomata) and fish in the oblast is 48, amphibians – 16, reptiles – 10 (The Nature of Zakarpattia Oblast, 1981). 233 species of birds have been recorded in Zakarpattia (Bashta, Potish, 2009), among which only 46 are sedentary, and 191 are nesting (including migratory and wintering ones). 81 species of mammals are identified in Zakarpattia oblast, which is 65% of the theriofauna of Ukraine (Bashta, Potish, 2007). The most numerous (26 species) is the order of rodents. Bats (Chiroptera) – 23 species; they sometimes form clusters of several thousand individuals. Among insectivores (a total of 9 species), moles, red-toothed shrews, white-toothed shrews, water shrews, and hedgehogs are common. There are 17 species of predatory mammals, 5 species of artiodactyls. The only representative of lagomorphs is the gray hare, or European hare (*Lepus europaeus*).

Five types of zoocenoses are distinguished in Zakarpattia oblast: 1) zoocenosis of cultivated lands, pastures and hayfields – agrocenoses in the broad sense; 2) zoocenosis of reservoirs and floodplain wet grasslands; 3) zoocenosis of plain oak groves; 4) zoocenosis of mountain beech and mixed forests; 5) zoocenosis of highlands – crooked forest and meadows (The Nature of Zakarpattia Oblast, 1981).

Zoocenosis of Cultivated Lands, Pastures and Hayfields

Amphibians are not numerous in terms of their species composition. The density of green toad (*Bufo viridis*) is high, the number of common or European toad (*B. bufo*) is lower. The garlic toad or the common spadefoot (*Pelobates fuscus*) was found on arable land; the European tree frog (*Hyla arborea*), the common frog or grass frog (*Rana temporaria*) and the moor frog (*R. arvalis*) – on pastures and hayfields. Reptiles here are very rare and few. The European green lizard (*Lacerta viridis*) occurs on Chorna Mountain near Vynohradiv town. The sand lizard (*Lacerta agilis agilis*) can be found on paddocks and pastures. The avifauna of the zoocenosis is quite diverse in all seasons, but the dominant species change seasonally. The Eurasian skylark (*Alauda arvensis*) dominates during the nesting period. Thousands of flocks of such species as European starlings or common starlings (*Sturnus vulgaris*), Eurasian tree sparrows (*Passer montanus*), house sparrows (*P. domesticus*), Eurasian jackdaws (*Corvus monedula*) can gather in areas of ripening crops. The Eurasian jackdaw, Eurasian tree sparrow, European goldfinch (*Carduelis carduelis*) dominate in the winter period. About 150 species of birds were registered in this zoocenosis within one year.

Mammals of the zoocenosis of arable lands, pastures, and hayfields maintain an almost constant species composition throughout the year, but some of them (hedgehogs, colonial species of bats, gophers, hamsters, birch mice) are active only during the vegetation season, and when the air temperature drops, they fall into hibernation. The following species of animals have been registered on the cultivated areas: European mole or common mole (*Talpa europaea*), white-bellied hedgehog (*Erinaceus concolor*), lesser white-toothed shrew (*Crocidura suaveolens*) and bicoloured white-toothed shrew (*C. leucodon*), lesser horseshoe bat (*Rhinolophus hipposidero*) and greater horseshoe bat (*Rh. ferrumequinum*), greater mouse-eared bat (*Myotis myotis*) and lesser mouth-eared bat (*M. blythii*), serotine bat (*Eptesicus serotinus*), stone marten (Martes foina), the common or red fox (Vulpes vulpes), Eurasian ermine (*Mustela erminea*), least weasel (*Mustela nivalis*) and European or common polecat (*Mustela putorius*), European or brown hare, European ground squirrel (*Spermophilus citellus*), brow or common rat (*Rattus norvegicus*), house mouse (*Mus musculus*), striped field mouse (*Apodemus agrarius*), wood mouse (*Apodemus sylvaticus*), yellow-necked mouse (*Apodemus flavicollis*) and harvest mouse (*Micromys minutus*), European or common hamster (*Cricetus cricetus*), common vole (*Microtus arvalis*), roe deer (*Capreolus capreolus*).

Zoocenosis of Reservoirs and Floodplain Wet Grasslands

The most valuable representatives of Zakarpattia ichthyofauna include the river or brown trout (*Salmo trutta morfa fario*), Danube salmon or huchen (*Hucho hucho*), grayling or European grayling (*Thymallus thymallus*), sterlet (*Acipenser ruthenus*). Less valuable species are considered to be the zander (*Sander lucioperca*), ide or orfe (*Leuciscus idus*), asp (*Aspius aspius*), wels catfish (*Silurus glanis*), Northern pike (*Esox lucius*), common or freshwater bream (*Abramis brama*), crucian carp (*Carassius carassius*), Eurasian or common carp (sazan) (*Cyprinus carpio*); the common nase

(*Chondrostoma nasus*), common barbel (*Barbus barbus*), European or common chub (*Squalius cephalus*), rutilus or common roach (*Rutilus rutilus*), European or common perch (*Perca fluviatilis*) are low-value species.

The most numerous species of amphibians in the oblast are the Carpathian newt (*Lissotriton montandoni*) (mountain reservoirs), yellow-bellied toad (*Bombina variegata*) (передгір'я), marsh frog (*Pelophylax ridibundus*) and pool frog (*P. lessonae*) (plain reservoirs).

The zoocenoses of reservoirs and floodplain wet grasslands of Zakarpattia oblast include the following species of reptiles: the viviparous or common lizard (*Zootoca vivipara*), slow worm or a long-cripple and hazelworm (*Anguis fragilis*), grass or ringed snake (*Natrix natrix natrix*) and dice snake (*N. tessellata*), common European adder or viper (*Vipera berus berus*), European pond turtle (*Emys orbicularis*).

Along the river banks there nest more than 30 species of birds (wrens, martins, Ciconiiformes, Anseriformes, water rails, Passeriformes), and among the waterside trees and shrubs – over 50 species (Anseriformes, predatory birds, owls, European roller, Columbinae, Picidae, Passeriformes). Riverbeds are of ecological importance for birds in different periods of the year. The bird fauna is the richest in artificial reservoirs, earlier riverbeds, and overgrown reservoirs. Many species nesting has been registered here (Eurasian or common coot (*Fulica atra*), common moorhen or swamp chicken (*Gallinula chloropus*), water rail (*Rallus aquaticus*), little crake (*Porzana parva*), mallard or wild duck (*Anas platyrhynchos*), Eurasian teal (garganey) (*Anas crecca*), black-headed gulls (*Larus ridibundus*) etc.).

Zoocenoses of reservoirs and floodplain wet grasslands include few species of mammals. Among the typical ones here are the Eurasian water shrew (*Neomys fodiens*) and Mediterranean water shrew (*N. anomalus*), European mink (*Mustela lutreola*), Eurasian otter (*Lutra lutra*), water vole or water rat, (*Arvicola terrestris*), muskrat (*Ondatra zibethicus*). Ecologically associated with wet grasslands are the field mouse and little pocket mouse, common vole, common hare, ermine, weasel, brown-toothed shrew, partially rat, fox and wild boar. During the whole year, the water vole dominates in the reservoirs, common shrew (*Sorex araneus*) and field mouse – on wet grasslands.

Zoocenosis of Plain Oak Groves

In oak groves with a well-developed underbrush and grass layer during the nesting period the background species are chaffinch (*Fringilla coelebs*) and Eurasian tree sparrow. In summertime, the Eurasian blue tit (*Parus caeruleus*) and great tit (*P. major*) are dominant, and in wintertime the Eurasian blue tit and Eurasian nuthatch or wood nuthatch (*Sitta europaea*) prevail.

The mammals inhabiting the oak groves include the European edible dormouse (*Glis glis*), forest dormouse (*Dryomys nitedula*), red squirrel (*Sciurus vulgaris*), European pine vole (*Microtus subterraneus*), field, wood and yellow-necked mice, Leisler's bat (*Nyctalus leisleri*). Among the mass species of insectivores are Eurasian pygmy shrew (*Sorex minutus*) and common shrew (*S. araneus*). A high number of hedgehogs and moles is observed in oak groves. Here there are all kinds of predators and artiodactyls, which are especially concentrated in oak groves during years of a good acorn harvest. Acorns attract wild boars, roe deer, red deer (*Cervus elaphus*), as well as rodents, which in turn are hunted by predatory birds and animals

Zoocenosis of Mountain Beech and Mixed Forests

In beech forests of Zakarpattia, typical representatives of amphibians are the Carpathian newt, fire salamander (*Salamandra salamandra*), yellow-bellied toad, tree frog, grass frog, European toad. Among the reptiles there are the sand lizard, slow worm, grass snake, common European adder, smooth snake (*Coronella austriaca austriaca*), Aesculapian snake (*Zamenis longissimus*).

Dominant species of avifauna of mountain beech forests are Eurasian chaffinch, great tit, nuthatch, song thrush (*Turdus philomelos*). The common species are stock dove or stock pigeon (*Columba oenas*), common buzzard (*Buteo buteo*), Ural owl (*Strix uralensis*), common cuckoo (*Cuculus canorus*), white-backed woodpecker (*Dendrocopos leucotos*), Eurasian jay (Garrulus glandarius), long-tailed tit (*Aegithalos caudatus*), grey wagtail (*Motacilla cinerea*), common blackbird (*Turdus merula*). Hazel grouse (*Tetrastes bonasia*), Eurasian woodcock (*Scolopax rusticola*), black stork (*Ciconia nigra*), Eurasian eagle-owl (*Bubo bubo*), Eurasian bullfinch or common bullfinch (*Pyrrhula pyrrhula*), white-throated dipper (*Cinclus cinclus*) are rare.

Among the mammals with the largest number in this zoocenosis there are common shrew, вечірниця руда common noctule (*Nyctalus noctula*), yellow-necked mouse and grey vole. The common species are European mole, brown long-eared bat (*Plecotus auritus*), Nathusius' pipistrelle (*Pipistrellus nathusii*), field mouse, least weasel, red fox, Eurasian brown bear ведмідь (*Ursus arctos*), grey wolf (*Canis lupus*), wild boar, red deer, European roe deer. The group of rare species includes the hedgehog, Alpine shrew, northern birch mouse (*Sicista betulina*), the European hare, European wildcat (*Felis silvestris*), Eurasian lynx (*Lynx lynx*), ermine, European badger (*Meles meles*), European mink.

Zoocenosis of Highlands – Crooked Forest and Meadows

The Carpathian highlands become more noticeably inhabited only in the warm season. There are 5-6 species of amphibians, 3-4 species of reptiles, 40-45 species of birds and about 30 species of mammals. The most typical vertebrates of this zoocenosis conventionally include alpine newt (*Mesotriton alpestris*), Carpathian viper, black grouse (*Lyrurus tetrix*), water pipit (*Anthus spinoletta*), alpine accentor (*Prunella collaris*), alpine shrew and European snow vole (*Chionomys nivalis*). Only the grouse, water pipit, alpine accentor and European snow vole are specific highland vertebrates that are not found in other zoocenoses of Zakarpattia oblast.

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1.7. LANDSCAPE TIERING AND ITS FEATURES *(M. Karabiniuk)*

The interaction and relationship among natural components (rocks, air masses, water, vegetation cover, etc.) lead to the formation of integral natural units on the earth surface, which in geographical science are called natural territorial complexes (landscape complexes, geocomplexes) (Herenchuk, 1968; Melnyk, 1999; Hrodzynskyi, 2005; Karabiniuk, 2020). Their functioning and development mainly depends on internal and external factors, among which an important role is played by climatic conditions. Sharp climatic changes at various stages of the development of Zakarpattia's landscapes impacted the specifics of the formation of landscape complexes and determined their main features, which were changing in the process of evolution. Therefore, the recent trends of climate change in Zakarpattia Region and the Carpathian region in general affect the current state and development of landscapes, whose functioning and geoecological state strongly depends on the interaction and influence of climatic factors and progressive anthropogenic loading.

The landscapes of the mountainous part of Zakarpattia Region were formed mainly in the conditions of dominance, in the geological substratum, of sandstone-argillite flysch, highly fragmented mountain relief and vertical differentiation of hydro-climatic conditions, which together determined the principal morphological features of landscape complexes of various ranks. The landscapes of the plain part of the oblast are characterized by accumulative and erosional origin, whose development is closely related to the evolution of the Carpathian mountain system. As a result, over 85 % of the territory of the oblast is characterized by a mountainous relief with a system of mountain massifs (Chornohora, Svydovets, Borzhava, etc.), steep ridges and their spurs, which are dissected and separated by deeply incised river valleys of the Tysa's tributaries (Fig. 1.7.1.).

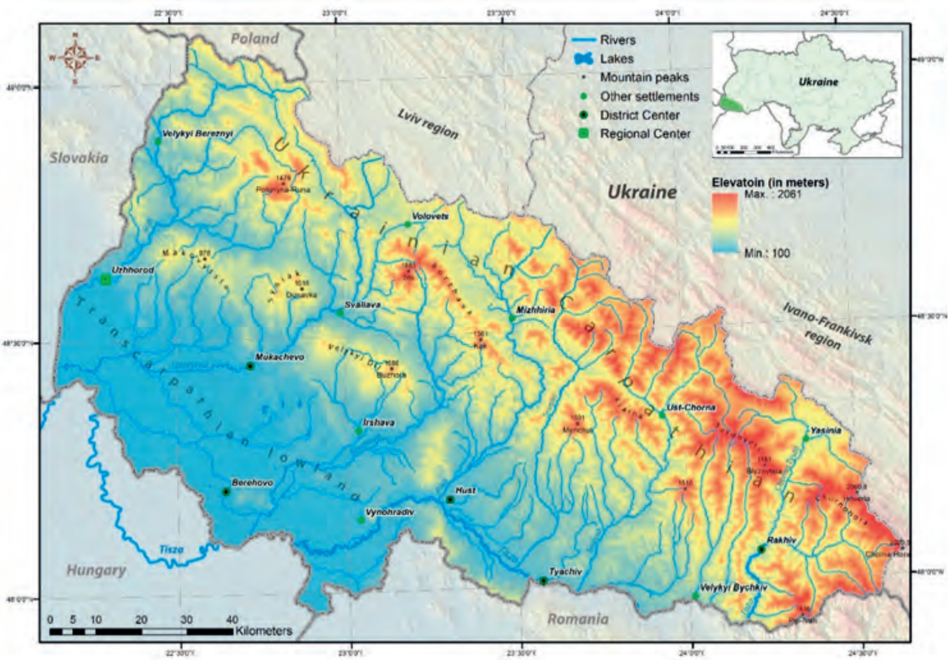

Fig. 1.7.1. Hypsometric Map of Zakarpattia Region (prepared by the author)

The landscapes of mountainous areas differ significantly from those of plain areas in the level and nature of the landscape organization. Therefore, an important aspect of our research is the use of the genetic approach in exploring the current state and development of the landscapes of Zakarpattia Region, which makes it possible to determine the spatial features of forming and locating geocomplexes of different genesis, as well as to analyze the contemporary landscape structure. In general, the landscape approach of the research involves the analysis of a continuous-discrete geographic envelope, via the prism of natural complexes of different ranks, which are directly located in a holistic landscape system, uniting natural territorial complexes of lower orders while simultaneously being a constituent part of the landscape unit of higher order (Melnyk, 1999; Hrodzynskyi, 2005).

Contemporary manifestations of global changes in the climate of the Ukrainian Carpathians have been repeatedly corroborated (Karabiniuk, Shuber, 2019; Karabiniuk, Markanych, 2020) and are relevant in view of studying the landscape organization of the cross-border territory of Zakarpattia Region. Changes in climatic conditions affect all dynamic processes and functioning of landscape complexes, circulation of substances, development of physical and geographical processes, etc. To the main manifestations of changes in the climate of mountainous regions belong changes in the features of altitudinal belting and disruption of landscape layering, which is one of the main geographical patterns of landscape differentiation of mountain systems (Karabiniuk, 2020).

There is no unanimous and clear understanding or interpretation of the notions of *landscape tiering* and *landscape tiers* in geographical science. According to H. Miller et al. (2002), landscape tiering manifests itself both at the regional level of landscape differentiation – through the layered arrangement of mountain landscapes, their referring to separate parts of a certain (low-mountain, medium-mountain or high-mountain) tier of the mountainous country, with which the formation of physical and geographical or landscape areas in the mountains is associated, as well as at the local, or intra-landscape level – through the differentiation of landscapes into morphological units (landscape layering within the landscape is shown via high altitude areas).

The study of the vertical differentiation of the landscapes of the Ukrainian Carpathians and Zakarpattia Region, in particular, testifies to the complex essence of landscape tiering, which expresses the altitudinal change of natural components and integral landscape complexes. Taking into account the complex features of the landscape tiering, it is clear that in different parts of the mountain system, there is the differentiation of individual natural components (relief, vegetation, climate, etc.) and their altitudinal limits are not always correlated (The Nature of the Ukrainian Carpathians, 1968; The Nature of Zakarpattia Region, 1981). In the academic literature, it is also noted that there are no clear altitudinal limits between landscape tiers, since they depend on a number of factors – the peculiarities of the geographical location and the complex of regional physical and geographical features (Karabiniuk, 2020). For example, the distribution of nival and glacial-exarational forms of the relief – corries, cirques, glacial troughs, nival niches, etc. is also an identifying feature of the highland landscape tier in the Ukrainian Carpathians (Kravchuk, 2006, 2008; Melnyk, Karabiniuk, 2018; Karabiniuk, 2020).

The regional understanding of the landscape tier is based on the study and analysis of the landscape organization of mountain systems, their regional division. Therefore, the regional-level landscape tier is a separate landscape area (low-mountain, medium-mountain, or high-mountain), which is formed by a group of landscapes of the corresponding low-mountain, medium-mountain, or high-mountain types (Karabiniuk, 2020). The hypsometric position and relative heights are considered the main criteria for determining whether landscapes belong to one or another landscape tier. According to H. Miller and O. Fedirko (1990), the foothills include the landscapes with maximum relative elevations above the river valleys of up to 150 m. This figure is up to 1 300 m for the mid-mountain landscape.

The highest relative elevations are characteristic of high mountain landscapes – up to 1 500 m. (Miller, Fedirko, 1990).

According to the landscape map of H. Miller and O. Fedirko (1990), three landscape tiers are distinguished in the Ukrainian Carpathians: high-mountain, medium-mountain and low-mountain ones. Within Zakarpattia Region, at the hypsometrically highest levels, the *landscapes of the high-mountain tier* are located, which are represented by paleoglacial-high meadow flysch (Chornohora, Svydovets, etc.) and paleoglacial-high meadow crystalline (Marmarosh landscape) types. The largest mountainous part of the territory of Zakarpattia Region from the urban-type village Velyky Berezny to Rakhiv is occupied by forested and steep-sided sloping *landscapes of the mid-mountain tier*, which stretch in strips from the northwest to the southeast. They are represented by the middle mountain-meadow and middle mountain-paleovolcanic types. In contrast, in the intermount basins (Yasinia basin, Mizhhiria basin, etc.) and in the hump foothill and lowland areas (Solotvyn plain, etc.) landscapes of low-mountain tier were formed, they are represented by three types: intermount-upland, low mountain-cliff and hump mountain-basin ones (Miller, Fedirko, 1990).

Based on the research conducted by us (in co-authorship) it was established that in the Ukrainian Carpathians it is appropriate to distinguish two levels of landscape tiers, the research and mapping of which is carried out at different scales and requires the use of special methodical approaches. Landscape tiers of *the regional level* are distinguished within the complete mountain system. Within individual mountain landscapes, their morphological structure and properties of landscape complexes change with elevation, which causes a consistent change in landscape tiers *at the local* (intra-landscape) *level* (Karabiniuk, 2020). Thus, in the local sense, the mountain landscape layer within the landscape manifests altitudinal differentiation of the morphological structure and features of natural complexes of different genesis, peculiarities of functioning and development (Karabiniuk, 2020). The best expression of such altitudinal change of landscape complexes is high terrain, which in mountain systems are located at different hypsometric levels depending on the manifestation of the principal factor of their formation – glacial exaration, denudation, erosion, etc.

Analyzing the features of natural conditions and the landscape structure of the mountainous part of Zakarpattia Region, it is also possible to distinguish three landscape tiers at the local level – low-mountain, medium-mountain and high-mountain tiers (Fig. 1.7.2). They consistently change with elevation and are characterized by significant differences. *The low-mountain landscape tier* is characterized by the dominance of geocomplexes of erosive and accumulative origin, as it is limited to the bottoms of river valleys and extensive intermount basins (Fig. 1.7.3).The undulating erosion relief and the leveled surfaces of the terraces of the river valleys are covered mainly by secondary grassland vegetation with fragments of beech and spruce forests, alder and other deciduous species (Miller, Fedirko, 1990; Melnyk, 1999).

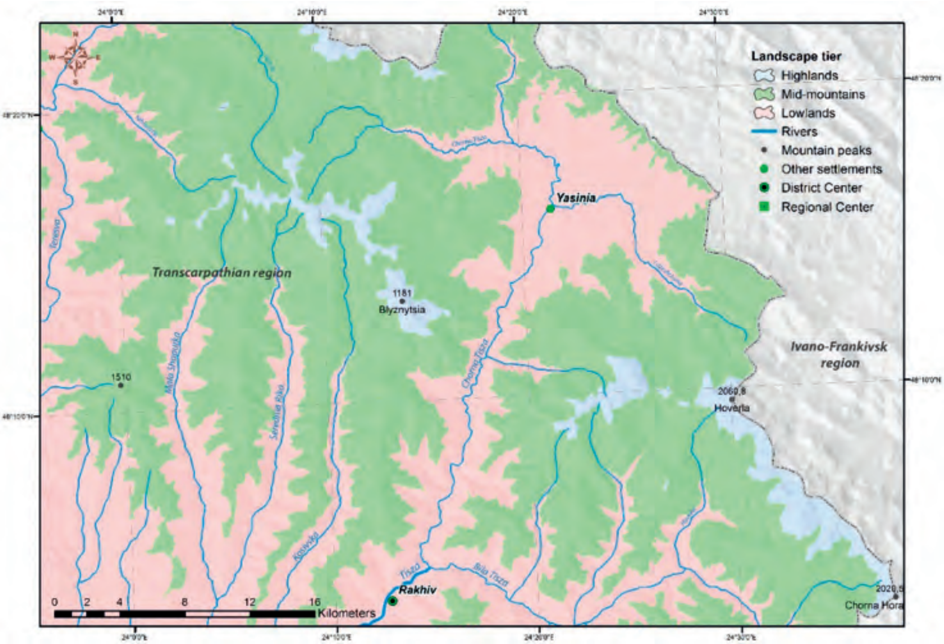

Fig. 1.7.2. Landscape tiers in the central part of the Ukrainian Carpathians in the upper reaches of the Tysa river basin (Zakarpattia Region) (prepared by the author)

The middle-mountain landscape tier covers the largest area and altitudinal range of the mountainous area of Zakarpattia Region and the Ukrainian Carpathians in general. It is represented by landscape complexes of mainly erosional and erosional-denudation origin, which are characterized by the predominance of steep slopes (over 15°) and dismembered spurs of mountain ridges with the dominance of coniferous, less often – deciduous forests on medium-thick brown soil (Melnyk, 1999; Karabiniuk et al., 2017; Melnyk et al., 2018). On well-moistened slopes, erosion processes are actively developing under the influence of permanent and temporary watercourses, which diversify the morphological structure of the landscapes of the middle mountains (Fig. 1.7.4).

a)

b)

Fig. 1.7.3. Low-mountain landscape tier within Yasinia landscape during summer (a) and winter (b) periods (photo by Yana Karabiniuk)

a)

b)

Fig. 1.7.4. Middle-mountain landscape tier of the Ukrainian Carpathians in Rakhiv district of Zakarpattia Region in summer (a) and winter (b) periods (photo by Viacheslav Yahodzynskyi)

The development of powerful water collection funnels and the deepening of dissection in in the mid-mountain landscape tier contribute to the overall evolution of the landscape structure of the territory, which depends on the amount of precipitation and petrographic and lithological features of bedrock deposits. As a result, the morphological structure and properties of the geocomplexes of the mid-mountain landscape layer in different parts of Zakarpattia Region can differ significantly depending on the above factors. A characteristic feature of the mid-mountain landscape tier is also a significant anthropogenic load from economic activity, the forest industry and agriculture, in particular, cattle breeding are actively developing (Fig. 1.7.5).

Fig. 1.7.5. Load from forest management operations (felling) on landscape complexes of the Upper Chorna Tysa river basin in Rakhiv district of Zakarpattia Region (a fragment of the space image from Google Earth)

Hypsometrically, the highest levels of the Ukrainian Carpathians are mainly occupied by denudation, glacial-exaration, and nival-erosion natural territorial complexes, which together form *a high-mountain landscape tier* (Fig. 1.7.6). In various mountain massifs (Chornohora, Svydovets, Marmarosh, etc.), the lower limit of the landscape layer varies between 1,450–1,600 m above sea level and often coincides with the contacts of the assises. For instance, within the landscape of Chornohora, on various sections, the lower limit of the highlands coincides with the contacts of the Chornohora and Yalove (Burkut and Yalove) assises, the whose lithological and petrographic differences also lead to a sharp contrast in relief forms and their morphometric features (steepness of slopes, exposure of slopes etc.) (Karabiniuk et al., 2017; Melnyk, Karabiniuk, 2018).

Fig. 1.7.6 High-mountain landscape tier of Chornohora massif of the Ukrainian Carpathians (Photo by the author)

A characteristic feature of the high-mountain landscape tier of the Ukrainian Carpathians is the dominance of massive relief forms with steep slopes and deeply incised glacial cirques, corries, nival niches and other geocomplexes. The landscape structure of the high mountains acquired its modern features during the ancient Pleistocene glaciations, and the modern development of landscape complexes occurs mainly under the influence of erosion and denudation (Karabiniuk, 2020). Subalpine and alpine vegetation is most common in the high mountains. The bottoms of corries, glacial troughs and lower parts of the massive slopes are covered with crooked forests of mountain pine, green alder and Siberian juniper. In the subalpine vegetation zone, there are also admixtures of fir-mountain pine groupings, which are sporadically distributed among continuous thickets of shrubs (Baitsar, 1994; Malynovskyi, 1980, 2003). At altitudes over 1850 m above sea level alpine meadow vegetation is widespread.

In the Ukrainian Carpathians, the high-mountain landscape tier is best expressed at the highest hypsometric levels of the Chornohora, Svydovets, Marmarosh, and Borzhava mountain landscapes. The dominance of hard sandstones in the geological base and the long history of the development of the high-mountain layer under the influence of intensive mountain formation, glaciations and modern climate changes caused a high landscape diversity (The State Geological..., 2009; Karabiniuk, 2020). The convex and flat surfaces of the crests of the main ridges of the high mountain massifs preserve the features of ancient denudation, and are now covered with juncus-fescue meadows and juniper. On the steep slopes of the high-mountain landscape, avalanche and crumbling processes are quite common, avalanches and manifestations of other physical and geographical processes are recorded annually.

1.8. CONTEMPORARY LANDSCAPE STRUCTURE *(M. Karabiniuk)*

On the earth surface, under the influence of zonal and azonal factors, there were formed numerous geocomplexes of various ranks and sizes, of different genesis and complexity of internal organization, forming a clear hierarchical structure, from the smallest landscape unit of the local level (facies) to the largest natural territorial complexes of the global order (geographic shell). Landscapes occupy a special place in this hierarchical system. The landscape studies approach envisages the exploration of the object taking into account its location in this landscape system and the features of the internal structure (Melnyk, 1999).

Each landscape complex at the local level is a clearly defined element of the internal structure of the landscape. They formed historically and separated primarily in the processes of development of the lithogenic (geological-geomorphological) base, and now are connected to one another by numerous 30 functional and energy connections (Miller, Fedirko, 1990; Miller et al., 2002). Such a system of internal organisation of the landscape, subordinated to functional quantitatively determined connections, which is represented by an aggregate of geocomplexes of lower ranks, that is, they are its morphological parts, with a peculiar character of spatial combination, shaped mainly in the process of historical development, is called a morphological structure (Melnyk, 1999; Karabiniuk, 2020). Analysing the landscape organisation of any territory, the boundaries of which do not coincide with the boundaries of landscapes as the lowest unit of physico-geographical zoning, it is appropriate to use the term «landscape structure».

According to the physico-geographical zoning of the Ukrainian Carpathians by A. Melnyk (1999), the territory of Zakarpattia Region is divided between Hirskokarpatskyi (Mountain Carpathian) and Zakarpattia physico-geographical lands (Fig. 1.8.1). The first of them occupies more than 85 % of the area of the region and is represented by 8 physico-geographical areas, which stretch mainly from the northwest to the southeast in the form of strips of various configurations and widths from 5-10 to 30-35 km, repeating the direction of the main mountain ranges of different genesis and geological structure. Each of the physico-geographical areas is characterized by unique lithological features and internal structure, which is constantly developing and transforming under conditions of climate change and a sharp increase in economic activity. The transversal division of physico-geographical areas by river valleys is due to the presence of a significant number of tectonic disturbances, which were formed during the geological development of the territory and serve as the location of the largest river valleys. Also, a number of river valleys (the Chorna Tisza river, the Teresva river, the Rika river, etc.) serve as boundaries between physico-geographical areas that were formed on lower-order morphostructures and are morphologically different from one another.

According to A. Melnyk's landscape map (1999) and own field research (Karabiniuk, 2020), the contemporary landscape structure of Zakarpattia Region is formed by 12 high-altitude areas of various origin and with significantly different properties (Fig. 1.8.2.). Hypsometrically, the highest and oldest high-altitude area is *a convex peneplenized alpine-subalpine highland* (1), which preserves relict traces of early denudation and today covers the exposed surfaces of the highest mountain massifs – Chornohora, Svydovets, etc. Strong Pleistocene glaciations in the Ukrainian Carpathians led to the formation of *the high terrain of the Paleoglacial-exaration subalpine highlands* (2), which are represented by powerful corries, cirques, through valleys and other tracts with peculiar morphometric features. Both high-altitude areas are located at altitudes above 1,450 m above sea level. and are unique in the landscape structure of the area.

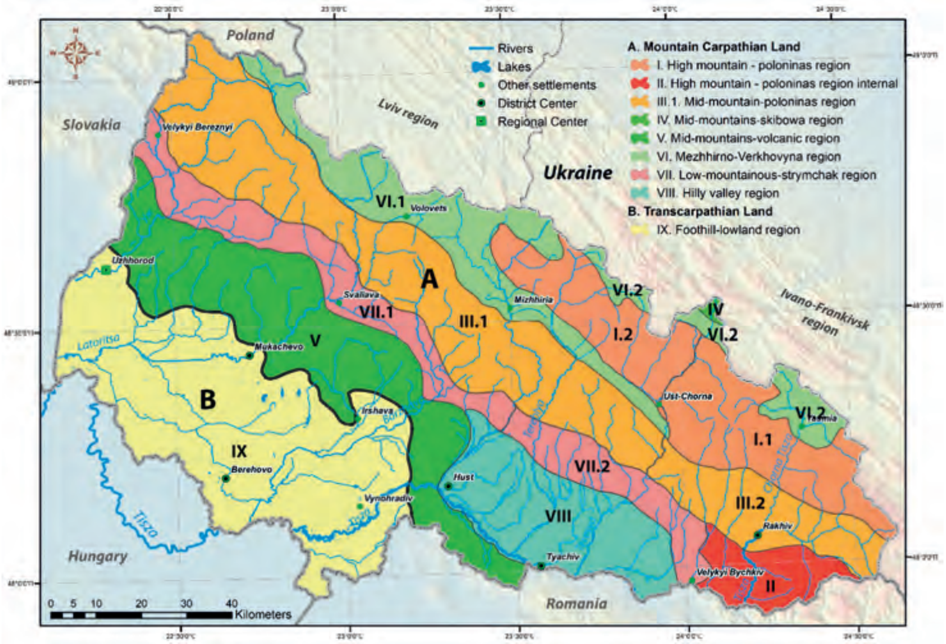

Fig. 1.8.1.Physico-geographical zoning of Zakarpattia Region (prepared according to A. Melnyk's materials, 1999)

A. Hirskokarpatskyi krai (translated as Mountain-Carpathian Land). ***I. Vysokohirno-Polonynska (Highland-Meadow) area.*** I.1. Svydovets-Chornohora district; I.2. Nehrovets-Bushtul district. ***II. Vysokohirno-polonynske yadro area (The area of High mountain-meadow core).*** Rakhiv-Chyvchyn district. ***III. Serednohirno-polonynska area (Middle mountain-meadow)***. III.1. Plonyna range district; III.2. Stih-Plai district. ***IV. Serednohirno-skybova (Middle mountain-skybova) area***. Gorgany district. ***VI. Mizhhirno-verkhovynska (Intermount-upland) area.*** VI.I. Mizhhiria district; VI.II. Mizhhirno-ulohovynny (Intermoinnt-basin) district; ***VII. Nyzkohirno-strimchakova (Low mountain-cliff) area.*** VII.1. Turia district. VII.2. Uholka district. ***VIII. Horbohirno-ulohovynna (Hump mountain-basin) area***. Solotvyno district.

B. Zakarpattia Land. ***IX. Peredhirno-nyzovynna (Foothill-lowland) area.*** Prytysianska Lowland district.

The territory of Zakarpattia Region is also home to *a high-altitude terrain of gently sloping ancient-glacial-accumulative forested midland* *(mid-mountains)* (3), the limited development of which is determined by the movement of ancient mountain glaciers during glaciation periods (Melnyk, 1999; Melnyk, Karabiniuk, 2018). It is represented by a system of loamy-boulder moraine ridges, dissected by a dense network of mountain streams and covered with fir-spruce forests. The largest glaciers in the Pleistocene period and the best-expressed paleo-glacial-accumulative landscape complexes are on the northern and northeastern macroslopes of Svydovets, Chornohora, and Maramures massifs. In the landscape structure of the oblast, the high-altitude terrains of glacial origin are unique and occupy the smallest areas (Table 1.8.1).

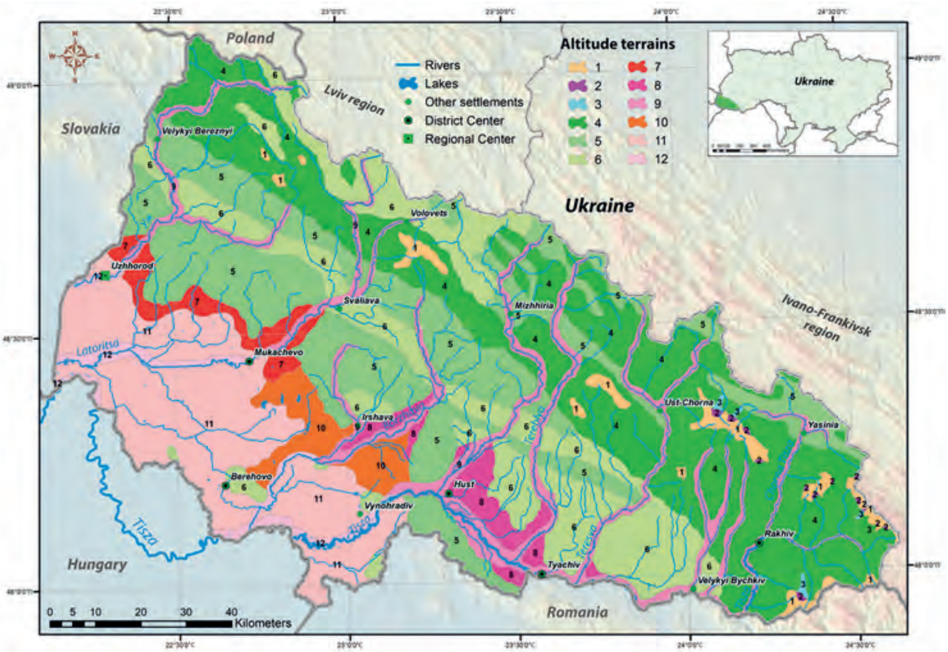

Fig. 1.8.2. Landscape map of Zakarpattia Region on the level of high-altitude terrains (based on the materials of A. Melnyk (1999) and M. Karabiniuk (2020)). Names of high-altitude terrains according to A. Melnyk (1999)

The high-altitude area of the steep sloping erosion-denudation forested middle mountains (4), the area of which is 3302.5 km^2 and covers the main part of the mid-mountain landscape layer of the Ukrainian Carpathians is the most representative in the landscape structure of Zakarpattia Region. It is characterised by a steep erosion relief, formed on massive sandstones and sandstone flysch, and the dominance of beech-fir-spruce and beech forests on low-strength brown soils (Miller et al., 1997; Melnyk, 1999; Melnyk et al., 2018).

Table 1.8.1.

Areas of High-altitude Terrains of Zakarpattia Region (calculated by the author)

Index of high-altitude terrain	Area, km²	%	Index of high-altitude terrain	Area, km²	%
1	244,6	1,9	7	275,7	2,16
2	17,8	0,14	**8**	291,2	2,28
3	19,2	0,15	**9**	1207,4	9,48
4	3302,5	25,9	**10**	353,6	2,77
5	2817,6	22,09	**11**	1917,3	15,03
6	2019,7	15,84	**12**	287,1	2,25

The basis of the low-mountain landscape tier is formed by high-altitude terrains of steep sloping erosion-denudation forested and secondary grass lowlands (5) and gently sloping erosion-denudation forested and secondary grass lowlands (6), which territorially border each other and are formed by basins and depressions of the terrain in places where argillite flysch occurs (The State Geological..., 2009; Melnyk, 1999). As a result of long-term economic development activities, a large part of the natural beech-fir-spruce and beech forests within the terrains was destroyed, and secondary grasslands were formed in their place, which are actively used as pastures and hayfields in agriculture.

The development and accumulative capacity of the river network of the Tisza River basin during the entire orogenic stage of forming the Ukrainian Carpathians and Zakarpattia, in particular, led to the formation of the system of high altitude terrains of gently sloping surfaces of high and medium terraces (7, 8), terraced bottoms of river valleys (9), etc., on different sections of lower hypsometric levels of the foothills and lowlands (Fig. 1.8.3.). On the flat territory of Zakarpattia lowland, *the high terrains of gently undulating surfaces of high terraces (10) and flat, wide, sometimes swampy surfaces of low terraces, floodplains of rivers and riverbeds (11)*, composed of pebbles and loamy alluvium, are actively developing.

Fig. 1.8.3. Riverbed and floodplain landscape complexes in the middle part of the Borzhava river basin (photo by Yana Karabiniuk)

The most complex landscape structure is typical of the mountain landscapes of Zakarpattia Region, which are characterised by a complex geological structure, a well-defined vertical differentiation of natural components and landscape complexes of various origins, sizes and possibilities of use. Therefore, the detailed exploration of the contemporary structure of mountain landscapes of Zakarpattia Region with regard to landscape studies was conducted on the example of the key area of the upper basin of the Chorna Tisza river. It is representative from the point of view of landscape tiering and placement of the main high altitude terrains of the mountainous part of the region. For a comprehensive analysis of the regularities of the spatial landscape organisation of the upper basin of the Chorna Tisza river, we developed a landscape map in scale of 1:25 000 at the level of high altitude areas and analysed the regularities of the morphological structure of the territory (Fig. 1.8.4.). The designed landscape map represents the detailed location of the high altitude terrains and was created on the basis of the analysis of numerous landscape, geological, topographic, industry maps and the author's own field research. The landscape surveying of the territory in the expeditionary manner became the primary purpose of modelling the landscape map and the comprehensive study of the natural territorial complex of the river basin. The software ArcGIS 10.4.1. became the environment for creating and modeling the natural territorial complex of the upper basin of the Chorna Tisza.

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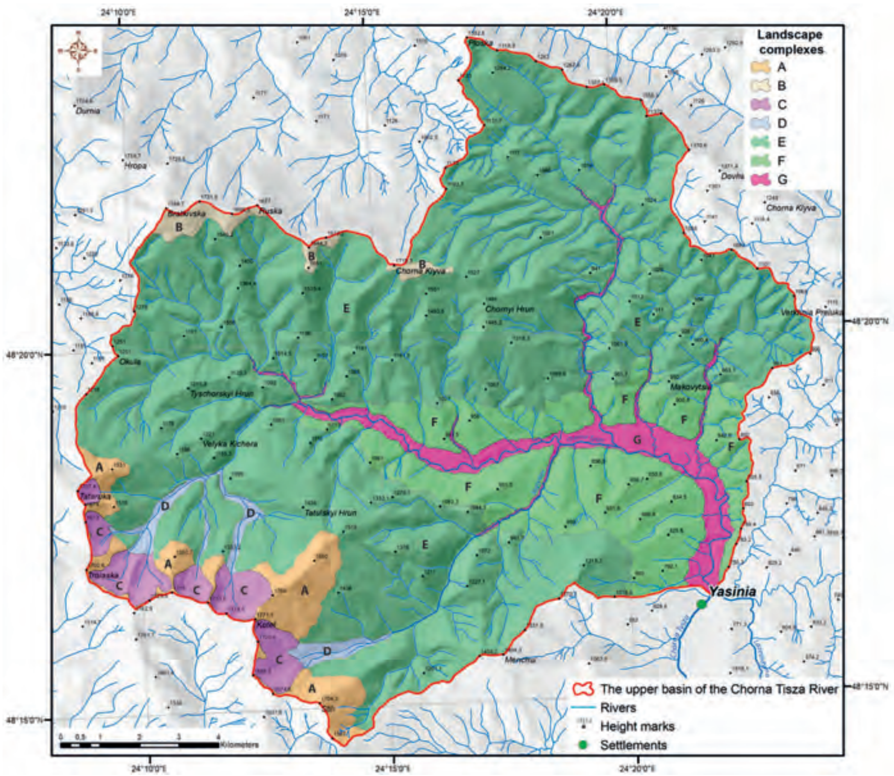

Fig. 1.8.4. Landscape map of the upper basin of the Chorna Tisza river in Rakhiv district of Zakarpattia Region (designed on the basis of A. Melnyk's (1999) and M. Karabiniuk's (2020) cartographic materials and the findings of the author's own field studies)

Map legend (Fig. 1.8.4.)

High-altitude terrains: **A** – The peneplenized very cold and very humid alpine-subalpine highlands are composed of conglomerates, massive sandstones and thick rhythmic flysch with alpine grasslands, wastelands, mountain-pine and green alder crooked forests on mountain-grassland- and mountain-peat-brown soils; **B** – Sharply concave paleoglacial-exarational very cold and very humid subalpine highlands composed of conglomerates and massive sandstones with mountain-pine and green alder crooked forests, secondary grasslands and wastelands on mountain-peat- and mountain-grassland-brown soils; **C** – Soft convex denudational cold and humid forested midlands composed of conglomerates and massive sandstones with the dominance of forests and secondary grasslands on brownsoils and sod-brown soils; **D** – Gently sloping old glacial-accumulative moderately cold and humid forested middle mountains composed of loamy-bouldery moraine with fir-spruce forests on brown soils; **E** – Steep sloping erosion-denudation moderately cold and humid forested midlands composed of sandstone flysch with spruce and beech-fir-spruce forests on low-strength soils; **F** – Steep sloping erosion-denudation moderately and humid forested and secondary grassland lowlands composed of sandstone flysch, argillites and aleurolites with interlayers of sandstones with spruce-fir and beech-spruce-fir forests on medium-strength brown soils; **G** – Terraced bottoms of the river valleys with a cool and humid climate composed of loam sandy and sandy pebbly alluvium with spruce and grey alder formations and secondary grasslands on на sod-brown soils and brown soils.

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Chapter 2.

GENERAL CHARACTERISTICS OF ENVIRONMENTAL DISEQUILIBRIUM MANIFESTATIONS IN ZAKARPATTIA OBLAST

(L. Felbaba-Klushyna, N. Kablak, Ya. Syvokhop)

In many literary sources dedicated to the study of the animate and inanimate nature of the Ukrainian Carpathians, there is information about the disturbance of the ecological balance in the ecosystems of the region. So, for example, an attempt to summarise this information was made in the works by L. M. Felbaba-Klushyna (Felbaba-Klushyna, 2010), where it is indicated that over recent decades in the Carpathian region and, particularly, in Zakarpattia, the incidence of environmental disasters has increased. The unbalanced use of nature has contributed to this. In particular, continuous felling of the forests in the past century, excessive cattle grazing on high mountain grasslands and the lowering of the upper boundaries of the forest, replacement of beech forests with spruce forests, the draining of swamps, floodplains and lakes of the lowland and other negative factors have led to the loss of water regulation, soil protection, climate-forming and other functions of the natural complex of the landscapes «mountains – lowland» (Holubets, 1978). This is confirmed by catastrophic floods, landslides, mudflow and, as a result, soil erosion and loss of water resources. As noted by V. I. Komendar, in the Ukrainian Carpathians from the late 19th to the mid-90s of the 20th century, catastrophic floods occurred 21 times, mudflows – 16 times, avalanches – 25 times, and windstorms – 12 times, which caused significant damage to the national economy (Komendar, 1994). These phenomena have become more frequent over the recent period. The most destructive floods happened in 1998, 2000, 2008 and 2010 (Felbaba-Klushyna, 2010).

Water erosion of soils is a dangerous and especially negative phenomenon in mountainous regions. According to V. I. Komendar's data, with the current state of many forests of the Carpathians, the average annual soil wash from the mountain slopes is 0.5 cm, as a result of which 4.5 million tons of fine grained soil and nutrients are carried out of the region by rivers (Komendar, 1994). P. M. Ustymenko and D. V. Dubyna believe that in

Zakarpattia oblast, among the anthropogenic changes, the most significant are the disruption of forest ecosystems under the influence of felling, since, unfortunately, compensating mechanisms of forestry management have not been found to date (Ustymenko, Dubyna, 2007).

The low technological level of land cultivation at peasant households and farms is also a source of concern. There is an increase in dehumification of soils (the content of humus in the oblast has decreased by 0.14% over the last 10 years), the deterioration of the phytosanitary condition and, accordingly, a decrease in their productivity. In the most favorable parts of Zakarpattia for agriculture, i.e. in the lowlands and in the foothills, small areas of natural and semi-natural vegetation (forests, grasslands, shrub communities) remained, they are separated by agricultural lands, industrial facilities, etc. (Ustymenko et al., 2015).

Erosion phenomena, as well as soil drainage, have become widespread all over the world. For example, 353.3 million tons of humus disappeared from the territory of Ukraine till the end of the last century, with the annual amount of soil wash reaching 600 million tons (Sytnyk, Bahniuk, 2004). Scientists' suggestion to reduce arable land in Ukraine by approximately 25% was not put into practice, however, in recent years, the efficiency of agriculture has gradually increased due to the introduction of high-yielding varieties of agricultural crops and the latest technologies of soil cultivation (Sytnyk, Bahniuk, 2004).

The most important natural resource of Zakarpattia oblast is drinking water. Due to the violation of the hydrological regime of the Tysa River basin and its tributaries, there has been a loss of water resources over the past decades. According to the results of I. Kovalchuk's research, the level of groundwater in Zakarpattia lowland decreased by 2.5 m from the end of the 60s to the beginning of the 90s of the last century, and since the mid-80s there has been a trend towards an increase in the average annual air temperature and an increase in the amount of precipitation, which are the result of a combination of factors – anthropogenic influence and global warming (Kovalchuk, 1997).

Changes in the level of groundwater lead to an increase in the degree of soil mineralization, which in turn provokes changes in flora and vegetation. Thus, groups of halophytes (salt-tolerant plants) appeared in the Transcarpathia. Among them are groups dominated by such species as *Typha laxmannii* and *Bolboschenus planiculmis*. If this trend of lowering the groundwater level continues, the region will eventually lose its unique natural features due to the invasion of synanthropic plant species. Simplification, unification, reduction of productivity and stability of all types of phytocenoses occur in the plant cover. P. L. Horchakovskyi predicted the danger of increasing rates of vegetation degradation and especially its divergence for the entire planet in the second half of the last century (Horchakovskyi, 1979). Loss of biodiversity occurs in all groups of living organisms. To illustrate, since the middle of the last century, at least 10 species of plants, confined to ecosystems with excess moisture, have disappeared from the Transcarpathia (Felbaba-Klushyna, 2010). Among them are *Carex diandra* Schrank, *Eleocharis multicaulis* (Smith) Desv., *Schoenus ferrugineus* L., *Trichoforum caespitosum*, *Gladiolus palustris* L., *Utricularia bremii* Heer, *Primula farinosa* L., *Ludwigia palustris* (L.) Elliott., *Sparganium angustifolium* Michx., *Buschia lateriflora* (DC.) Ovcz., *Carex appropinquata* Schum. To those, which are on the verge of extinction, particularly, belong the ones known only from one or two localities. These are *Potentilla palustris* (L.) Scop.), *Ledum palustre* L., *Carex davalliana* Smith.

We believe that a very important task today is the restoration of vegetation in all high-altitude zones of the region and the stabilization of its main functions in order to increase the reliability and resilience of natural ecosystems (Felbaba-Klushyna, 2010).

The war in Ukraine caused a significant increase in anthropogenic impact on the plain and foothill ecosystems of Transcarpathia in connection with displacing tens of thousands of residents of the eastern regions of Ukraine to this region, and specifically to the lowland and foothill areas. There is a growing demand for land resources to develop settlements, for water, recreational, forest and other resources to meet the needs of the population.

Given the fact that Zakarpattia Oblast, occupying only 2.2% of the area of Ukraine, plays the role of an ecological donor not only for Ukraine, but also for many regions of Europe, it is necessary to implement the latest mechanisms of nature management, built on the principles of preserving and restoring the functional core of the Tysa river basin.

L. M. Felbaba-Klushyna proved that at the current stage of the development of mountain systems, their preservation and reproduction should be based on the protection of the fluvial basin ecosystem, which, by I. I. Kovalchuk's definition (Kovalchuk, 1997), is a stable unity of interconnected and, accordingly, interdependent elements, which also depend on the processes of development of this system of elements. Yet when there are close connections in the system, a change in one element is the reason for a change in an adjacent, and sometimes more distant, element (Symonov, 1976).

There has been proposed a new approach to the protection of the Tysa River basin under the title «Fluvial Concept of Protecting the Vegetation Cover of the Tysa River Basin».

The essence of the fluvial concept is to reproduce the natural development of ecosystems of watercourses, reservoirs, swamps and floodplain complexes in all vegetation zones (from the lowland to the alpine belt) of the upper part of the river basin, which is ensured by the restoration of the hydrological function of the vegetation cover by reproducing the areas of the main types of natural vegetation close to their natural correlation, age and coenotic structure of forest vegetation, especially on the Vododilnyi (Watershed) ridge and in the lowlands (Felbaba-Klushyna, 2010).

Principal provisions of the necessity to restore and preserve the vegetation cover of the upper reaches of the river catchment area:

1) the upper reaches of the river catchment area in the mountainous region is the territory with the relatively largest area of natural vegetation and is characterised by significant biodiversity;

2) the upper reaches of the mountain rivers are the wettest areas of the mountain systems, where natural vegetation plays an extremely important role as a regulator of surface and underground flows;

3) the upper reaches of the river catchment area have the densest water network and the vegetation has an extremely important soil protection (anti-erosion) function;

4) at the upper reaches of the river catchment area, the main part of the water resources of the basin on the whole is formed and the largest reserves of clean water are concentrated, and the vegetation to a large extent ensures the maintenance of moisture circulation within the natural complex of landscapes «mountains-lowland»;

5) mountain rivers are characterized by torrential flow regime, which is manifested through devastating floods, landslides, mudflows, yet forest vegetation reduces significantly the risk of floods;

6) the upper reaches of the catchment areas of mountain rivers are poorly suitable for farming and, accordingly, are economically depressed regions. Therefore, the profit from the functions of preserved natural ecosystems is much higher than from their economic use (Felbaba-Klushyna, 2010).

The upper reaches of the Tysa river basin should play the role of a model region for the embodiment of the concept of balanced (sustainable) development not only in Ukraine, but also in Europe, and it should be given the status of «The region of a special ecological regime» in order to implement the principle of synergistic nature management.

Conducting vigorous environmental education activities among schoolchildren and other layers of the society is a prerequisite for the implementation of new environmental protection ideas in practice (Felbaba-Klushyna, 2010).

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Chapter 3.

AIR POLLUTION ISSUES IN ZAKARPATTIA OBLAST

(M.Vakerych)

3.1. AIR POLLUTION SOURCES, NATIONAL ISSUES OF THEIR CONSERVATION

The Importance of the Atmosphere

The atmosphere is one of the most important components of the biosphere. It reliably protects living organisms from cosmic and ultraviolet radiation, determines the overall thermal regime of the Earth's surface, and influences climatic conditions, which in turn affect river flows, soil and vegetation cover, and landforms. It is the atmosphere that regulates the amount of solar energy needed for life. If there were no atmosphere, the Sun would heat the Earth's surface to +100°C during the day and space would cool it to -100°C at night. The range of fluctuations in daily temperatures of 200°C exceeds the survival capabilities of the vast majority of living organisms.

The presence of an atmosphere is one of the most important conditions for life on the planet. A person can go without food for a month, without water for a week, and without air for even a few minutes. **The atmosphere** is the gas (air) shell that surrounds the Earth. The mass of the Earth's atmosphere is about 5. 15 multiplied by 1015 tonnes.

Chemical Composition of the Atmosphere

The atmosphere is composed of a mixture of gases known as air, along with liquid and solid particles in suspension. The collective mass of these particles is minuscule compared to the total atmospheric mass. Near the Earth's surface, atmospheric air typically contains water vapor, which is water in its gaseous state, in addition to various other gases.

Air without water vapour is referred to as dry air. Near the Earth's surface, dry air is primarily composed of nitrogen (approximately 78% by volume or 76% by mass) and oxygen (around 21% by volume or 23% by mass). Both of these gases exist as diatomic molecules, nitrogen as N2 and oxygen as O2. Argon (Ar) constitutes nearly 1% of the atmosphere. Carbon dioxide (CO2) makes up only 0.03%. In addition to these main components, the atmosphere contains various trace gases in minute concentrations, including krypton, xenon, neon, helium, hydrogen, ozone, iodine, radon, methane, ammonia, hydrogen peroxide, nitrous oxide, and many others.

All the aforementioned gases consistently remain in the gaseous state at the temperatures and pressures found in the atmosphere, not only near the Earth's surface but also in the upper layers. The percentage composition of dry air above the Earth's surface is constant and nearly uniform worldwide. The carbon dioxide content is the primary variable. Due to respiratory and combustion processes, its volume concentration in enclosed, poorly ventilated spaces and industrial centres can increase significantly, sometimes reaching 0.1-0.2%. The percentage of nitrogen undergoes only minimal fluctuations.

Vertical Structure of the Atmosphere. The atmosphere is conventionally divided into concentric spheres that vary in their characteristics, as illustrated in Figure 3.1.1.

Troposphere. The lower layer of the atmosphere, in which the temperature on average decreases with height, is called the troposphere. In the tropics, this layer extends from the earth's surface to an altitude of 15-17 km, in temperate latitudes of both hemispheres – to an altitude of 10-12 km and above the poles – to 8-9 km. The phrase "on average" is significant because the decrease in temperature with altitude in the troposphere is characteristic of average conditions: monthly average, seasonal average. In any given period of time, the temperature decrease in the entire layer may be interrupted by individual layers where the temperature may remain unchanged (isotherm) or even increase with altitude (inversion).

In the troposphere, the average annual temperature in equatorial latitudes decreases with altitude from +26°C near the Earth's surface to -80°C at the top of the troposphere, in temperate latitudes from +3°C to -54-58°C (50 degrees N) and above the North Pole from -23°C to -60°C in winter and -48°C in summer. The average temperature decrease with altitude is approximately 0.60°C per 100 metres, though this value can vary significantly. The troposphere contains 4/5 of the total mass of atmospheric air, contains almost all of the atmosphere's water vapour and forms almost all clouds. The troposphere is often subject to strong vertical movements and mixing, and strong instability. It is directly influenced by the underlying surface: different heating of land and sea, snow-covered and snow-free areas, warm and cold sea currents create temperature differences in the air. As a result of the interaction with the Earth's surface, warm and cold air currents arise in the troposphere.

The height to which the troposphere extends above each location on Earth varies from day to day, fluctuating around the average values mentioned above. The air pressure at the upper boundary of the troposphere is 3-10 times lower than at the Earth's surface.

Fig. 3.1.1 Atmosphere Vertical Structure
(https://geomap.com.ua/uk-g6/198.html#&gid=maps&pid=1)

The lowest thin layer of the troposphere (50-100 m), immediately adjacent to the Earth's surface, is called the surface layer. Due to its proximity to the earth's surface, it is most affected by it. In this layer, temperature changes during the day are particularly pronounced: the temperature drops particularly sharply with altitude during the day and often increases with altitude at night. Wind speed also increases most strongly with altitude.

The layer from the earth's surface to altitudes of 1000-1500 m is called the planetary boundary layer, or friction layer. In this layer, the wind speed is noticeably weaker than in the layers above, and it is weaker the closer you get to the Earth's surface.

Stratosphere. Above the tropopause and extending up to an altitude of 50-55 km is the stratosphere, characterised by temperature patterns. In the lower stratosphere (from the tropopause to 25 km), temperatures either remain constant or increase gradually with altitude. During winter, in polar latitudes, there may be a slight temperature drop. However, from 34-36 km and upward, there's a more rapid increase in temperature with altitude, continuing up to 50 km where we find the stratopause, marking the upper boundary of the stratosphere. At this level, the stratosphere is nearly as warm as the air near the Earth's surface, with an average temperature of 270 K.

The temperature increase with altitude creates significant stability in the stratosphere. This stability is characterised by the absence of turbulent (convective) vertical movements and the active mixing typically found in the troposphere. Nevertheless, there are occasional slow vertical movements, such as subsidence or uplift, that can affect extensive stratospheric layers.

Water vapour in the stratosphere is negligible. However, at altitudes of 22-24 km in high latitudes, very thin nacreous clouds are sometimes observed. These clouds are not visible during the day, but at night, they become visible as they are illuminated by the sun, which is located below the horizon. These clouds consist of supercooled droplets. The composition of stratospheric air differs from tropospheric air only due to the presence of ozone. Ozone is closely linked to temperature increases in the stratosphere, as it absorbs solar radiation. Hence, the stratosphere is often referred to as the ozonosphere from this perspective.

Mesosphere. Above the stratosphere lies the mesosphere layer, extending from the stratopause to an altitude of approximately 80-82 km. In the mesosphere, the temperature decreases with altitude, sometimes reaching as low as -110°C in its upper region. The rapid decrease in temperature with altitude leads to the development of turbulence in the mesosphere.

In the upper part of the mesosphere, the so-called silver clouds form, likely composed of crystals. The shape of these clouds indicates the existence of waves and vortices within the mesosphere. The upper boundary of the mesosphere is known as the transition layer, the mesopause, situated at an altitude of about 82 km. At the mesopause, the air pressure is roughly 1,000 times lower than at the Earth's surface.

Thus, the troposphere, stratosphere, and mesosphere together contain over 99.5% of the total mass of the atmosphere up to an altitude of 80 km. The layers above account for only 0.5% of the atmosphere's mass.

Thermosphere. The upper part of the atmosphere, extending above the mesosphere, is referred to as the thermosphere. In the thermosphere, the temperature rises dramatically with altitude. During years of intense sunshine, it can exceed 1500°C at an altitude of 200-250 km. At higher altitudes, there is no further increase in temperature with height. Only in regions with intense aurorae does the temperature briefly rise to 3000°C.

The high temperatures of the thermosphere mean that the molecules and atoms of atmospheric gases move at very high speeds in this layer. However, the air density in the thermosphere is so low that the heat capacity of the gases is negligible. Therefore, any body located here (for example, a satellite in space) will not be heated by heat exchange with the air.

The temperature regime of the satellite will depend on its direct absorption of solar radiation and the emission of its own radiation into the surrounding space.

Up to an altitude of 100 km, the air in the atmosphere is well mixed, and its composition is the same everywhere. This area is sometimes called the turbosphere. Above 100 km, the composition of the air changes significantly: atomic oxygen appears, carbon dioxide and argon disappear, and the air is highly ionised. This part of the thermosphere, from the mesopause to an altitude of 800-1000 km, is called the ionosphere. The ionic content here is many times higher than in the lower layers, despite the overall rarefaction of the air.

Exosphere: The atmospheric layer located above 800-1000 km is referred to as the exosphere, also known as the outer atmosphere. In this region, the velocities of gas particles, particularly light gases, are exceedingly high. Due to the extreme rarefaction of the air at these altitudes, particles can traverse elliptical orbits around the Earth. Additionally, individual particles can attain speeds equivalent to the second cosmic velocity, approximately 11,000 m/s for non-charged particles. These exceptionally fast-moving particles escape the atmosphere and journey into outer space, following parabolic trajectories. Consequently, the exosphere is often referred to as the "sphere of escaping gases."As we already know, the primary cause of escape in this region is the presence of hydrogen and helium atoms, which are the predominant gases in the highest layers of the atmosphere.

Magnetosphere: It was previously assumed that the exosphere marked the uppermost boundary of Earth’s atmosphere, reaching altitudes of approximately 2000 to 3000 km. However, observations conducted via rockets and satellites have revealed that hydrogen escaping from the exosphere gives rise to a structure known as Earth's corona, which envelops our planet, extending over 20,000 km. It is important to note that the gas density within the Earth’s corona is exceedingly low, averaging approximately one thousand particles per cubic centimetre. In the interplanetary space surrounding Earth, the particle concentration, primarily composed of protons and electrons, is roughly ten times lower. This region is termed the magnetosphere due to the influence of Earth's magnetic field on the movement of charged particles.

Radiation Belt: Satellites and geophysical rockets have unveiled the presence of Earth's radiation belt in the upper atmosphere and near-Earth space. This belt commences at an altitude of several hundred kilometres and extends tens of thousands of kilometres from the Earth's surface. It is composed of electrically charged particles, specifically protons and electrons, which travel at very high velocities, approximately 400 km/s, and are entrapped by the Earth's magnetic field. These particles possess energies in the hundreds of thousands of electron volts. The radiation belt undergoes a constant loss of particles from Earth's atmosphere and is replenished by solar corpuscular radiation, also known as the solar wind.

Sources of Air Pollution

The issue of air pollution is not a recent one. For over two centuries, air pollution has been a significant concern in large industrial centres across many European countries. However, for a considerable period, these pollutants have remained localised. Smoke and soot contaminated relatively small portions of the atmosphere, easily diffused by the abundance of clean air, especially during times when factories and plants were limited. The rapid expansion of industrial and transportation sectors in the twentieth century has led to the release of substances into the air that can no longer be effectively dispersed. Consequently, their concentration is on the rise, resulting in perilous and even fatal consequences for the biosphere in the twenty-first century.

Today's atmosphere contains approximately one-twentieth of the oxygen available on our planet. The primary oxygen reserves are concentrated in carbonates, organic compounds, and iron oxides, with some oxygen dissolved in water. The atmosphere maintains an approximate balance between oxygen production through photosynthesis and its consumption by living organisms. However, there is a recent concern that human activities may be depleting oxygen reserves in the atmosphere. The observed depletion of the ozone layer in recent years poses a significant danger, a phenomenon largely attributed to human activity by most scientists.

The oxygen cycle within the biosphere is highly intricate, involving reactions with numerous organic and inorganic substances. It also encompasses the combination of oxygen with hydrogen to form water.

Carbon dioxide is utilised in the process of photosynthesis to generate organic matter, thereby closing the carbon cycle within the biosphere. Similar to oxygen, carbon is a constituent of soils, plants, and animals, participating in various natural cycle mechanisms. The carbon dioxide content in the air we breathe remains relatively consistent across different regions of the world, with the exception of major cities, where the gas's concentration exceeds normal levels.

Fluctuations in the carbon dioxide content within a specific area are influenced by factors such as the time of day, season, and the biomass of vegetation. Concurrently, research indicates that since the beginning of the last century, there has been a gradual but persistent increase in the average carbon dioxide concentration in the atmosphere. This process is linked to human activities.

Nitrogen is an essential biogenic element since it constitutes a part of proteins and nucleic acids. The atmosphere serves as an inexhaustible reservoir of nitrogen, yet most living organisms cannot utilise atmospheric nitrogen directly; it must first be bound in the form of chemical compounds.

A portion of nitrogen is released from the atmosphere into ecosystems in the form of nitric oxide, a product of electrical discharges during thunderstorms. However, the majority of nitrogen enters water and soil through biological fixation. Several types of bacteria and blue-green algae are capable of fixing atmospheric nitrogen. Through their activities, as well as the decomposition of organic residues in the soil, nitrogen is converted into a form that is accessible for plant uptake.

The nitrogen cycle is closely interconnected with the carbon cycle. Although the nitrogen cycle is more intricate than the carbon cycle, it generally operates at a faster pace. While other atmospheric constituents do not actively engage in biogeochemical cycles, the presence of substantial amounts of anthropogenic pollutants in the atmosphere can lead to severe disruptions in these cycles and alter the composition of atmospheric gases. The formation of anthropogenic air pollution is influenced by the nature of pollution sources in technological units that emit harmful substances into the atmosphere during their operation. We can distinguish between stationary and mobile sources of air pollution. Atmospheric air becomes polluted with various gases, fine particles, and liquid substances that have detrimental effects on living organisms, thereby deteriorating their living conditions. Sources of air pollution can be categorised as natural or artificial (anthropogenic) (See Figure 3.1.2).

Natural Atmospheric Pollution: Natural sources of atmospheric pollution encompass phenomena such as dust storms, volcanic eruptions, cosmic dust, and more (see Figure 3.1.2). The products of natural air pollution primarily consist of inorganic substances, comprising approximately three-quarters of the total. These substances include weathering products of rocks, soil particles, ash, salt, and other similar materials.

The Earth’s atmosphere contains a variety of organic impurities, which are byproducts of organisms' life processes. These impurities encompass hydrocarbon alcohols, organic acids, esters, and aldehydes. Gaseous excretions with chemical activity produced by plants are referred to as "atmovitamins," which serve essential functions for many organisms. Organic substances that exhibit antimicrobial properties against bacteria, microorganisms, and fungi are known as "phytoncides."

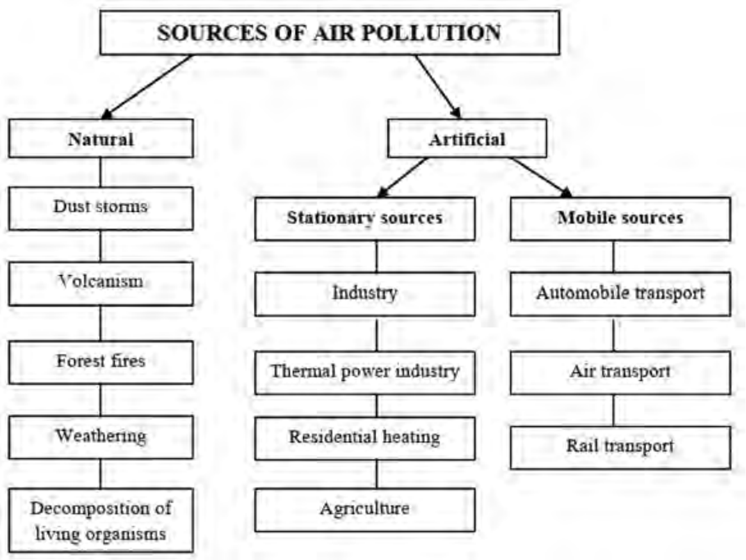

Fig. 3.1.2. Sources of Air Pollution

The annual inflow of sea salts into the atmosphere is estimated at 0.700 to 1.5 billion tonnes, while the removal of soil dust amounts to 7-700 million tonnes. Aerosol formation resulting from forest fires is estimated at 35-360 million tonnes. Altogether, a total of up to 2.3 billion tonnes of naturally occurring aerosols are released into the atmosphere from various sources.

If natural sources of pollution remain below the maximum permissible concentration (MPC), they do not induce significant alterations in the atmosphere. However, the widespread release of pollutants from natural sources within a specific region, such as ash and gas emissions from volcanoes or forest and steppe fires, can pose a serious threat to air quality. In some cases, these events can lead to the formation of an impenetrable barrier around the Earth, resulting in shifts in its heat balance. Nonetheless, natural atmospheric pollution generally has limited impact on human health, as it adheres to specific biological laws and is regulated by substance cycles, occurring periodically and predictably.

Manmade (anthropogenic) air pollution arises from human activities, leading to alterations in the composition and properties of the atmosphere. Manmade pollution sources can be categorised as stationary and mobile sources.

The most significant manmade sources of pollution include:

● *Thermal power plants*, which release emissions comprising sulphur dioxide, nitrogen oxides, soot (a carrier of tarry substances), dust, and ash containing salts of heavy metals.

• *Ferrous metallurgy plants*, which encompass blast furnaces, steelmaking and rolling facilities, mining shops, sinter plants, coke and chemical plants, and facilities for processing waste from primary production processes, as well as thermal power plants. Emissions from these operations consist of carbon monoxide, sulphur dioxide, dust, nitrogen oxides, hydrogen sulphide, ammonia, carbon disulfide, chromium and manganese aerosols, benzene, phenol, pyridine, and naphthalene.

• *Non-ferrous metallurgy*, which contaminates the atmosphere with fluorine compounds of non-ferrous and heavy metals (often in aerosol form), mercury vapours, sulphur dioxide, nitrogen oxides, carbon monoxide, polymetallic dust, resinous substances, and hydrocarbons containing benzo(a)pyrene.

• *Machine building and metal processing*: Air emissions from enterprises in this sector comprise aerosols of non-ferrous and heavy metal compounds, including mercury vapours, and organic solvent vapours.

• *Oil refining and petrochemical industry*: These industries serve as sources of the following air pollutants – hydrogen sulphide, sulphur dioxide, carbon monoxide, ammonia, and hydrocarbons, including benzo(a)pyrene.

• *Inorganic chemical enterprises*: Emissions from these operations include sulphur and nitrogen oxides, hydrogen sulphide, ammonia, phosphorus compounds, free chlorine, and carbon monoxide.

• *Organic chemical enterprises*: These facilities release substantial quantities of organic substances with complex chemical compositions, hydrochloric acid, heavy metal compounds, soot, and dust.

• *Construction materials production facilities* release pollutants into the atmosphere, including dust containing heavy metal compounds, fluorine, silicon dioxide, asbestos, gypsum, and fine glass dust.

• *Chemical air pollution from motor vehicles* is a significant factor that influences the geographical distribution of pollutants. The geographical patterns of pollutant dispersion are highly complex and are shaped not only by the layout of the motorway network and traffic density but also by the multitude of intersections where vehicles operate in varying modes.

The global number of motorised vehicles currently stands at 630 million and is projected to double within the next 20 to 30 years.

Environmental pollution resulting from motor vehicles poses a significant threat to human health. Exhaust gases released by these vehicles enter the lower atmospheric layer, where dispersion becomes challenging. Moreover, residential buildings located near motorways act as barriers, trapping pollutants.

The Primary Constituents of Air Pollution in vehicle exhaust emissions include carbon monoxide (0.5-10% by volume), nitrogen oxides (up to

0.8%), unburned hydrocarbons (0.2-3.0%), aldehydes (up to 0.2%), and soot. In absolute terms, for every 1000 litres of fuel consumed, a carburettor engine emits the following with exhaust and ground-level emissions: 200 kg of carbon monoxide, 25 kg of hydrocarbons, 20 kg of nitrogen oxides, 1 kg of soot, and 1 kg of sulphurous compounds.

The most common air pollutants enter the atmosphere mainly in two forms: either as suspended particles (aerosols) or as gases. By weight, gaseous emissions account for the largest share (80-90%) of all air emissions.

The main harmful impurities of anthropogenic origin are:

• **Carbon monoxide**. Carbon monoxide is produced through the incomplete combustion of carbon-based materials. It is emitted into the atmosphere through processes such as solid waste incineration, as well as from industrial enterprises' exhaust gases and emissions. Carbon monoxide is a compound that readily reacts with atmospheric constituents, leading to an elevation in global temperatures and the greenhouse effect.

•**Sulphur dioxide** is a colourless gas with a pungent odour. It is released during the combustion of sulphur-containing fuels or the processing of sulphurous ores. Some sulphur compounds are emitted during the combustion of organic residues in mining dumps. Sulphur dioxide is discharged into the environment as a result of emissions from heat and power generation, utilities, and transportation. It ranks as the second-largest air pollutant, following carbon dioxide. Sulphur dioxide is also a component of acid precipitation.

• **Hydrogen sulphide and carbon sulphide.** Hydrogen sulphide and carbon sulphide are released into the atmosphere either independently or in conjunction with other sulphur compounds. The primary sources of these emissions include the production of man-made fibres, sugar refining, coke and chemical industries, as well as oil refineries. When present in the atmosphere and interacting with other pollutants, these compounds undergo gradual oxidation, ultimately forming sulphur dioxide.

• **Nitrogen oxide.** Nitrogen oxide is a compound formed by the combination of nitrogen and oxygen. Depending on the degree of oxidation, the following nitrogen oxides exist: NO, N2O, N2O3, NO2, and N2O5. Oxides N2O3 and N2O5 are in solid form, while all others are gaseous. Natural sources of nitric oxide in the environment include lightning and volcanic eruptions. Man-made sources of nitrous oxide emissions encompass chemical plants, the production of mineral fertilisers, explosives, nitric acid, bacterial decomposition of silage, and more. The most significant volume of nitrogen oxide emissions arises from road transportation. The concentrations of nitrogen oxides in urban air during the day closely correlate with traffic intensity and solar radiation. Consequently, nitrogen oxide accumulates in the atmosphere during daylight hours due to the photo-chemical oxidation of this gas. Nitrogen oxide is a hazardous pollutant due to its high toxicity and its adverse effects on the atmosphere, including acid precipitation and smog. Moreover, in the stratosphere, nitrogen oxide contributes to ozone depletion.

• **Fluorine compounds.** Pollution sources include facilities involved in aluminium, enamel, glass, ceramics, steel, and phosphate fertiliser production. Substances containing fluorine are released into the atmosphere as gaseous compounds, such as hydrogen fluoride, or as dust containing sodium and calcium fluoride. These compounds exhibit toxic effects, and fluorine derivatives are potent insecticides.

• **Chlorine compounds.** They enter the atmosphere from chemical plants producing hydrochloric acid, chlorine-containing pesticides, organic dyes, hydrolysis alcohol, bleach, and soda. Chlorine molecules and hydrochloric acid vapours occur in the atmosphere as impurities. The toxicity of chlorine depends on the type of compounds and their concentration. The metallurgical industry releases various heavy metals and toxic gases into the atmosphere during iron smelting and steelmaking. For instance, for every tonne of pig iron produced, in addition to 12.7 kg of sulphur dioxide and 14.5 kg of dust particles containing arsenic, phosphorus, antimony, lead, mercury vapour, tar substances, and hydrogen cyanide, the industry emits.

• In addition to gaseous pollutants, a significant amount of particulate matter is released into the atmosphere, including **dust, soot, and ash**. Environmental contamination with heavy metals poses a significant danger. Lead, cadmium, mercury, copper, nickel, zinc, chromium, and vanadium have become nearly constant components of the air in industrial centres.

Harmful effects of polluted air on people, animals and plants. The harmful effects of polluted air on humans, animals, and plants are of great concern. A crucial issue concerning these effects is the adherence to environmental regulations in the operation of enterprises, facilities, and other activities. Compliance with these regulations can be achieved through the implementation and more efficient utilisation of environmental protection measures. Among these measures, preventing air pollution is of paramount importance, as any breach of air quality inevitably impacts the condition of water and land. Therefore, air protection measures should ensure the preservation of flora and fauna. Thus, safeguarding the environment from harmful biological effects necessitates a comprehensive approach to preventing air and water pollution caused by industrial emissions.

Air pollution is defined as an increase in the concentration of physical, chemical, and biological components beyond levels that disrupt natural systems. Within industrial emissions, the primary sources of air pollution are low-process and ventilation emissions (such as shop lights and ventilation systems), which make up approximately 80% of total emissions. A crucial characteristic of such emissions, in terms of air pollution, is that the highest concentrations of harmful substances are found in close proximity to their source, unlike high sources where this occurs at a distance of up to fifteen times the chimney height. As a result, industrial emissions into the atmosphere primarily impact humans and the environment, with the most severe manifestations taking place near industrial sites and their surrounding areas. Here, the air contains significantly higher concentrations of harmful substances, exceeding maximum permissible levels by 2-5 times, and often even more. These areas also accumulate a substantial portion of these pollutants in the soil and on the surface of water bodies.

Therefore, addressing the issue of preventing air pollution is particularly critical in cities, where a significant portion of the population and industrial activity is concentrated.

The unfavourable environmental situation is attributed to unresolved issues concerning the implementation of environmental protection measures, imperfect methodological materials for the design of air purification devices, and insufficient baseline data for environmental assessments of manufactured products and developed technological processes.

Industrial emissions into the atmosphere disperse over a considerable distance, contaminating the surface air layer not only at industrial sites but also in neighbouring residential areas. Both organised and fugitive process emissions have a substantial impact on air pollution. Existing regulatory and technical documentation permits maximum air pollution levels at the air intake points of industrial ventilation systems, which is set at 0.3 times the Maximum Permissible Concentration (MPC). Furthermore, air pollution resulting from ventilation system emissions should not exceed 1 MPC. Nevertheless, many enterprises fail to meet these requirements, resulting in air pollution that often exceeds not only the MPCs but also the Maximum Permissible Emission (MPE) standards by several times.

The consistent or periodic presence of harmful substances in the air of residential areas, with concentrations exceeding standard values, leads to various health issues, including the development of diseases, and even cancer. It also contributes to substance abuse among certain individuals, complicates the progression of cardiovascular diseases, and triggers the onset and development of respiratory and nervous system conditions. Studies indicate that in areas with relatively low levels of air pollution, the incidence of respiratory diseases increases by two or more times, while in highly polluted areas, it may surge by up to 40 times. Children are particularly vulnerable to the effects of pollutants, with the damage to their health being several times greater than that experienced by adults.

It has been established that a persistent exceedance of the permissible concentration of just one type of controlled pollutant results in a 1.7-fold increase in morbidity, and in certain age groups, even up to three times. Atmospheric pollution also directly impacts building facades, decorative ornaments, vehicles, monuments, clothing, and more.

The Impact of War on Air Quality in Ukraine

The quality of the air in Ukraine has deteriorated due to hostilities in both direct and indirect ways. The direct impact of hostilities involves the detonation of shells and the use of artillery and aerial bombs. According to the State Emergency Service, more than 120,000 explosive devices, including 1,978 aircraft bombs, were defused in Ukraine during the first three months of the war. Additionally, the Russian army fired 2,275 missiles at Ukraine, with some of these missiles hitting Ukrainian ammunition depots, leading to further detonations. Such explosions release lead, soot, carbon, and other harmful substances into the air. The remnants of the shells contain sulphur, copper, iron, and carbon. When these pollutants reach the soil, they contaminate water and subsequently pose risks to human and animal health.

Indirect impacts of the hostilities include fires in ecosystems, explosions of oil depots, attacks on industrial facilities, and hazardous waste storage facilities, such as polyurethane foam, mineral fertilisers, paint and varnish, ammonium nitrate, etc. As of May 24, 2022, 36 hits on oil infrastructure facilities were recorded. Fires at oil depots emit heavy metals, sulphur dioxide, soot, nitrogen oxides, and other pollutants into the air, which are harmful to human health. Moreover, these pollutants that seep into the soil gradually degrade the quality of groundwater and surface water. Emissions from forest fires, oil depots, and other facilities total approximately 182 million tonnes of harmful substances. According to the Ministry of Environment of Ukraine, the amount of harmful substances emitted into the air during the war is equal to the amount of emissions from one steel plant for a full year of operation.

Measures for Atmospheric Air Protection

Atmospheric protection comprises a system of local, state, and international measures aimed at preserving, rationally utilising, and safeguarding the qualitative and quantitative attributes of the air and atmospheric circulation that are beneficial for society and the entire natural environment. It is an integral part of the broader endeavour to protect the natural world.

These atmospheric protection measures can be categorised into three main groups:

➢ Measures to prevent air pollution through the rational, dispersed location of industrial enterprises, taking into account natural conditions, pollution, and air self-purification capabilities.

➢ Measures to reduce the gross volume of pollutants released into the atmosphere, including the improvement of fuel quality and technological processes (low- and no-waste technologies).

➢ Measures to disperse, treat, and neutralise harmful emissions, encompassing the construction of chimneys, installation of treatment facilities (filters), bacterial decomposition of pollutants, and their absorption by plants.

Additionally, there are economic, technological, organisational, administrative, and political methods for combating air pollution.

The primary and most effective methods are economic in nature. Many developed countries have well-designed systems of incentives and penalties aimed at reducing pollutant emissions. Businesses that implement zero-waste technologies and new treatment facilities benefit from significant tax advantages, thereby enhancing their competitiveness. Conversely, companies that contribute to atmospheric pollution face substantial taxes and fines, with the fines determined by the quantity of pollutants released into the air (exceeding the MPC) and the duration of emissions.

Technological methods (measures) for addressing air pollution are typically considered after economic ones. Among these, the following are the primary measures:

1. Reducing the number of thermal power plants by constructing larger, more efficient facilities with advanced systems for cleaning and utilising waste gases and dust (aerosols). A single large thermal power plant pollutes the air much less than 100 boiler houses of the same capacity. Special facilities, such as cyclones, are used to clean the gases emitted from thermal power plant furnaces before they are released into the atmosphere. Some countries have nearly complete purification of thermal power plant gases from harmful impurities, resulting in economic benefits. For example, France meets its sulphuric acid needs by utilising gases from thermal power plants, as it lacks its own sulphur deposits, which are sourced from other countries. Certain thermal power plants have even established briquette production using captured dust, which serves as a building material.

2. Precombustion cleaning of coal to remove pyrite (ferrous (II) sulphide – FeS2) before its use in thermal power plant furnaces. Pyrite decomposes during oxidation in furnaces, releasing SO2. Pyrite purification is particularly relevant due to the declining quality of coal used in thermal power plants over the years, with increasing pyrite content. Effective coal cleaning can result in a reduction of sulphur oxide emissions by 98-99%.

3. Substituting coal and fuel oil with cleaner fuels (such as natural gas) at thermal power plants and transitioning to environmentally friendly energy sources (solar, wind, water, geothermal). Gas-fired power plants emit only CO2 and nitrogen oxides, the latter of which can also be captured from emissions.

4. Raising the height of chimneys. The greater the chimney's height, the better the dispersion of dust and gas emissions in the atmosphere. A chimney of 100 metres can disperse harmful substances within a radius of up to 20 kilometres, while a chimney of 250 metres can disperse up to 75 kilometres. There was once a proposal to construct ultra-high chimneys (over 300 metres) at thermal power plants, initially in the West and later in our country. The world's tallest chimney, exceeding 400 metres in height, was built at the Sudbury Copper and Nickel Plant in Canada. However, releasing emissions through tall chimneys can exacerbate environmental damage, as aerosols linger in the upper atmosphere for years, leading to the pollution of more remote areas and an overall increase in background air pollution. Additionally, as the height of a chimney increases, its construction cost rises significantly, making it advisable not to build chimneys over 150 metres in height.

5. Enhancing the efficiency of power plants.

6. Enhancement of power plant treatment facilities. The construction of emission treatment facilities is an effective but expensive measure, with costs ranging from 8-10% of the total expense of the primary production facilities. The European Parliament has enacted legislation mandating that thermal power plants install facilities not only for dust and smoke removal but also for addressing all other gases. The cost of implementing such facilities may account for up to 40% of the total expenditure on the power plants themselves.

7. Regulation of internal combustion engines in vehicles, including the installation of catalysts that convert carbon monoxide to CO2, the introduction of electronic fuel control systems, and the replacement of environmentally hazardous leaded petrol with less harmful unleaded petrol.

Organisational measures include the following:

1. The rational spatial arrangement of residential and industrial areas within cities. Maximising the distance between these areas is crucial, and the creation of green sanitary protection zones between them is recommended.

2. The planning of major traffic routes, especially for heavy vehicles such as trucks, outside of residential regions.

3. The design of power transmission lines located outside of towns and villages.

4. The introduction of greenery into settlements. During the growing season, one hectare of forest can trap 40-60 tonnes of airborne dust and

neutralise over 200-250 kg of sulphur (IV) oxide, 100 kg of chlorine, and 50 kg of fluorine. Gas-resistant plants exhibit even greater absorption of harmful substances. Polluted air entering middle-aged green spaces at depths of 100-150 metres is nearly devoid of suspended particles, with a tenfold reduction in other impurities.

The purifying capacity of green spaces exceeds the amount of impurities carried by precipitation, especially during the summer. Within a year, 1 hectare of forest can purify more than 18 million cubic metres of air, removing dust and other harmful components. This is 3 to 10 times more than what field plants cultivated by humans on a similar area can achieve. Moreover, a forest of this size releases 2-4 kg of phytoncides into the air daily, and just 30 kg of phytoncides is sufficient to combat pathogens in a large city. Tree canopies also alter the direction of surface air currents, contributing to the formation of upward drafts, ultimately dispersing pollutants.

5. Utilisation of soundproofing materials in the construction of industrial facilities.

The State of Air Quality in Ukraine

The primary sources of air pollution in Ukraine include ferrous metallurgy (33%), energy production (30%), coal mining (10%), and the chemical and petrochemical industries (7%). Annually, approximately 17 million tonnes of hazardous substances are released into the atmosphere across Ukraine. Over a third of all industrial air pollutant emissions originate from fuel-fired thermal power plants. The energy sector, ferrous metallurgy, and coal mining contribute significantly to sulphur dioxide emissions, accounting for 80% of the total. Nitrogen oxide emissions are primarily associated with energy and metallurgical enterprises, representing 72% of the emissions. The chemical, petrochemical, and gas industries are responsible for the majority of hydrocarbon emissions (43%). Motor vehicles contribute to more than a third of total harmful air emissions, amounting to 6.5 million tonnes annually. In Yevpatoria and Uzhhorod, this figure accounts for 91% of the total emissions.

It has been established that prolonged exposure to air pollution, including substances such as sulphur dioxide, carbon monoxide, nitrogen oxides, and others, has adverse effects on human health. This exposure can lead to an increase in overall morbidity among the population, resulting in damage to specific organs and bodily systems. Ukraine is home to approximately 1,500 enterprises that release harmful substances into the atmosphere, contributing to an annual increase of 12 million tonnes in total waste production.

The highest levels of air pollution are typically observed in the Donetsk and Transnistrian regions of Ukraine, as well as around regional centres.

Our country is taking steps to reduce air emissions by equipping sources of harmful substances with dust and gas cleaning units. Outdated dust and gas cleaning units are either being replaced or subject to reconstruction, and low- and zero-waste technological processes are being introduced. Transportation is a major contributor to air pollution, accounting for over 40% of carbon monoxide, 46% of hydrocarbons, and approximately 30% of nitrogen oxides in the total emissions of these substances into the atmosphere. The collective volume of harmful emissions from motor vehicles amounts to 2.7 million tonnes annually. In Ukraine, emissions from motor vehicles constitute about 27% of the total pollutant emissions.

According to the State Statistics Service of Ukraine, in 2020, emissions of air pollutants from stationary sources amounted to 2,238.6 thousand tonnes, which is 220.9 thousand tonnes (9.0%) less than in 2019.

The overall emissions of air pollutants, including chlorine vapours, iron, and manganese oxides, remain low and do not exceed 1 kg per year.

In the same year, stationary pollution sources emitted 109.1 million tonnes of carbon dioxide, a greenhouse gas influencing climate change, marking an 8.99% decrease compared to 2019.

On the other hand, mobile pollution sources, particularly road transport, released 1,778.7 thousand tonnes of pollutants into the atmosphere, an increase of 129.9 thousand tonnes compared to the previous year.

In 2020, the total emissions of pollutants from both stationary and mobile sources reached 4,017.3 thousand tonnes, with 2,238.6 thousand tonnes from stationary sources and 1,778.7 thousand tonnes from mobile sources.

Notably, the highest emissions from stationary sources in 2020 were recorded in the Donetsk Oblast (750.9 kt), Dnipropetrovsk Oblast (534.6 kt), and Zaporizhzhia Oblast (155.4 kt).

For the same year, the per capita air pollutant emissions for each resident of Ukraine amounted to 53.6 kg, while each square kilometre of the country's territory accounted for 3.8 tonnes of pollutants.

Among Ukrainian settlements, four cities experienced the highest anthropogenic load (over 100 thousand tonnes of pollutants) in 2020: Burshtyn, Kurakhove, Kryvyi Rih, and Mariupol. The total air pollutant emissions in these cities account for 35% of all emissions in the country.

The primary chemical components that were released into the air from stationary sources in 2020 included substances in the form of suspended particulate matter (248.9 thousand tonnes, 11.1% of the total pollutants), sulphur dioxide and other sulphur compounds (782.1 thousand tonnes, 34.9%), methane (429.1 thousand tonnes, 19.1%), and others.

The major toxic elements that polluted the air due to the operation of mobile pollution sources were carbon monoxide (76.3% or 1358.4 thousand tonnes), nitrogen dioxide (10.6% or 189.9 thousand tonnes), non-methane volatile organic compounds (9.8% or 175.3 thousand tonnes), soot (1.5% or 27.7 thousand tonnes), and sulphur dioxide (1.1% or 20.8 thousand tonnes).

The anthropogenic and man-made air pollution burden in Ukraine is several times higher than in developed countries. The primary air pollutant sources are the extractive and processing industries, electricity, gas, steam, and air conditioning, with their emissions accounting for more than 90% of the total air emissions in Ukraine.

In terms of economic activity, the manufacturing industry is responsible for the largest share of pollutant emissions, accounting for 38.8%.

The second-largest source of pollution is the supply of electricity, gas, steam, and air conditioning, representing 37.9% of emissions. Specifically, metallurgy contributes to 32.6% of the country's total emissions. Meanwhile, the mining and quarrying industry accounts for 16.3% of overall air emissions.

3.2. STATE OF THE AIR IN ZAKARPATTIA: MAIN POLLUTION THREATS AND CONSERVATION ISSUES

In 2020, there was a slight decrease in air pollutant emissions from stationary sources. According to the Main Department of Statistics, the amount of pollutants entering the air basin in 2020 from stationary sources of pollution decreased by 10.8% compared to 2019, amounting to 3.3 thousand tonnes, as opposed to 3.7 thousand tonnes in 2019. Greenhouse gas emissions, including methane, accounted for 28.9% of the total pollutant emissions, with carbon dioxide emissions contributing 0.2 million tonnes.

Among the total air pollutant emissions, the most significant contributors are as follows:

Raions and cities with the most polluted air		**Raions and cities with the cleanest air**	
Uzhhorod	40,51%	Tyachiv	1,16%
Volovets	12,35%	Rakhiv	0,93%
Svaliava	8,92%	Mukachevo	0,65%
Perechyn	7,23%	Khust city	0,58%
Mukachevo city	6.39%	Irshava	0,47%
Mizhhirya	4,9%	Vynohradiv	0,33%
Khust	4,72%	Berehovo	0,14%
Berehovo	4,54%	Chop city	0,05%
Uzhhorod city	3,53%	Velykyi Bereznyi	1,16%

On average, in 2020, each enterprise in the region emitted 19.8 tonnes of pollutants into the atmosphere.

The decrease in air pollutant emissions in the region can be attributed to major contributors, such as JSC "Zakarpathaz" and the main gas pipelines of the Zakarpattia Oblast Linear Production Department of Main Gas Pipelines. More specifically, these emissions are directly proportional to the amount of gas pumped by these enterprises.

The volume of pollutant emissions from stationary sources per person decreased compared to 2019, dropping from 3.0 kg to 2.6 kg.

The main factors contributing to air pollution include the volume of gas pumped, outdated technical equipment, and maintenance practices at compressor stations. Inefficient operation of antiquated gas cleaning equipment has been observed at asphalt concrete plants of the Zakarpattia Oblast Road Service and powerful boiler houses in Mukachevo, Berehove, Vynohradiv, and Khust raion heating networks. Additionally, the boiler houses of the Ministry of Transport and Communications of Ukraine are inadequately equipped with ash collectors.

Motor vehicles remain the primary air pollutant in Zakarpattia Oblast, contributing to over 90% of the total emissions. In recent years, there has been a significant increase in the number of motor vehicles, along with a rise in the number of petrol stations, which constitutes a significant source of air pollution.

Among the enterprises responsible for the largest air emissions in the region are JSC "Zakarpathaz" and the main gas pipelines of the Zakarpattia Linear Production Department, which collectively account for 68.1% of the total emissions, amounting to 2.3 thousand tonnes. Consequently, the reduction of pollutant emissions into the atmosphere is closely tied to these enterprises, particularly in terms of the volume of gas they pump and the maintenance practices at their compressor stations.

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Chapter 4.

POLLUTION ISSUES OF THE WATER BODIES OF ZAKARPATTIA

(M.Vakerych)

4.1. SOURCES OF POLLUTING WATER BODIES, NATIONAL ISSUES OF THEIR PRESERVATION

Water is one of the most common substances on planet Earth. The total amount of water on Earth is about 1.5 billion km^3, and its weight is 1.5 × 1018 tons. On average, the amount of water per person constitutes 1/5 km^3, or 200 million tons! However, the salty waters of the World Ocean constitute 96,5% of all water on the planet, land waters (rivers, lakes, swamps, underground waters, glaciers, permafrost) account for 3,5%. All these water bodies have certain typical properties and in aggregate make up a single continuous water shell of the globe – the hydrosphere.

So, the hydrosphere is the water shell of the Earth, that is, water in all its possible aggregate states. The hydrosphere includes the totality of all water bodies on the globe: oceans, seas, rivers, lakes, reservoirs, swamps, groundwater, glaciers, and snow cover.

Water resources are a strategic, vital natural resource of special importance. They are the national wealth of every country, one of the natural pillars of its economic development; ensure the functioning of all spheres of human life and economic activity, determine opportunities for the development of industry and the agro-industrial complex, the location of settlements, the organization of recreation and the improvement of people's health. Water is the basis of life on our planet. Over 20% of it is concentrated underground and only 1% circulates in rivers, lakes, swamps and the atmosphere. The proportion of water in the soil is not less than 20%, in plants and animal organisms – up to 50%. The human body is made of 70% water: 99% of it is in the vitreous body of the eye, 83% is in the blood, 75% is in the brain and muscles, 22% is in the skeleton, and 0.2% is in tooth enamel. Of the total amount of water, 97.5% is the salt water of the World Ocean. A little more than 2% of all water, or about 39,500 km^3, is usable by humans. Of the indicated volume of water, 69% is snow and ice of Antarctica and Greenland, about 30% is underground water, and only 0.12% is the surface water of rivers and lakes. About 9,000 km^3 is suitable for direct use, and about 4,000 km^3 is consumed. If we consider the needs of water with repsect to parts of the world, the largest amount is consumed in Asia – 55% of all water, in North America – 19, Europe – 9.2, Africa – 4.7, South America – 3.3, the rest of the territories – 8.8%. By sectors of the economy, agriculture uses 70% of water, industry – 22%, households account for 8%. The annual world average water intake from rivers and underground sources is 600 m^3 per person, of which 50 m^3 is drinking water, i.e. 137 liters per person per day. In North America and Japan, water consumption per day is 600 liters, in Europe – 250-350, in countries near the Sahara – 10-20 liters.

Water resources of Ukraine consist of the flow of rivers and fresh underground waters. The resources of the local river flow, that is, the flow formed in the river network on the territory of the country, in an average-flow year are 52.4 billion m^3, and in a very low-flow year with 95% water availability – 29.7 billion m^3. The inflow of river waters from the neighbouring territories in such years amounts to 157.4 and 121.7 billion m^3, respectively, of which 122.7 and 95.5 billion m^3 come through the Kili branch of the Dunai. The total amount of water resources of the river flow in an average-flow year are 209.8 billion m^3, and in a very low-flow year – 151.4 billion m^3. Water resources available for wide use are formed mainly in the basins of the Dnipro, the Dnister, the Siverskyi Donets, the Pivdennyi Buh (Southern Buh) and Zakhidnyi Buh (Western Buh), as well as small rivers of Pryazovia (the Azov Sea region) and Prychornomoria (the Black Sea region). Lakes in Ukraine occupy 0.3% of the country's territory. Big lakes are located in the lower reaches of the Dunai and on the coast of the Black Sea (Sasyk, Yalpuh, Katlabuh, Kahul, Kytai); in the basin of the Zakhidnyi Buh (Western Buh) – Svitiaz, the biggest of the mountain lakes is Synevyr (Fig. 4.1.1.). Based on the approximate estimates, the volume of water in fresh lakes reaches 2.3 billion m^3. Freshwater lakes are used for local water supply, irrigation, the breeding of fish, waterfowl and valuable fur-bearing animals, and as fresh water accumulators.

According to long-term observations, in an average-flow year, the potential resources of the river waters in Ukraine amount to 88 billion m^3 (without the flow of the Dunai river), of which only 52 billion m^3 are formed within Ukraine. In a low-flow year, these reserves are much lower and amount to 56 billion m^3 and 32 billion m^3, respectively. In most regions of Ukraine, the transit flow exceeds the local flow. The highest amount of water resources (58%) is concentrated in the rivers of the Dunai basin in the border regions of Ukraine, where the demand for water does not exceed 5% of its total reserves. Donbas, Kryvyi Rih, Krym and other southern oblasts of Ukraine, where the largest water consumers are concentrated, are the least provided with water resources. The issue with the supply of water resources in Ukraine is particularly acute, because in terms of water reserves that are formed on the territory of the country and are available for use, it is one of the least supplied countries in Europe. The minimum level of water supply determined by the UN is 1.7 thousand m^3 per year per person. In Ukraine, this figure is only 1.0 thousand m^3. According to the international classification, only Zakarpattia oblast belongs to the regions with the average supply local flow (6.3 thousand m^3 per 1 person). The water supply in Chernihiv, Zhytomyr, Volyn and Ivano-Frankivsk oblasts (3.3–2.0 thousand m^3) is low, in other oblasts – very low and extremely low (1.98–0.12 thousand m^3 per person). Taking into account the different natural and climatic conditions of the regions of Ukraine, the issue of their water supply is solved by the State Water Agency of Ukraine at the expense of territorial and seasonal redistribution of water resources. In providing low-water regions with water resources, a significant role is played by large state main water lines of complex purpose, which supply about 3 billion m^3 of water every year. In order to provide the population and sectors of the economy with the required amount of water, there were built 1,103 reservoirs with a total volume of over 55 billion m^3 and about 49,000 ponds, 7 large canals 1,021 km long and 10 large-diameter aqueducts, which supply water to low-water regions of Ukraine.

Fig. 4.1.1. The biggest mountain lake of Ukraine – Synevyr (Zakarpattia oblast)

In recent years, as a result of global climate change, signs of water scarcity have been observed since 2015 in relation to the accumulation of surface water resources. For example, the hydrological situation on the rivers of Ukraine in the summer of 2016 was characterized as unfavorable, due to low boundary water levels and local (short-term) torrential rains, which caused negative consequences on water bodies.

Surface freshwater bodies of Ukraine occupy an area of 24.1 thousand km^2 or 4.0% of the total territory (603.7 thousand km^2) of our state. These bodies include rivers, lakes, reservoirs, ponds, canals, etc. The most important water bodies of Ukraine are rivers. There are 63,119 rivers in Ukraine, of which 9 are large (the water catchment area of more than 50 thousand km^2), 81 rivers are medium (from 2 to 50 thousand km^2), and 63,029 rivers are small (less than 2 thousand km^2). The total length of rivers is 206.4 thousand km, of which 90% are small rivers. The big rivers include the Dunai, Dnipro, Dnister, Tysa, Pivdennyi Buh (Southern Buh), Pripiat, Desna, Siverskyi Donets, and Zakhidnyi Buh (Western Buh). Most of the rivers are in the basins of the Chorne sea (Black sea) and the Azovske sea (Azov sea), and only 4.4% are in the Baltic Sea basin. The largest number of rivers is in the Dnipro basin – 27.7%, the Dunai – 26.3%, the Dnister – 23.7% and the Pivdennyi Buh – 9.3%. 3.3 thousand rivers are over 10 km long; their total length is 94.4 thousand km. The average density of the river network is 0.34 km/km^2. The highest density of the river network is in the Carpathians, where it reaches 2.0 km/km^2. This indicator is also significant in the Crimean Mountains, primarily on the Southern coast of Krym (Crimea). The lowest density of rivers is in Kherson oblast, where large areas are endorheic. Among all the rivers of Ukraine, the Dnipro has the largest water catchment area – 504 thousand km^2. According to this characteristic, the river ranks third in Europe. Among the rivers with a very large water catchment area, the Dunai stands out – 817 thousand km^2. The largest Ukrainian part of the Tysa river catchment has an area of 12.8 thousand km^2. According to long-term observations, the potential resources of Ukrainian river waters amount to 209.8 km^3 (together with the Dunai river), of which only 25% are formed within Ukraine, the rest comes from the Russian Federation, the Republic of Belarus, Romania.

According to the results of the regional assessment carried out in 1975–1980, the estimated resources of underground waters of Ukraine amount to 61,689.2 thousand m^3/day, of which 57,499.9 thousand m^3/day with mineralization up to 1500 mg/dm^3. The predictable groundwater resources are distributed unevenly by region, which is due to the distinction in the geological-structural and physical-geographical conditions of different regions of Ukraine. Most of the predictable resources are concentrated in the northern and western oblasts of Ukraine, the resources of the southern part are limited. The largest amount of forecast groundwater resources is concentrated in Chernihiv oblast – 8,326.7 thousand m^3 / day, the smallest – in Kirovohrad (404.6 thousand m^3 / day), Chernivtsi (405.3 thousand m^3 / day) and Mykolaiv (441.6 thousand m^3/day) oblasts.

Underground waters account for 13.8% of the state's total water consumption. They determine the provision of drinking water for the population of cities and urban-type villages in Luhansk, Lviv, Volyn, Zakarpattia, Zhytomyr, Kirovohrad, Rivne, Poltava, Sumy, Ternopil, Kherson, Khmelnytskyi, Chernivtsi, Chernihiv oblasts and the Autonomous Republic of Crimea, where the use of underground water for these needs reaches 30–70%. Agricultural water supply is also based on the use of water from underground sources. Mainly, underground water is used for domestic and drinking water supply, agriculture, industrial and technical purposes. Agricultural water supply almost everywhere in local systems is carried out by means of using underground water resources.

4.2. WATER RESOURCES OF ZAKARPATTIA: MAJOR POLLUTION THREATS AND CONSERVATION ISSUES

Water resources of Zakarpattia oblast are formed due to the surface flow of the rivers of the Tysa river basin (Fig. 4.2.1.), local river flow formed within the oblast, transit river flow formed on the territory of Romania, Hungary, and Slovakia, as well as due to operational underground water reserves. The rivers of Zakarpattia oblast are geographically located and belong to the basin of one of the largest tributaries of the Dunai – the Tysa river, which is the main water artery of the oblast. The total length of the Tysa river is 967 km, of which 262 km is within the borders of Ukraine. All rivers originate in the high mountain part of the Carpathians. The territory of the oblast is cut across by a dense river network, and its average density is 1.7 km/km^2. In general 9,426 rivers, with a total length of 19,723 km, flow in the oblast. The total length of 155 rivers, each of them being longer than 10 km, is 3.43 thousand km. Each of the rivers Tysa, Borzhava, Latorytsa and Uzh is over 100 km long.

The surface flow on the territory of the oblast is formed by the right-bank tributaries of the Tysa river – the rivers Teresva, Tereblia, Rika, Borzhava, which flow into the Tysa river, and the Uzh and Latorytsia rivers, which flow into the Laborets and Bodroh rivers in Slovakia. Lakes in the Tysa basin are usually of glacial origin. Some of them were formed as a result of mountain collapses or have a volcanic origin. The biggest lake is Synevyr, located in the upper reaches of the Tereblia river at an altitude of 989 m above sea level. The area of its water mirror is about 7 hectares, the average depth is 16-17 m.

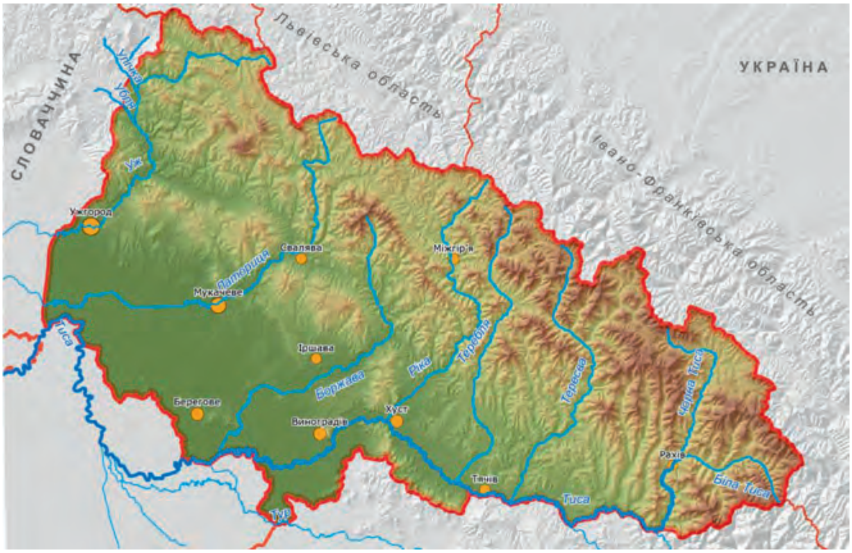

Fig. 4.2.1. The scheme of the Tysa river basin (https://buvrtysa.gov.ua/newsite/)

Agricultural water supply, with the exception of a small number of water intakes from mountain streams, is based primarily on underground water. Zakarpattia is the most humid oblast of Ukraine. All explored or operating underground water intakes in the oblast feature infiltration, so the quality of water extracted from them depends entirely on the characteristics of surface flow and requires special protection. In general, drinking underground waters are sufficient to meet the population's drinking water needs, but they are distributed very unevenly. The total amount of calculated exploitable reserves and predictable underground water resources in Zakarpattia oblast is 1125.11 thousand m^3/day.

In the flat part of the oblast, underground water resources significantly exceed the volumes of their possible use. In the mountainous part of Zakarpattia, especially in the areas with impermeable flysch rocks, drinking underground water resources are insignificant. In this regard, mountain streams in forested areas outside settlements are promising for the centralized supply of quality water to the population.

The largest consumers of water are enterprises of housing and communal services of the oblast (41.41% of total water use in the oblast) and agriculture (40.31% of total water consumption). Regarding total water consumption in terms of fresh water use, the smallest water user of the oblast is industry, which accounts for 4.88% of the total volume. This is explained by a significant reduction in industrial production in the oblast. In the agro-industrial complex of the oblast, water resources are used in two main directions: agricultural water supply and fisheries. The technical condition of agricultural water supply systems in general is at an unsatisfactory level. A significant number of existing water pipelines were built without projects or with large deviations from them. Most of the networks, due to their technical condition, require replacement, the facilities are in need of modernization. From the point of view of sanitary and hygienic reliability, most rural water pipes do not meet regulatory requirements.

Pollution of water bodies. The main causes of *surface water* pollution are discharges of untreated and insufficiently treated municipal and industrial wastewater into water bodies and through the city sewage system; entry of pollutants into water bodies in the process of surface water flow from built-up areas and agricultural land, as well as soil erosion in the water intake area.

For the vast majority of industrial and municipal enterprises, discharges of polluting substances significantly exceed the established level of maximum permissible discharges. Wastewater treatment facilities are technologically outdated, often operate with significant overloads and accidents, and in some places in villages with centralized water supply and urban-type villages they do not exist at all, or they are primitive, often overloaded filtration fields.

According to the results of summarizing the data of the state water use accounting in 2016, 5,399 million m^3 of wastewater were discharged into surface water bodies, including: industrial enterprises – 3,444 million m^3, housing and communal services – 1,551 million m3, and agricultural enterprises – 336 million m^3.

Of the total volume of wastewater discharged into water bodies, the polluted water amounts to 698.3 million m3 (13%), normatively purified – 1,381 million m3 (25%), normatively clean without purification – 3,120 million m^3 (58%), mine and quarry waters, which are not categorized – 199,7 million m^3 (4%).

In total, there are 558 enterprises polluting water bodies.

For example, in the summer of 2016, there were 16 cases of river pollution that led to negative consequences (death of aquatic living resources and deterioration of the ecological condition).

The quality of surface water is also negatively affected by the discharge of mine and quarry water, which is discharged into surface water bodies in a volume of 295.3 million m^3 without purification.

Together with wastewater, 22.67 thousand tons of suspended solids, 275.2 tons of oil products, 5.6 thousand tons of ammonium nitrogen, 45.4 thousand tons of nitrates, 1.55 thousand tons of t of nitrites, 238.2 tons of synthetic superficial-active substances, 431.1 tons of iron, 4541 tons of phosphates, etc. In addition, the total indicator of Chemical Oxygen Demand

(COD) was 73,01 thousand tons and Biological Oxygen Demand (BOD) – 16,8 thousand tons.

The main factors of *ground water* pollution in the most part of the territory of Ukraine are municipal effluents, effluents from animal husbandry complexes, mineral fertilizers, agrochemical products, lead, manganese, petroleum products. Pollution of interlayer ground water has a local character, depends on man-made load on the geological environment and protection of ground water. Areas of pressure ground water pollution are mainly located in the zone of influence of the surface complex of drainage water utilization of mining and extractive works, unorganised warehouses for the storage of industrial waste, mineral fertilizers and toxic chemicals, animal husbandry complexes, oil refineries and other local objects that affect the condition of underground water.

As a result of the concentration of waste disposal sites, caused by the concentration of industry and population, there is a focal development of industrial pollution of underground water (industrial zone of Donbas, Western Donbas and Kryvbas – Luhansk, Donetsk, Dnipropetrovsk and Zaporizhia oblasts). The use of mineral and organic fertilizers and pesticides during the development of agricultural land in the southern oblasts of Ukraine also leads to the deterioration of the quality of underground water, but this process is less intensive and has a regional character (Kherson, Mykolaiv, Odesa, Poltava oblasts). Consequently, a significant man-made load on the territory led to the formation of persistent centers of underground water pollution. On the territory of Ukraine, as of January 1, 2017, the number of registered surface centers of underground water pollution remained unchanged and amounted to 200, local ones – 262. Groundwater in the zone of influence of the main centers is contaminated with chlorides, sulfates, nitrates, ammonia, rhodanides, phenols, petroleum products, manganese, lead, strontium in quantities that, in some cases, several times exceeded the limits of permissible concentration.

In Zakarpattia oblast, most food industry enterprises (the processing of vegetables and fruits) are equipped with mechanical treatment facilities. There are enterprises that are equipped with mechanical and biological treatment facilities, but do not discharge return water directly into surface water bodies. All gas stations in Zakarpattia oblast are equipped with treatment facilities for contaminated rainwater run-off (mud settling tanks and gasoline oil traps).

On the territory of some petrol stations there are also installed purification facilities of deep biological purification of domestic wastewater.

In 2020, 3.259 million m^3 of insufficiently purified and 0.273 million m^3 of unpurified wastewater were discharged into surface reservoirs of the region. The total volume of polluted wastewater discharged into surface reservoirs is 3.532 million m^3, which is 25.54% more than in 2019. The share of polluted (insufficiently purified and unpurified) wastewater in the total discharge is 9.26%.

According to the data provided by the Department of Ecology and Natural Resources of the Zakarpattia Oblast State Administration, the total volume of pollutants with return water discharged into surface water bodies in the period from 2018 to 2020 increased from 18,345 to 21,753 thousand tons (Table 4.2.1.).

Table 4.2.1.

Discharge of pollutants with return water into surface water bodies

Discharge of pollutants by region	2018	2019	2020
	Amount of pollutants, thousand tons	Amount of pollutants, thousand tons	Amount of pollutants, thousand ton
ammonium nitrogen	0,088	0,101	0,101
BOD5	0,468	0,620	0,613
suspended solids	0,466	0,462	0,475
nitrates	0,236	0,188	0,233
nitrites	0,015	0,019	0,018
sulfates	1,916	1,655	1,837
mineralization	11,96	11,75	13,195
chlorides	1,604	2,593	2,215
COD	1,484	1,392	1,380
iron	0,009	0,824	0,723
petroleum products	0	0,008	0,004
surface-active substances	0,009	0,889	0,857
phosphates	0,068	0,072	0,084
total phosphorus	0,022	0,017	0,018
amount of discharged pollutants, in total	18,345	20,59	21,753

The objects of housing and communal enterprises of the oblast still remain the largest pollutants of surface water bodies (Table 4.2.2). 93% of the existing sewage treatment facilities of communal enterprises need reconstruction, increase in capacity and introduction of new wastewater treatment technologies. During 2019, there were no emergency situations in the oblast that would have led to pollution of the surface water bodies of the Tysy river basin.

Table 4.2.2.

Discharge of return water and pollutants by the main water users polluting surface water bodies

Name of the water user-polluter	Availability, capacity (m3/day), utilization efficiency (capacity utilization of treatment facilities)	2018 year			2019 year			2020 year		
		Waste water discharge volume, mln. m^3	Including discharge of contaminated (untreated) and insufficiently treated wastewater, million m3	Amount of pollutants discharged with wastewater, tons	Volume of wastewater discharge, mln m^3	Including discharge of contaminated (untreated) and insufficiently treated wastewater, million m^3	Amount of pollutants discharged with waste water, tons	Volume of wastewater discharge, mln m^3	Including the volume of discharge of polluted (untreated) and insufficiently treated wastewater, million m^3	Amount of pollutants discharged with wastewater, tons
1	2	3	4	5	6	7	8	9	10	11
Public utilities Vodokanal of the city of Uzhhorod	50000	19,38	1,128	10630	18,54	0,292	10469	19,331	1,031	11039
Vodokanal Karpatviz LLC	5280	0,458	0,362	427	0,519	0,367	577	0,539	0,367	470
Mukachevvodokanal	16000	7,900	0,165	3318	7,870	0,165	4614	7,720	0,169	4760
Municipal Enterprise of Chop City Council «Vodokanal Chop»	2250	0,245	0,245	198	0,223	0,223	284	0,223	0,223	309
Rakhivteplo, Rakhiv	10800	0,218	0,218	120	0,197	0,197	157	0,154	0,154	297
Public utilities Vodokanal of Vinohradiv	5500	0,589	0,589	435	0,526	0,526	363	0,525	0,525	516
Public utilities Vodokanal of Tyachiv	1800	0,085	0,085	12	0,085	0,085	11	0,080	0,080	119
Public utilities Vodokanal of Solotvino	2500	0,062	0,062	38	0,059	0,059	35	0,049	0,049	36
Kommunalnyk, Perechyn	1200	0,167	0,167	78	0,177	0,177	33	0,164	0,164	152
Public utilities Vodokanal of Mizhiria	80	0,118	0,118	64	0,122	0,122	76	0,110	0,110	81
Public utilities Vodokanal of Khust	3490	0,544	0,216	432	0,536	0,219	462	0,544	0,544	287
Vodokanalservice	200	0,071	0,024	33	0,063	0,063	20	0,059	0,015	34

Ways of Solving Water Management Issues of Ukraine

Solving water management and environmental problems in Ukraine is a priority area of state policy in the field of use, protection and reproduction of water resources and should be carried out in the following 5 ways, namely:

– protection of surface and underground waters from pollution – the strategic goal of which is to achieve ecologically safe use of water resources. This will guarantee the ecological safety of water bodies, balance the harmful effects on water resources and ensure their ability to self-clean and self-renewal.

– ecologically safe use of water resources – the strategic goal of which is to ensure, in the process of using water resources, the priority of environmental protection functions over the economic use of surface and underground waters, to introduce water-saving technologies in all sectors of the economy.

– revitalization and maintenance of a favourable hydrological state of rivers and measures to counteract the harmful effects of water (silting, erosion of banks) – it has the strategic goal of improving the general ecological state of water bodies based on the basin approach, which will ensure the sustainable functioning of natural ecosystems and the harmonious development of economic complexes.

– improvement of the system of managing water protection and water resources use – the goal of which is to implement the principles of improving the ecological condition of water bodies based on the basin approach, on whose foundation water protection programs of areas, oblasts, and individual settlements will be developed and implemented.

– reducing the impact of radioactive pollution.

The priority measures are the implementation and operation of the basin principle of water resources management, which is currently the only correct one from the theoretical, methodological and practical points of view. For this it is necessary:

1. To urgently restore the ecological certificates of enterprises.
2. To carry out the certification of rivers on a qualitatively new methodological basis, starting with the most anthropogenically overloaded ones.
3. To carry out an inventory of reservoirs and ponds, since the regulation of river flow exceeded the upper ecologically acceptable and economically feasible limits, which significantly worsened the ecological state of water ecosystems.
4. To organize an ecological assessment of surface waters taking into account hydrochemical, toxicological, bacteriological, radiological indicators – only then can you obtain information about the real ecological state of water resources.
5. To carry out water management and ecological zoning of river basins and, on its basis, establish the priority of investments related to water protection measures.
6. To establish a differentiated fee for the use of water resources depending on the water supply of the region and water quality.
7. To establish stations for monitoring quality indicators of water resources on all cross-border rivers.
8. To develop Plans of river basin management.

To assess the anthropogenic load on water ecosystems, the level of rationality of water use in the river basin, the water use management system, it is advisable to keep in mind the following indicators:

- water supply is considered satisfactory for the existence of ecosystems under conditions of consumption of less than 10% of river run-off;
- in case of using 20% of the run-off, there is a need to limit water use and implement measures to regulate the flow;
- if water use exceeds 20% of the flow, the water body is not able to meet the requirements of water users and, correspondingly, ensure the socio-economic development of the region;
- 70% is the critical limit that leads to a fundamental violation of the condition of water systems.

These restrictions are especially relevant for small rivers, considering that in the case of an increase in irreversible consumption, the ability of the watercourse to self-regulate is significantly reduced and the natural interrelationships of the ecosystem of a small river are disturbed.

A critical situation with water resources occurs when the volume of river flow does not provide at least a 10-fold dilution of polluted water flows.

When studying the ecological state of water bodies and the impact of anthropogenic load on water ecosystems, it is necessary to rely on the initial information regarding:

- pollution of surface water by point water users-pollutants and the level of efficiency of technologies used at their enterprises;
- pollution by the agricultural sector, due to surface pollution of water by soil washed away from the fields;
- the level of organization of monitoring surface water quality of the basin;
- the technical condition of sewage treatment facilities and the presence of own treatment facilities in the populated areas;
- compliance with the regime of water protection zones and coastal protective strips;
- the scale of flooding of settlements and agricultural lands;
- the level of certification of water bodies;
- the presence of environmentally dangerous objects in the pool;
- the impact of energy complexes on the natural environment;
- the state of the natural structure of river basin landscapes;
- plowed area of the basin territory;
- the focus of economic activity on the territory of the basin;
- existing problems of preserving biological and landscape diversity and forming an eco-network in the river basin;
- the validity of the measures for afforestation of the territory in view of their physical and geographical location.

State policy in the field of water management should ensure: the implementation of the rights of current and future generations to use ecologically friendly water resource potential; balancing the needs of economic and social development and the possibilities of ecologically sound water resources.

Achieving ecological security of Ukraine and its balanced development depends to a large extent on the conditions of water resources.

The main areas of implementation of the state water policy are as follows:

- the establishment of conditions for uninterrupted satisfaction of economic and drinking needs of citizens of Ukraine within the framework of sanitary and hygienic standards;
- protection of the population and the industrial and economic complex from the harmful effects of floods, high waters, water erosion, underflooding, droughts, etc.;
- regulation of economic activity to achieve a balance between the needs of economic development and the possibilities of reproduction of ecologically friendly water resources;
- step-by-step restoration of disturbed water ecosystems, primarily their self-cleaning capacity.

Measures to improve the condition of water bodies in Zakarpattia oblast. In order to solve environmental problems, ensure balanced economic and social development of the territory, effective use of the natural resources of the oblast, in 2020 the Environmental Protection Program of the Zakarpattia region for 2019-2020 was implemented. It was approved on December 13, 2018 by the oblast council's decision No. 1335 (with ammendments). The financing of environmental protection measures was carried out at the expense of the oblast fund of environmental protection from the oblast budget.

The main measures that will improve the situation in the industry:

– construction of wastewater purification facilities for residential and communal sector;
– reconstruction of the existing wastewater purification facilities of the residential and communal sector;
– construction of sewage facilities and networks;
– reconstruction of existing sewage facilities and networks.

Solving the problem of wastewater purification and stopping the pollution of water bodies is possible with sufficient financial support of existing environmental protection programs at the national, regional and local levels.

Chapter 5.

ISSUES OF SOIL POLLUTION IN ZAKARPATTIA

(Ya. Hasynets)

5.1. SOURCES OF SOIL POLLUTION AND TYPES OF SOIL DEGRADATION. NATIONAL ISSUES OF SOIL CONSERVATION

Soil is a significant natural resource and a vital component of ecosystems, essential for producing crucial human products, including food. Therefore soil, through ecosystem services, is a global factor in regulating the planet's climate and managing natural resources worldwide (Pozniak, 2017).

Unfortunately, pollution and degradation have inevitably accompanied humanity throughout its historical development.

Soil contamination – is the input of physical agents, chemicals and organisms that change soil properties and disrupt its functions.

Pollution, which is one of the causes of soil loss and degradation, can be divided into

- technogenic, related to the activities of industrial enterprises and transport;
- agrogenic, associated with agricultural land use (application of fertilisers, pesticides, chemical ameliorants, etc.).

Types of soil contamination:

- ***chemical*** can occur:
- deliberately – chemicals are deliberately introduced into the soil, most often in agriculture and forestry: pesticides, mineral fertilisers, plant growth stimulants, etc. The introduction of these substances into the soil is a controlled process and they are only dangerous if introduced into the soil in excess, when agrochemical and hygienic application regulations are not followed;
- unintentionally – substances are introduced together with domestic and industrial wastewater and solid waste, atmospheric emissions from industrial enterprises, and vehicle exhaust fumes.

Accordingly, the radius of action and intensity of pollution can vary across different regions.

Based on their aggregate state (gaseous, liquid, solid) and mode of action, pollutants can be simplistically divided into the following groups:

• gases (especially sulphur-containing industrial emissions, halides and nitrogen oxides);

• dust (ash, lime dust, particles containing heavy metals, especially industrial emissions);

• salts (transported by air and water, especially while sprinkling streets in winter to remove ice or when salt is extracted and processed);

• agrochemicals (plant protection products, fertilisers);

• organic gases and liquids (primarily fossil fuel products);

• radioactive precipitation (mainly in case of air pollution).

Changes in soil chemical parameters affect the growth and productivity of individual species and their populations over a short or long period of time, or lead to more or less severe disruption of the structure of phytocoenoses and even to the development of succession.

- ***biological*** – soil contamination by alien microorganisms as a result of domestic and agricultural waste entering the soil, as well as by aerosols from microbiological production. Domestic waste can introduce potentially dangerous microorganisms (pathogenic and toxicogenic) into the soil that can cause intestinal infections and food poisoning in humans, epidemic diseases in animals, and plant toxicosis.

Another type of bio-pollution is the spread of allergenic weed species.

- ***mechanical*** pollution is contamination by residues of construction materials, asbestos, broken glass, ceramics and other relatively inert waste.

The most common pollutants (contaminants) of soils are chemicals, among which the following groups can be distinguished.

1. Pesticides are chemicals used in agriculture to control pests of crops and products, as well as to increase crop yields. Pesticides are divided into: insecticides – insect control agents, acaricides – tick control agents, herbicides – weed control agents, algaecides – alga control agents, fungicides – fungus control agents, bactericides – bacterium control agents, molluscicides – snail and slug control agents, nematicides – nematode control agents, zoocides – vertebrate pest control agents (Havrylenko, 2008).

The environmental hazard of pesticides is mainly due to their behaviour on agricultural land, as this is where they actively interact with the environment and can easily migrate to other areas and environments. Therefore, in addition to the potentially dangerous circulation in the biosphere, there is also a detrimental impact on flora and fauna, and thus on human health through crop products;

2. <u>Mineral fertilisers</u> are inorganic chemical compounds used in agriculture to improve soil fertility. There are macrofertilisers, which include

macroelements such as nitrogen, phosphorus, potassium, and microfertilisers, which include microelements such as boron, molybdenum, copper, manganese, zinc, and cobalt that are applied to the soil in relatively small quantities (10-100 times less than macrofertilisers).

The ingress of fertiliser components from the soil into the groundwater and their removal from the soil with surface runoff can cause increased algae growth and lead to eutrophication of natural waters. The improper use of mineral fertilisers worsens the nutrient cycle and balance, agrochemical properties and fertility of the soil. On the contrary, the use of fertilisers in violation of the technology and their imperfect quality and properties can reduce crop productivity, significantly affecting product quality (for example, nitrate accumulation);

3. Compounds of heavy metals (mainly lead, cadmium, tin, mercury), whose sources of income are divided into natural and technogenic. Natural sources include weathering of rocks and minerals, erosion processes, and volcanic activity. Technogenic sources of soil contamination with heavy metals include air emissions from ferrous metallurgy enterprises, motor vehicles, liquid and solid municipal waste (including wastewater), pesticides, organic and mineral fertilisers.

A significant part of heavy metals is extremely toxic, even in minimal amounts. They are not subject to decomposition processes and can only be redistributed among natural environments. The uptake of heavy metals by plants and their subsequent accumulation along the food chain is a potential threat to human and animal health;

4. Components of gas and smoke emissions (dioxins, etc.). Dioxins are a large group of polychlorinated dibenzodioxin and furan derivatives. These are highly toxic and highly stable impurities of some pesticides and industrial chemicals that are formed during the synthesis of these compounds, as well as in the result of various technological processes and everyday economic activities (metallurgical industry, pulp and paper production, oil refining, vehicle exhaust fumes, disinfection of drinking water with molecular chlorine, household stoves, waste incineration).

In the biosphere, dioxin is rapidly absorbed by plants, soil and various materials, where it remains almost unchanged under the influence of physical, chemical and biological environmental factors. Due to its ability to form complexes, it binds strongly to soil organic matter, interacts with the remains of dead soil microorganisms and dead plant parts. The half-life of dioxins is quite long, so they persist in the environment for a long time and accumulate in the food chain. Dioxins enter the human body with the consumption of food products of animal origin, enriched with fats (~90%), mainly meat, fish and milk. They are extremely stable in the human body, accumulate mainly in adipose tissue, skin, and liver, and can cause reproductive and developmental problems, damage the immune system, disrupt hormones, and cause cancer;

5. Oil and oil products (petrol, diesel fuel, lubricants, etc.) are the most widespread and dangerous technogenic pollutants that enter the soil as a result of oil pipeline accidents; through industrial wastewater; with precipitation; when using agricultural machinery in the fields; when washed off the roadbed, car washes and transport enterprises. When oil products enter the soil, they are absorbed by means of capillary forces and can remain in this state for a long time, completely depriving the soil of fertility and turning it into a sponge saturated with oil products. This changes the physical and chemical characteristics of the soil horizons, changes the water and physical properties of soil, and ultimately reduces land productivity. In soils impregnated with oil, the structure is dispersed, water permeability decreases, oxygen is displaced, and biochemical and microbiological processes are disrupted. As a result, the water, air and nutrient regime deteriorates, root nutrition of plants is disrupted, and their growth and development are inhibited. Oil pollution creates a new environmental situation, which leads to a profound change in all links of natural biocenoses or their complete transformation.

6. Radionuclides (radioactive isotopes) are atoms that have unstable nuclei and move to a stable position through radioactive decay accompanied by radiation. The phenomenon of spontaneous emission of radiation by chemical elements with high penetrating power and ionising properties is called natural radioactivity. Radioactivity means that the nuclei of radioactive elements spontaneously decay with the release of α-, β-particles and γ-quanta or by fission; the original nucleus is transformed into a nucleus of another element. A sequence of nuclides, each of which spontaneously transfers to the next through radioactive decay until a stable isotope is obtained, is called a radioactive series. Artificial radioactivity is the spontaneous decay of nuclei of elements obtained artificially through appropriate nuclear reactions.

There is natural radioactivity of soils caused by the content of isotopes of Uranium, Radium, Thorium, Potassium-40, Rubidium-87, Carbon-14 and Tritium, the superheavy isotope of Hydrogen, in soils and rocks. Concentrations of natural radionuclides are low and do not pose a threat to the environment and humans.

The problem of radioactive contamination of the environment became more acute after the invention of nuclear weapons and the development of nuclear power. Radioactive contaminants are characterised by the fact that they do not change the level of soil fertility, but remain in the soil for a long time and pose a great environmental hazard. From the soil, they get into plants, and then to animals and humans.

The most dangerous are long-living anthropogenic radionuclides, which are characterised by remaining in soils for a long time. They include: Strontium-90 (^{90}St), Cesium-137 (^{137}Cs), Iodine-129 (^{129}I), Rubidium-106 (^{106}Ru), Plutonium-239 (^{239}Pu), Uranium-238 (^{238}U), Cerium-144 (^{144}Ce), Thorium-232 (^{232}Th), Radium-226 (^{226}Ra). Strontium-90 has a half-life of 28 years, Cesium-137 – 33 years, some long-living radionuclides have a half-life of hundreds and thousands of years, and Uranium-238 – 4.5 10^9 years.

The main sources of soil pollution

Technogenic emissions result from the combustion of various fuels or from gaseous and aerosol waste from industrial enterprises of ferrous and non-ferrous metallurgy, chemical plants, and motor vehicles. A significant source of technogenic pollution is fuel transportation, oil and gas production and transportation, industrial wastewater, and industrial and domestic waste dumps.

<u>Industrial enterprises.</u> Industrial waste contains substances that can cause toxic effects on living organisms and their communities. For example:

- metallurgical waste contains salts of non-ferrous and heavy metals;
- radioactive contamination accompanies all parts of the complex nuclear energy sector: uranium mining and processing, NPP operation, fuel storage and regeneration, nuclear waste disposal, and increases catastrophically in the event of accidents at nuclear power plants and nuclear weapons testing;
- environmental pollution by cyanides, arsenic and beryllium compounds from the machine-building industry;
- waste of benzene and phenol, methanol, phenol, turpentine in the production of plastics and artificial fibres;
- cube residues – typical waste from the pulp and paper industry.

<u>Transport.</u> Internal combustion engines of transport emit nitrogen oxides, plumbum, hydrocarbons and other substances that fall on the soil surface or penetrate plants. Petrol and oil residues, and dirt containing toxic substances from motor vehicles, which settle on roads and subsequently leach into nearby soils with precipitation are also dangerous.

<u>Heat power industry.</u> The combustion of coal releases sulphur oxides, soot, etc. into the air, which eventually get into the soil.

Residential buildings and domestic enterprises. Pollutants include household waste, food waste, faeces, construction waste, waste from heating systems, and waste from public facilities.

Agriculture is an agrogenic pollution. It is caused by substances harmful to plants and animals that enter the soil during their agricultural use. The sources of pollution are mineral fertilisers, chemical ameliorants, pesticides, chemical plant protection products, wastewater used for irrigation, etc. Furthermore, they are sources of soil pollution by heavy metals (lead, mercury, zinc, manganese).

Armed conflicts. Soil conditions are also heavily affected by armed conflicts, especially as a result of the use of modern weapons technology. Military activities alter soil not only during conflicts, but also in peacetime through shelling, military bases, industrial operations, detonation and dropping of munitions.

Soil degradation

The general consequences of anthropogenic impacts on soils have been a reduction in the area of land suitable for agriculture, and soil degradation.

The reduction of land suitable for farming is due to urbanisation, land allocation for construction, transport networks, water reservoirs, and landfills. Land is lost in the course of mineral extraction as mining waste.

Degradation is a natural and anthropogenic process of deterioration of natural soil properties and regimes that cause persistent negative changes in their functions, reduce stability and decrease fertility. Under such conditions, the intensity of soil destruction processes exceeds the intensity of soil formation or soil reproduction. Soil that has irreversibly impaired ecological functions and that has been characterised by reduced crop productivity for a long time should be considered degraded.

The main causes of soil loss and degradation include

- irrational and excessive ploughing;
- soil erosion, which manifests itself in the destruction of soil cover by water flows (water erosion) or wind (wind erosion);
- overgrazing, which causes the destruction of grass cover, soil compaction with subsequent erosion;
- deforestation, which leads to leaching of nutrients from the soil, changes in moisture and possible subsequent erosion;
- irrigation in arid areas can lead to the rise of salts into the surface layers and cause salinisation;
- acidification of soils – lowering of their pH;
- waterlogging caused by irrational irrigation of land, infiltration of water from reservoirs, flooding and submergence of territories;
- damage of the mechanical structure of soils when using heavy machinery for cultivation;
- soil pollution (by excessive mineral fertilisers, pesticides, oil products, heavy metals, etc.).

The most common negative natural and anthropogenic process that leads to soil degradation is erosion.

Soil ***erosion*** is the process of destruction of the soil profile by water (water erosion) and wind (wind erosion or deflation).

Erosion is divided into:

1. *Geological (natural)* – a natural process that occurs without human influence, under the influence of wind and water. It has always existed in nature as a normal geological process. Its speed is the same as that of soil formation. It is very slow, does not cause much damage, does not reduce soil fertility, and is almost impossible to prevent.

2. *Accelerated (destructive)* – the result of human activity: improper farming, forestry, construction, industry, transport, road building activities, when the integrity of the soil surface and its sod protection are violated leading to the appearance of furrows, ditches, and ravines. It occurs rapidly.

Depending on the factors of destruction, erosion is divided into water and wind types:

1. *Water erosion* is the washing away of soil by surface water (rain, melt and irrigation (irrigation and watering). There are two types of water erosion:

- surface – when the upper fertile soil horizons are washed away over large areas;
- deep – occurs on steep slopes and leads to the formation of ravines.

Water erosion occurs mainly on ploughed slopes, especially where ploughing is carried out along the slope rather than across it. As a result, longitudinal furrows are created, along which melt and rainwater flows. Water erosion leads to a significant washout of the topsoil, much of which flows into water bodies, enriching them with biogens.

Water erosion is exacerbated by:

- deforestation, devastation of grass cover, ploughing of slopes;
- shallow ploughing;
- a significant amount of precipitation;
- irrational land reclamation.

2. *Wind erosion (deflation)* is the destruction of the soil layer by the wind. It usually occurs in areas that are poorly protected or not protected by vegetation, often where there is no soil sod cover. The most dangerous manifestation of wind erosion is dust storms caused by strong winds. Wind erosion is predominantly common in desert-steppe zones.

Wind erosion is exacerbated by:

- ploughing of light sandy loam and sandy soils;
- lack of crop rotation;
- violation of land reclamation.

The causes of accelerated erosion are:

a) Uncontrolled deforestation. Forests are the most effective in protecting soil from erosion, as the root system of trees holds and loosens the soil, allowing it to better accumulate rainfall water. Such soil absorbs water gradually, providing it with sufficient moisture, and three times reduces water evaporation. In addition, forest areas have a significant impact on the climate of the area, softening it and preventing the soil from drying out.

b) The ploughing of meadows. Herbaceous plants have a well-developed root system, which often forms turf on the soil surface, which performs soil protection functions.

c) Overgrazing is dangerous because

- vegetation cover is destroyed and reduced;
- the soil structure is disturbed as a result of being knocked out by livestock limbs;
- of gradual degradation of vegetation and loss of soil structure, leading to erosion;
- waterlogged depressions are formed on the routes of the livestock drive and around the livestock corral as a result of soil compaction, which accelerates erosion;
- excessive grazing of livestock in dry and arid areas with light (sandy) soils causes the destruction of turf, leading to wind erosion.

d) Improper agricultural practices:

- lack of crop rotation – long-term cultivation of the same crop in one place leads to soil depletion, deterioration of its structure, and increased wind and water erosion;
- longitudinal ploughing of slopes (Kazimirova).

Intensive production, the use of heavy agricultural machinery and improper crop rotation have a negative impact on both soil structure and fertility. These imperfect agricultural practices cause soil ***overcompaction***, regardless of soil type. The consequences of overcompaction include

- disruption of the soil structure due to the destruction of capillaries, an increase in the density and hardness of the topsoil, which leads to a deterioration in the circulation of water and air within the soil layers;
- disruption of soil thermoregulation. In overcompacted soil, temperature fluctuations during the day are more significant and sharper;
- the process of moisture evaporation is disrupted. The movement of moisture to the lower soil layers is restricted, which causes it to accumulate in the upper layer and can lead to the formation of so-called "saucers" in the fields, causing oxygen starvation of plant roots.

Soil protection

Soil protection is a global issue that is linked to the preservation of biodiversity and the provision of population with food. Therefore, the ***rational use of soils*** is important, i.e., a system of measures aimed at improving, protecting and sustainable using of land resources.

In protecting land resources, the priority measures are the fight against wind and water erosion, the implementation of a system of melioration measures, and land reclamation (Boychuk, Soloshenko, 2005).

To prevent *soil exhaustion*, whose external manifestation is reflected in a sharp decline in crop yields, it is necessary to observe crop rotations, improve soils by applying organic fertilisers, and grow resistant varieties.

Important measures to combat *resalinisation* include crop rotation, rational tillage to maintain soil structure; rational irrigation regimes; and effective melioration measures (including the formation of drain screens or the creation of forest plantations).

The introduction of progressive forms of tillage, modern mechanisation, minimisation of repeated tillage, and the introduction of plowless tillage can significantly help to preserve soil.

An important measure is the introduction of organic (biological) farming without the use of pesticides and ineffective mineral fertilisers (Havrylenko, 2008).

Legal regulation in the field of land protection is carried out in accordance with the Constitution of Ukraine, the Land Code of Ukraine, and the Law of Ukraine "On Land Protection".

Current state of soil resources in Ukraine

Agricultural land in Ukraine comprises 41.9 million hectares (69.5%) of the total land area. hectares (69.5%) of the total land area; forests and other forested areas – 10.7 million hectares (17.7%); built-up area – 2.5 million hectares (4.1%); underwater and open waterlogged land – 3.4 million hectares (5.6%); open land without vegetation or with little vegetation (stony places, sands, ravines) and dry open land with special vegetation cover – 0.6 million hectares (1.1%). Ukraine has one of the world's highest per capita availability of agricultural and arable lands. Thus, arable land accounts for 54.2% and has the largest share, pastures – for 8.8%, hayfields – for 3.8%, and perennial plantations – for 1.4% (National Report on the State of the Environment in Ukraine in 2018). Such a distribution of land characterizes high ploughing and agricultural development of the territory of Ukraine, which leads to a violation of the ecologically balanced ratio of agricultural land, forests, water bodies, and negatively affects the sustainability of agricultural landscapes and causes a significant technogenic burden on the ecosphere. There is an overuse of agricultural land, which to varying degrees affects soil fertility due to its erosion, overcompaction, loss of lumpy-grained structure, water permeability and aeration capacity, leading to the environmental consequences.

Every year, Ukraine loses about 740 million tonnes of soil, including more than 24 million tonnes of humus, 0.5 million tonnes of nitrogen, 0.7

million tonnes of mobile phosphate, 0.8 million tonnes of potassium, and a large amount of trace elements. Erosion processes, destroying soils, primarily affect their supply with organic matter. Thus, the humus content in lightly eroded chernozems decreases by 5-10%, in medium-eroded chernozems – by 25-30%, and in heavily eroded chernozems – by 35-40% compared to their full-profile analogues (National Report on the State of Soil Fertility in Ukraine, 2010). At the same time, 500-700 kg of nutrients are lost per hectare, which is 2.3 times more than the amount applied with fertilisers. The amount of land in Ukraine damaged by water erosion reaches 32% of the total area, or 13.3 million hectares. Of these, 4.5 million hectares are medium- and highly denuded soil, while 68,000 hectares have completely lost their humus horizon. More than 6 million hectares in Ukraine are systematically affected by harmful wind erosion, and in years with dust storm these figures reach the level of 20 million hectares (Baliuk and Medvediev, 2012). All this indicates a high degree of erosion processes, which is one of the most significant factors in reducing land productivity and causing great damage to agricultural production. Scientists estimate that, depending on the degree of land erosion, each hectare of land is not harvested by 10 to 50% of the crop. The negative effects of anthropogenic erosion affect not only agricultural production, but also all components of the natural environment – relief, surface and groundwater, vegetation and all biota.

The increase in erosion in recent years is due not only to the increase in arable land, but also to the use of heavy tillage machinery that compacts and destroys the soil structure. The water resistance of the structure of denuded soils has decreased to 10-15%. The reasons for the intensification of erosion processes in Ukraine are the massive neglect of the simplest agrotechnical anti-erosion measures, imperfect land management in terms of erosion protection, and underestimation of shelterbelt forestry.

Physical degradation as a result of intensive agricultural land use, namely excessive ploughing, intensive mechanical cultivation and a decrease in soil organic matter content, has covered almost all arable land in Ukraine. It is manifested in topsoil destructuring, clodding after ploughing, flooding and crusting, plough treads, and overcompaction of subsoil and deeper layers. Physically degraded soils are prone to erosion, absorb and retain atmospheric moisture less intensively, and limit the development of plant root systems (Baliuk, Medvediev et al., 2012).

About 8.5 million hectares, or almost 21% of all agricultural land in Ukraine, is covered by soils with excessive acidity, which limits the normal development and growth of crop yields. They are widespread in Polissia, Prykarpattia, the Carpathian Mountains, Zakarpattia, and the western and northern forest-steppe regions. Among arable land, acid soils cover a total area of about 5.46 million hectares, including 0.64 million hectares with a strong acid reaction, 1.37 million hectares – with a medium acid reaction and 3.45 million hectares – with a weak acid reaction. There are about 3.04 million hectares of acid soils under natural forage lands. In the absence or insufficient level of chemical amelioration, a gradual increase in acidity occurs on a significant part of acid soils (Baliuk and Miroshnychenko, 2020).

The area of saline soils is 2.8 million hectares (mainly in the steppe), approximately 2/3 of which are ploughed, and about 0.8 million hectares are irrigated (Baliuk, Medvediev et al., 2012). Salinisation processes are almost omnipresent on chestnut, dark chestnut, some meadow chestnut and meadow chernozem soils of Prysyvashshia, the Azov and Black Sea coasts in the northern part of Crimea and the southern parts of Zaporizhzhia, Kherson, Mykolaiv and Odesa oblasts. Salinisation of soils and their agrophysical degradation (compaction, destructuring, crusting, etc.) necessitate the application of melioration measures on irrigated and non-irrigated lands. Over the past twenty years, melioration of saline soils in Ukraine has been unsatisfactory. Under this farming system, there is a widespread deterioration in the quality of saline soils, a loss of their fertility and the productivity of agrocenoses on these lands.

Soil pollution in Ukraine is associated with atmospheric emissions from industrial enterprises and motor vehicles, violations of the rules of extraction, transportation and processing of minerals, application and storage of agrochemicals and pesticides, disposal of wastewater and its sludge, domestic and industrial waste, the consequences of the Chornobyl disaster, and military operations (Baliuk, Medvediev et al., 2012).

Aerotechnogenic soil pollution. The soils of large industrial cities in Ukraine are exposed to the cumulative impact of gas and dust emissions from industrial enterprises, motor vehicles, heat and power facilities, and housing and communal services. The emissions and discharges form a halo of regional pollution (urbanised background), which is overlaid by local pollution foci around individual pollutant emission sources (in particular, high levels of such pollution are recorded in Mariupol, Makiivka, Lysychansk, Donetsk, Odesa, Rubizhne, Horlivka and others). One of the most dangerous types of technogenic burden – road traffic pollution also affects significantly soils and terrestrial ecosystems along the roadside. The lead content in the soils of the ten-metre roadside is 2-7 times higher than background levels, and in some cases – by one to two orders of magnitude. In general, soils in Ukraine are most contaminated with zinc and lead, and less with cadmium, manganese, and copper (Baliuk, Medvediev et al., 2012).

Soil contamination by pesticide residues. The gradual transition of agricultural producers to the use of safer chemical plant protection products contributes to reducing soil and plant products contamination. For example, in 2007-2009, residues of stable organochlorine compounds were detected in only 5-7% of soil samples, including less than 1% exceeding the MAC, which was observed mainly on land plots adjacent to former pesticide warehouses and dissolving units, and less frequently on fields that were former vineyards, orchards and hop houses (Baliuk, Medvediev et al., 2012).

The situation in Ukraine with unsuitable and banned pesticides requires urgent attention. According to official data, the system of the Ministry of Agrarian Policy and Food of Ukraine alone has accumulated 21,000 tonnes of unusable pesticides, owned by legal entities of various forms of ownership or by no one. Unauthorised dumping of unusable and banned pesticides poses a particular environmental hazard, which can lead to contamination of drinking water.

Radioactive soil contamination. The collection, analysis and generalisation of data from the radiological survey of arable land in Ukraine showed that as of 1 January 2010, cesium-137 contamination of more than 37 kBq/m^2 on agricultural land in Ukraine spread over 462 thousand hectares, including 346 thousand hectares of arable land. Contaminated areas are located in 12 oblasts, where 8.8 million hectares were surveyed (in particular, in Zhytomyr – 156 thousand hectares, Cherkasy – 76, Rivne – 52, Chernihiv – 52, Kyiv – 34 thousand hectares).

Soil contamination with strontium on agricultural land of Ukraine is observed on a much larger scale than with cesium. Strontium-90 contaminated 4.6 million hectares within the range of 0.74-5.55 kBq/m^2, which is 52% of the surveyed area. The territory of agricultural lands in Vinnytsia, Kyiv, Cherkasy and Chernihiv oblasts is completely contaminated with radiostrontium. Such an intensive spread of this radionuclide in Ukraine is primarily due to global releases of strontium-90 during nuclear weapons testing in the atmosphere. The contamination of land with strontium-90 as a result of the Chornobyl disaster was less intense and spread mainly within the exclusion zone and adjacent territories, but strontium spread much further in aerosol deposition (Baliuk, Medvediev et al., 2012).

In general, the radiation situation in the contaminated areas has improved compared to the early post-accident period, which is caused by

- natural autoremediation processes (radioactive decay, fixation and redistribution of radionuclides in the soil);
- implementation of a set of countermeasures aimed at strengthening biogeochemical barriers to block radionuclides in soils, which ensures reduction of radiation contamination of locally produced food;
- enhanced radioecological monitoring of soils and agricultural products, their radiological control and strict adherence to recommendations on agricultural production (Baliuk, Medvediev et al., 2012).

Of all human activities, *war* has the most devastating impact on the environment, whose consequences will be felt for decades to come. Whilst crimes against the environment may not be immediately apparent, their long-term effects can be severe.

The movement of heavy machinery, the construction of fortifications and hostilities damage the soil cover. This leads to degradation of vegetation and increases wind and water erosion.

Soil contamination is mainly caused by the use of nitroaromatic explosives (such as trinitrotoluene (TNT), octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX) and 1,3,5-trinitroperhydro-1,3,5-triazine (RDX)), which are toxic to the environment and human health. In nature, they are resistant to evaporation, hydrolysis and biodegradation, and as a result, can be absorbed by plants or leach into groundwater.

The detonation of rockets and artillery shells produces a number of chemical compounds: carbon monoxide (CO), carbon dioxide (CO_2), water vapour (H_2O), brown gas (NO_2), nitrogen (I) oxide (N_2O), formaldehyde (CH_2O), cyanide vapour (HCN), nitrogen (N_2), as well as a large amount of toxic organic matter, oxidises surrounding soils, wood, turf, and built structures (Ekol. Problem viiny , 2022).

The negative effects of the use of incendiary weapons containing white phosphorus are associated with its auxiliary pollutants and combustion residues. Phosphorus combustion products and their solutions form salts when they enter the soil, which increases the migration of phosphorus compounds from the affected area to areas free of hostilities (Bilyi fosfor..., 2022). Such weapons can lead to soil contamination with trace elements, hydrocarbons, organic solvents, surfactants, synthetic phenols, cyanides, dioxins and radionuclides.

The metal fragments of shells released into the environment are not completely inert and pose a significant safety risk. The decomposition of shells and other remnants of metal weapons contaminates the soil, mainly with lead. Cast iron with steel impurities is the most common material used to produce ammunition casings and contains not only standard iron and carbon, but also sulphur and copper. These substances enter the soil and can migrate to groundwater and eventually enter food chains, affecting living organisms (Omelchuk and Sadohurska, 2022).

Mine detonation causes negative impact on the soil with metal and plastic fragments, as well as explosive residues. In addition to lead, uranium and stibium, the explosive remnants contain a large number of toxic elements that quickly enter the natural cycle.

On a smaller scale (but with a greater variety of impacts), burnt-out tanks, vehicles, downed aircraft and other remnants of warfare are also a source of pollution.

Soil contamination with fuels and lubricants and other oil products occurs as a result of the movement and damage of land-based military equipment. Soils soaked in fuels and lubricants reduce water permeability, displace oxygen, and disrupt biochemical and microbiological processes. As a result, water and air regimes and nutrient cycling deteriorate, root nutrition of plants is disrupted, and their growth and development are inhibited, leading to death.

Shelling of industrial and infrastructure facilities leads to fires that cause additional air, soil and water pollution. Combustion products released into the air consist of toxic gases and particulate matter. Significant soil and water contamination will be also observable at these sites. At the places where firefighting activities have been carried out, contamination may include residual firefighting foam (Omelchuk and Sadohurska, 2022).

Therefore, it is important that Ukraine's post-war recovery plan includes measures to restore and preserve ecosystems, and that plans for the reconstruction of settlements should include nature-based solutions and climate change adaptation measures.

5.2. SOIL RESOURCES OF ZAKARPATTIA: MAIN THREATS OF POLLUTION AND DEGRADATION, PROBLEMS OF CONSERVATION

The land fund of the region, according to the Main Department of the StateGeoCadastre in Zakarpattia Oblast (as of 01.01.2016), is 1275.3 thousand hectares, or 2.1% of the territory of Ukraine. Of the total land area, 56.8% is occupied by forest land (the most forested region in Ukraine), 36.8% is agricultural land, 3.7% of the region's territory is built up, 1.4% is under water, 1.2% is open land and 0.1% is open wetlands. Of the 1275.3 thousand hectares of the oblast's land fund, 469.2 thousand hectares are agricultural land, including 451.0 thousand hectares of farmland, 200.2 thousand hectares of which are arable (Report on the state of the environment of the Zakarpattia oblast for 2021). There are no significant reserves for increasing arable land, and therefore it is necessary to use the existing arable land fund properly. There are no significant reserves for increasing the area of arable land, and therefore it is necessary to use the existing arable land stock properly.

The wide variety of oblast’s soils results in uneven potential fertility and varying degrees of land use. The most favourable conditions in terms of natural fertility are in the lowlands, while the worst are in the mountains. However, the level of land use depends not only on natural but also on economic conditions: population density, availability of agricultural land and labour resources, location and sectoral structure of industry, level of specialisation and intensification of agriculture, and the state of development of roads and other service industries.

Taking these features into account, Zakarpattia oblast is divided into three agricultural zones: lowland (over 17% of the oblast territory), foothill (about 17%), and mountainous (2/3 of the oblast's territory, of which 60% is covered by forest). The specific nature of the relief strongly influences the structure and level of use of land resources, which do not comprise a significant part of agricultural turnover (Pryrodni bahatstva Zakarpattia, 1987).

Soil erosion. Soil erosion causes the greatest damage to agriculture under all methods of land use. The development of erosion processes is relatively weak, despite extensive ploughing, due to the unique aspects of the soil formation process. The relatively dense structure of heavy and medium loams and the shallow occurrence of a dense gley horizon counteract deep erosion. This is also facilitated by the low water permeability of the Transcarpathian soils and weathering crust, which become very viscous during rains.

The intensity of erosion processes increases sharply with the approach to mountain ranges. This is due not only to the increase in surface slopes, but also to the increase in precipitation over the slopes. Erosion processes are often combined with landslides. The intensive development of these two processes is observed in the valley sides of 93 rivers. Hanging ravines up to 6-7 metres deep are located on slopes of 15-200 metres. Their steep bare walls are complicated by landslide forms. The development of landslide processes is due to the close occurrence of groundwater and clay masses that easily erode and float.

Precipitation affects the soil both mechanically and chemically. It destroys the soil structure, leaches organic and other nutrients from the soil, and causes the process of podzolisation. Underground moisture also affects soil formation. A high groundwater level causes the formation of a horizon that is unfavourable in terms of its physical, chemical and biological characteristics for plant growth. Adverse natural phenomena that lead to increased erosion processes include heavy rains, windstorms, hail, dust storms, intensive blizzards, snowfall, frost, forest fires, dry winds, and frost.

With daily precipitation of 10-20 mm in mountainous areas, soil is washed away and eroded on slopes. In the Ukrainian Carpathians, in the area of erosion processes, daily precipitation can reach 150-180 mm, so land-wash processes are quite intense. One third of arable land is affected by erosion. In the mountainous part of the Carpathians, heavy rains are quite common, with 50 mm or more of precipitation falling in 12 hours. Rains can accompany western cyclones. Most often, they fall within one day, but can last for 2-5 days. The rains begin in the west and gradually shift to the east, their distribution is spotty.

The scarcity of land in the mountains and the need to provide themselves with food forced villagers to plough the slopes. There are 39.6 thousand hectares of eroded land in the oblast. Each hectare is annually demolished with 34.8 tonnes of fertile soil. For example, in Berehove district, with an average annual rainfall of up to 540 mm, land-wash ranges from 5 to 10 tonnes per hectare. In Mukachevo district, with an average annual rainfall of up to 780 mm, this figure is already 20-30 tonnes per hectare. With this amount of soil, 300-340 kg/ha of humus is lost.

The mountains of Zakarpattia are mostly forested, but intensive deforestation, which became particularly dangerous after World War II and during the Soviet period and which continues to this day, has led to soil denudation and water and wind erosion over large areas. This negative factor of mechanical damage further exacerbates improper skidding and heavy vehicles transportation of timber. Such unsustainable forest management continues to this day, causing enormous damage to the Carpathian ecosystems. Erosion processes are particularly intense on slopes in mountainous areas that are free of forest and shrubs. Here, the average annual land-loss ranges from 40 to 70 tonnes per hectare. During floods, which are not uncommon here, each cubic metre of runoff contains up to 12 kg of soil.

The level of soil cultivation in the oblast is 47.9%. However, in some districts, this figure is significantly higher. For example, in Mukachevo district, 66.3% of land is ploughed, in Vynohradiv district – 70.1%, and in Berehove district this figure reaches 74.5%. Less ploughed land is in mountainous areas (27.1% on average), although in Rakhiv district, arable land occupies only 7.4%. But even here, this figure is too high, as most of the arable land is located on 94 erosion-hazardous slopes. Given that in mountainous areas the average annual precipitation reaches 1500-1600 mm and that the soil layer is shallow (mostly 40-70 cm), the amount of arable land should not exceed 10%.

Analysing the factors that influence soil formation processes in the oblast, it should be noted that, according to geomorphological and climatic indicators, the soils of Zakarpattia can be considered both subject to erosion and periodic waterlogging. In recent years, as a result of a violation of the environmentally acceptable proportions of arable land, natural lands and forest resources, spring and autumn floods have become more frequent in the oblast, exacerbating the degradation of the region's land fertility. As a result of catastrophic floods (1995-1996, 2001), 40.5 thousand hectares of agricultural land, including 29 thousand hectares of arable land, were flooded twice, and as a result of erosion processes, 233.84 thousand m^3 of soil is washed away from the slopes annually at average water content of the year, and 935.36 thousand m^3 at heightened water content. The most intensive land-loss occurs on arable land located on slopes with a steepness exceeding 7°. It amounts to 151.13 thousand m^3 and 604.52 thousand m^3, respectively, at average and heightened water content of the year. In total, according to a large-scale soil survey conducted by the Institute of Land

Management, there are about 200 thousand hectares of erosion-hazardous land in the oblast, of which 40.7 thousand hectares are arable (Dopovid pro stan navk. pryr. sered. v Zak. obl. za 2020 r.).

Thus, land on slopes, where soil erosion is possible, requires a series of measures. The first step is to follow proper agricultural practices of land cultivation, use crop rotation, improve soil structure and water-air characteristics through fertilisation and liming. Terracing slopes on which orchards and vineyards are laid out is particularly effective in combating erosion. Terracing slopes is costly and requires special equipment and considering site-specific features. Already devastated areas require engineering intervention to stop linear erosion and allow for further reforestation or reclamation (Pryroda Zak. obl., 1981).

The problem of drained agricultural land. The soils of the lowland of Zakarpattia oblast are glued to varying degrees in most areas, which significantly worsens their water and physical properties and reduces their fertility. In this regard, regulating the water regime is a very important task. Shallow groundwater is also an important issue, due to the slight waterline of rivers into the lowland surface and, as a result, flooding of low interfluves by river water. At the same time, the water from open drainage ditches and pottery drainage collectors often needs to be pumped into rivers, whose waterline is often higher than in drainage.

Today, a series of negative factors have been identified on some drained agricultural land:

– subsoil layers are over-compacted (according to water-physical indicators);

– sharp decrease in the profile infiltration rate in drained soils compared to 30-year data;

– significant waterlogging of the tilth top soil in autumn and spring;

– development of surface erosion processes;

– acidification of the soil as a result of constant waterlogging;

– negative water-air regime of the soil;

– repeated waterlogging of agricultural land.

Whereas previously drainage system maintenance was mandatory and carried out at the expense of farms, today they are not properly maintained and are often in a state of disrepair due to a series of problems, including imperfect legislation on land issues (the issue of the property operator of drained agricultural land), lease terms (the issue of maintenance of drained agricultural land), and lack of funds.

Among the recommended measures in the development of projects for the maintenance and reconstruction of drainage systems one can highlight the most effective ways to regulate the water-air regime and increase soil fertility, namely

– measures aimed at improving the water permeability of the subsoil layer of heavy soils, including various methods of deep loosening (deep shelfless, deep, and layer ploughing). Deepening of the arable horizon increases soil permeability and aeration, promotes the intensive development of aerobic microbiological processes, accumulation of nutrients, development of a branching root system, and improves the physical and chemical properties of the soil;

– measures aimed at improving the surface condition by levelling and creating an artificial slope of the surface (levelling, ploughing, profiling, furrowing, etc.), regulating the water regime (groundwater level) to prevent waterlogging of the canal strips;

– chemical reclamation measures aimed at radically changing the physical and chemical factors of soil fertility (acidity, base saturation) by adding limestone;

– measures to alkalise canals to prevent the erosion of canal slopes and their protection zones (strips);

– agrotechnical measures, which include proper crop rotation with sowing a mixture of perennial legumes and grasses, use of organic and mineral fertilisers, deepening of the arable horizon, etc. (Rozvytok silsk. hosp., 2010).

Soil acidity. With a few exceptions, the parent rocks of the oblast are carbonate-free, and the significant development of podzolic and pseudo-podzolic processes has led to high soil acidity. Almost 90% of the arable land requires liming, with the most commonly used amounts being 3.5 to 6.0 t/ha (Pryroda Zak. obl., 1981). Liming helps not only to reduce excessive soil acidity, which is harmful to most crops, but also improves microbiological processes in the soil and its physical properties, enhances the mobilisation of both nitrogen and phosphorus nutrients, increases the activity of organic and mineral fertilisers, and has a favourable effect on the physiological processes in plants, increasing yields and quality.

Providing soils with humus and certain chemical elements. The problem of soil humus is important for the region, as high rainfall (over 1000 mm per year) contributes to its washout, especially on sloping lands. The soils are mostly medium humus rich, with the average humus content ranging from 2.2% to 3.83%. It should be noted that the average humus content is typical for agricultural land (arable land) that has not been cultivated for more than 5-10 years (available in Uzhhorod district) and whose organic matter is restored naturally. However, the bulk of intensively used arable land has a low humus content. The most effective agrotechnical measures to restore soil organic matter reserves are manure application, ploughing of post-harvest residues, straw, sowing of perennial legumes and green manure.

The soils of the Transcarpathia are low in easily hydrolysable nitrogen compounds, with a weighted average of 107.23 mg/kg of soil. Soils have an average supply of mobile phosphorus – 88.43 mg/kg of soil, and good supply of exchangeable potassium – 139.42 mg/kg of soil. Therefore, organic and mineral fertilisers need to be applied to restore soil fertility in the oblast. If this issue is not addressed, and liming operations are not resumed and mineral and organic fertilisers are not applied at least to the extent of nutrient removal from the soil by the harvest, soil degradation may occur, and the living conditions of soil microorganisms will deteriorate, which in turn will lead to a sharp decline in soil fertility and agricultural productivity (Rozvytok silsk. hosp., 2010).

Pesticide pollution. There are unusable chemical plant protection products in Zakarpattia that need to be disposed of. There are 41 reinforced concrete containers in eight settlements in Mukachevo district that store chemical plant protection products that pose a risk to the soil. In addition, 225 tonnes of pesticide-contaminated soil is stored in Rokosovo village, Khust district, which, according to the Ukrainian Scientific Research Institute of Environmental Problems (Kharkiv), is toxic waste of hazard classes I-II, negatively affects human health and requires urgent removal outside the oblast or neutralisation in special ovens at a temperature of 1000-1200°C. The contaminated soil contains simazine, atrazine, DDT, promethrin, phosphamides, metaphos, and other unsuitable and unknown toxic substances (Dopovid pro stan navk. pryr. sered. Zak. obl. za 2020).

Technogenic pollution. Direct technogenic pollution has a significant negative impact on soil. Such significant pollutants, in particular, include both certified and unauthorised landfills, which are a source of accumulation of foreign substances in the soil (glass, ceramics, bricks, iron pieces, fabric, paper, rubber, fuel and oil waste, etc.). Some of these substances decompose quickly (paper, fabric), while others do not decompose at all (plastics).

In Zakarpattia, centralised solid waste collection is organised in 471 settlements, which is 77.5% of the total number (608) of settlements in the oblast. According to the register data of waste disposal sites (hereinafter referred to as WDS), as of 01.01.2021, 62 certified WDS were registered in the Zakarpattia oblast, including 59 solid domestic waste (SDW) disposal sites, 2 wood waste (wood sawdust) sites and 1 faux fur waste site. Almost all the WDSs, except for the SHW landfill in Uzhhorod (Fig. 5.2.1), Mukachevo and the Borzhava village landfill, operate without proper design justification, state environmental review findings, and do not meet sanitary and environmental requirements (leachate is not disposed of, fences are missing, access roads are clogged). Most of the existing WDS have exhausted their capacity, being 80-85% full, and the lifetime of the Vynohradiv landfill and the SDW landfill in Uzhhorod has expired. (Dopovid pro stan navk. pryr. sered. Zak. obl. za 2020).

Fig.5.2.1. Solid domestic waste landfill in the Barvinok village (Zakarpattia oblast, Uzhhorod district). (Photo by the author).

The negative impact on the environment is caused by the industrial purpose facilities, namely:

- *Solotvyno salt mine* in Tiachiv district of Zakarpattia oblast is one of the oldest enterprises in Zakarpattia and one of the largest rock salt deposits in Ukraine. Since the mid-90s of the last century, its operating mines have been experiencing problems that have led to a dangerous technogenic ecological situation. Thus, according to a 2010 audit by the Control and Audit Department in Zakarpattia Oblast, the floods of 1995-1996 and 2001 worsened the hydroecological situation, with groundwater entering the mines, flooding them, washing out salt, and contributing to the formation of underground cavities, which led to the formation of sinkholes. In 2005, shear failures and karst collapses intensified in Solotvyno, damaging residential buildings, roads and infrastructure. Two of the nine mines were completely flooded. Collapses and related accidents at the enterprise led to the suspension of salt production in February 2007 and the closure of the underground department of the Ukrainian Allergic Hospital in September 2008 due to the inability to operate safely. The situation was getting worse and in 2010 the problem became a national issue (expert opinion of the Ministry of Emergencies of Ukraine of 09.12.2010 No. 02-17292/165). In 2013 Solotvyno was declared a national emergency zone.

Currently, the salt mine and the surrounding areas are subject to hazardous natural and technogenic processes, mainly salt karst, both underground and surface, sinkholes in the areas where the mines are located, and shearing processes. Since collapse formation intensified, 5 million 300 thousand cubic metres of earth have fallen into the funnel. The volume of cavities in the workings that are not filled with soil or water is estimated to be 280,000 cubic metres.

Fig. 5.2.2. Solotvyno salt mine area. Collapse and shear in the mine area. (https://hromadske.radio/news/2018/07/01/cherez-zatopleni-shahty-u-solotvyni-na-zakarpatti-znovu-mozhe-statysya-obval-foto-video)

The risk area continues to expand at a maximum rate of 5 cm/year (Szűcs, et al., 2021). Observations of deformations have not shown any slowdown in the processes. The situation remains complicated, with soil subsidence continuing, and new sinkholes forming that threaten human safety (Pakshyn, Liaska, et al., 2021). All these processes indicate that the situation in Solotvyno remains unstable and requires constant and reliable monitoring of the earth's surface deformation;

- *TOV Zakarpatpolimetaly gold mining enterprise*, a limited liability company under the laws of Ukraine (Muzhiyevo village, Berehovo district) – as a result of the production activities of TOV Zakarpatpolimetaly, which ceased operations on 01 January 2007, environmental pollution, in particular, of soil, surface and groundwater, was caused. The industrial site has 5 dumps of impoverished (contaminated) and waste rocks with a total volume of up to 164 thousand tonnes and a place for ore beneficiation in semi-liquid mass of up to 168 thousand m^3 located in a disused open pit. According to the Zakarpattia Geological Exploration Expedition, these dumps contain sulphite impurities and heavy metal minerals that are toxicants. Under the influence of atmospheric factors, heavy metal sulphites are oxidised, resulting in the formation of water with high salinity and low pH at the bottom of the dumps, saturated with heavy metal sulphites, which are leached into surface and groundwater. According to the monitoring data, the areas adjacent to the enterprise have exceeded the content of lead and copper in soil samples, and the water has an increased content of cadmium.

In accordance with the Unified Register of Environmental Impact Assessment, the Ministry of Ecology and Natural Resources of Ukraine issued an environmental impact assessment conclusion on the permissibility of the planned activity of Limited Liability Company Karpatska Rudna Company "Disposal of ore dumps of rocks in order to extract the following sulphide minerals: pyrite, galena, sphalerite and chalcopyrite" (registration case №20192262943) № 7-03/12-20192262943/1 of 29.07.2019. The company's planned activities include the utilisation of ore dumps of rocks to extract the following sulphide minerals: pyrite, galena, sphalerite and chalcopyrite. The maximum extraction of sulphide minerals will make it impossible to continue the oxidation processes and increase the acidity of wastewater. At the same time, the content of components in sands and sludges will be close to the background values for rocks containing area.

Fig. 5.2.3. TOV «Zakarpatpolimetaly» gold mining enterprise. https://dyvys.info/2020/12/22/zakarpattya-chy-mozhna-znovu-v-regioni-vydobuvaty-tsinnyj-metal/

- *the territory of the former ZAT Velykobychkivskyi Lisokhimkombinat* was liquidated by a decision of the Economic Court of Zakarpattia Oblast of 30 November 2004. Following the liquidation procedure, the timber and chemical plant's operations were suspended, the process equipment was dismantled and sold, and the contaminated territory and waste remained unclaimed. The results of the analytical control carried out in 2013 by the State Environmental Inspectorate in Zakarpattia oblast on the territory of the former Velykyi Bychkiv timber and chemical plant (V. Bychkiv urban-type settlement, Rakhiv district) and adjacent territories indicate contamination of both land resources and surface water and the upper underground aquifer (up to 20 m). Concentrations of petroleum products in soil samples exceed background levels 3 to 50 times (boiler house of the chemical shop of the former V. Bychkiv timber and chemical plant). The concentrations of pollutants in surface waters exceed the MPC for fishery water bodies in terms of chemical oxygen demand (COD) up to 3 times (the flow before getting into the Shopurka River), and in terms of phenols – 3000 times (the flow before getting into the Shopurka River). In the Shopurka River, downstream of the timber and chemical plant, the COD meets the requirements of the current standards, and the phenol content 30 times exceeds the MPC. Concentrations of pollutants were also detected in the mine wells of the residents of V. Bychkiv (COD is up to 600 mg/l (the norm is 4.0 mg/l), phenols – up to 4.0 mg/l (the MPC of drinking water supply (centralised) for phenols is 0.001 mg/l).

The work of *Perechynskyi Lisokhimichnyi Kombinat* is also a cause for concern. The long-term operation (for 100 years) of the timber and chemical plant in Perechyn has led to the contamination of the enterprise's territory with phenolic compounds, and in recent years, there has been a constant washout of these compounds from the territory along with groundwater, which leads to pollution of surface runoff (Dopovid pro stan navk. pryr. sered. Zak. obl. za 2020).

Fig. 5.2.4. Perechynskyi Lisokhimichnyi Kombinat. (Photo by the author).

Trans-European export pipelines (gas, oil and product pipelines) with a total length of 1700 km pass through the territory of Zakarpattia (Dopovid pro stan navk. pryr. sered. Zak. obl. za 2020).

In the places where they pass, engineering interventions disrupt the relationship between vegetation, soil and underlying rocks, which disrupts the natural functioning of mountain ecosystems. These changes in the conditions of excessive moisture, steep slopes, and rock destruction often cause processes harmful to both pipelines and surrounding ecosystems, such as linear and planar erosion, landslides, and waterlogging. The most effective way to accelerate the consolidation of the surface soil layer is to create phytocoenoses on the routes, consisting of plant species that are resistant to these environmental conditions and can perform a reclamation function. Important phytomelioration measures that will contribute to optimising the environmental regime along the main pipeline routes include

- grassing of pipeline routes with legume-grass mixtures;
- soil stabilising planting of trees and shrubs in landslide areas (white and yellow acacia, grey and green alder, red and goat willow, green broom, dog rose, spruce, sycamore);
- water-absorbing planting of trees and shrubs in areas of standing groundwater (various types of willow, grey and glutinous alder).

Due to the fact that the effectiveness of phytomelioration is determined by the technical reclamation carried out, on some routes of main pipelines, especially gas pipelines, it is supplemented by the following technical measures:

- construction of drainage ditches and trays;
- filling in artificial microterraces (Pryrodni bahatstva Zakarpattia, 1987).

Localised accidents resulting from illegal cutting-in on pipelines by citizens pose a major threat to soils. For example, in 2018, due to the depressurisation of the Druzhba oil pipeline near the village of Ruske, the system leaked crude oil, which contaminated about 250 square metres of soil (Na Zakarpatti cherez nezakonnu vrizku..., 2018). In 2009, there was an accident of a larger scale, when 100-120 cubic metres of diesel fuel leaked from the main product pipeline near Kostryno village (Uzhhorod district) as a result of the depressurisation, contaminating more than two dozen wells and the soil of 35 household plots (“Prykarpatzahidtrans” ..., 2009).

Pollution from transport emissions. Zakarpattia has a fairly developed transport system, especially in the flat part, which is represented by an extensive network of rail, road and pipeline transport. The total length of the region's roads is over 3.5 thousand kilometres, of which 97% are paved. The density of motorways per thousand square kilometres of territory is 268 km, compared to 271 km in Ukraine on average (Dopovid pro stan navk.

pryr. sered. Zak. obl. za 2020). Soils are negatively affected by all types of transport, especially road transport. These are oxides of carbon, nitrogen, sulphur, hydrocarbons (all types of fuel), de-icing materials (most often salt), heavy metals (plumbum, cadmium, nickel, etc.), dust and soot. It has been established that 73% of the total amount of plumbum released into the air with exhaust gases from car engines is deposited on the roadside. The highest concentration of plumbum in the soil is observed near the roadbed and exceeds its background value 20-30 times. Thus, products grown along motorways contain an increased amount of lead, and depending on the traffic intensity, this danger zone can extend from 10 to 500 m. Therefore, only forest species should be planted or fodder crops should be grown along roads. In Zakarpattia, due to the problem of small landholdings, this precaution is often neglected and crops as well as gardens are often planted, and cattle are grazed there. Besides, roadsides are used as hayfields.

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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.

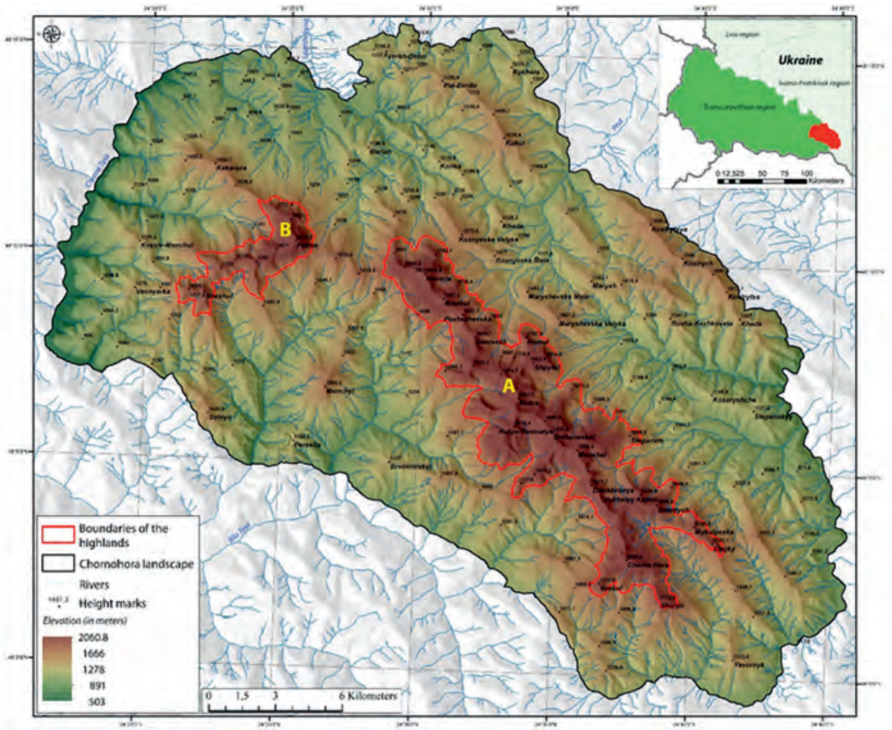

Figure 6.1.2. Location of the highland landscape tier in the highest mountain landscape of the Ukrainian Carpathians – Chornohora (Karabiniuk et al., 2022a)

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).

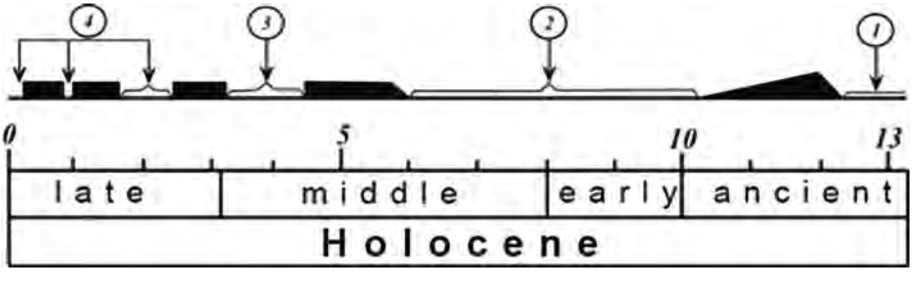

Fig. 6.2.1. Scale of natural rhythmicity in the Holocene for the alpinotypic midlands of the Carpathians (on the example of Chornohora) (Kovalukh et al., 1985)

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).

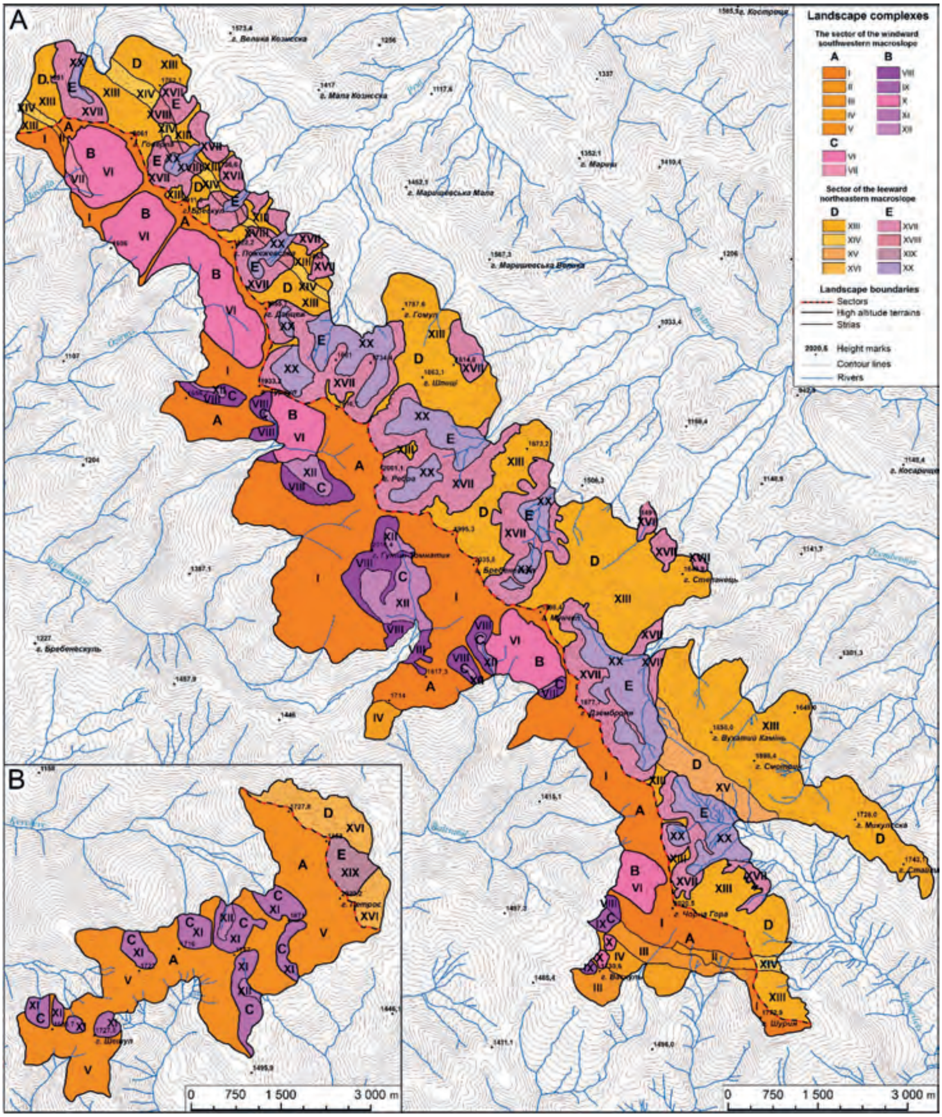

Fig. 6.2.3. Landscape map of the subalpine and alpine highlands of Chornohora (sectors, altitudes, strata): A) Hoverla-Shuryn section; B) Sheshul-Petros section (Karabiniuk, 2020a).

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/km², is observed in the old glacial-exaration highlands (B, D) covering an area of 24.8 km² (30.8 %). This category is predominantly affected by avalanches (7.5 units/ km²), rockfalls (6.7 units/km²), and screes (5.6 units/km2). The nival-erosion highlands, which span 6.6 km² (8.2 % of the total area), display a slightly lower overall intensity of negative processes (18.0 individuals/km²). However, they are particularly susceptible to waterlogging (3.9 individuals/km²) and shrub drying (0.8 individuals/ km²). In contrast, the denudation highlands (A, D), with a collective area of 49.1 km² (61.0 %), exhibit nearly half the intensity (10.3 individuals/km²) 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/ km² (Karabiniuk, 2020a).

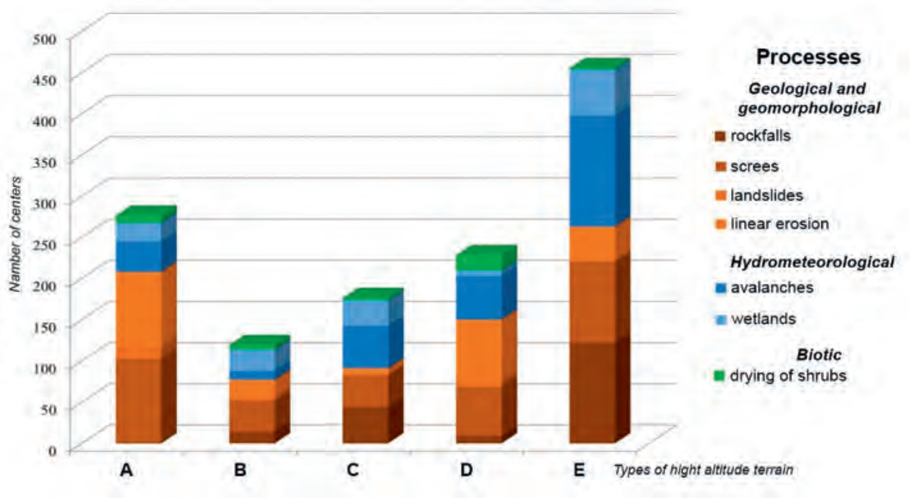

Fig. 6.3.1. The structure of modern negative physical and geographical processes in the high-altitude terrain of the subalpine and alpine highlands of Chornohora (Karabiniuk, 2020a)

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).

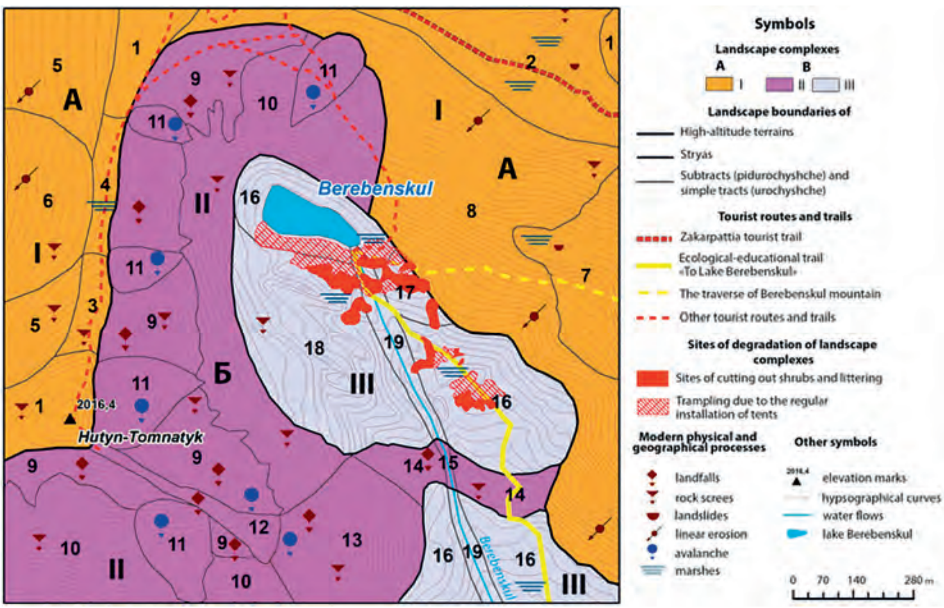

Fig. 6.3.4. Sites of degradation of natural territorial complexes of the subalpine and alpine highlands of Chornohora in the vicinity of Lake Brebeneskul (Karabiniuk et al., 2020).

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.

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Chapter 7.

MODERN CHANGES IN THE STRUCTURE OF THE FOREST COVER OF ZAKARPATTIA

(L. Felbaba-Klushyna, V. Klushyn, L. Miklovsh)

7.1. FOREST STRUCTURE AND TRENDS IN THEIR CHANGE

Forests are the most significant biomass accumulators among all types of phytocoenoses, playing a crucial role in regulating the biosphere's balance on our planet. According to V.A. Bokov and A.V. Lushchyk (Bokov and Lushchyk, 1998), forests accumulate 82% of the Earth's total phytomass, exceeding 1960 billion tonnes. Alarmingly, the world loses more than 21 hectares of forest every hour, with an annual harvest of about 5 billion m^3 of wood, progressively undermining the biosphere functions of forests.

Zakarpattia oblast claims the highest forest cover percentage in Ukraine, reaching 50.4%. Beech forests dominate this region, while spruce forests prevail in the Ukrainian Carpathians as a whole. Geobotanical research conducted by P.M. Ustymenko has identified 1305 associations of forest vegetation in the Ukrainian Carpathians (based on dominant classification principles), which constitutes approximately 70% of the phytocoenofond of Ukrainian forests (Ustymenko, 2005). Zakarpattia contributes to this diversity by describing 600 associations, representing about 50% of the syntaxonomic diversity of Ukrainian forests.

L.M. Felbaba-Klushyna (2010) conducted an analysis of the forest vegetation, highlighting significant changes in forests over the centuries due to economic activities. These changes have been exacerbated by the absence of well-defined theoretical foundations for regional forestry and nature conservation models. Additionally, practical laws and indicators of interdependencies and relationships within these ecosystems have been lacking. The forest cover in the Ukrainian Carpathians has undergone a nearly 50% reduction compared to its original biogeocenotic cover. Mature and overgrown forests now occupy only 14% of the area, and young growth predominates at 40% (Holubets, 1965; Holubets and Malynovskyi, 1967). In regions accessible for forest exploitation on mountain slopes, the natural forest structure has been significantly altered. A common characteristic of anthropogenically modified forest phytocoenoses in the Ukrainian Carpathians is the simplification of their vertical and horizontal structure, resulting in decreased flora and coenotic diversity. These changes have led to significant alterations in functional indicators, including disruptions in the water and radiation balances of the territory, reduced biological productivity, and a general imbalance in self-regulation mechanisms within forest ecosystems (Holubets, 1978, 1994, 2005, 2010; Holubets et al., 1992; Golubets et al., 2001, as cited in Felbaba-Klushyn, 2010).

In the Ukrainian Carpathians, the distribution of forest types is as follows: spruce forests occupy 37.7% – 46.4% of the forested area, beech forests cover 35.1% – 37.7%, and fir forests account for 6.8% (Bilous et al., 1975).

Among these forest types, spruce forests demonstrate the highest productivity in the Ukrainian Carpathians. In Zakarpattia, their productivity reaches 323.9 m^3/ha, which is 40 m^3/ha higher than the regional average for the Ukrainian Carpathians. However, in recent decades, a significant and widespread decline in spruce forests, especially on their southern slopes, has been observed. This phenomenon is largely attributed to climate warming (Gensiruk, 2006).

In mature beech forests of Zakarpattia, the stand productivity averages between 420-517 m^3/ha (Chubatyi, 1972). This productivity is nearly half of what is found in the central part of the beech's range (Molotkov, 1966, as cited in Felbaba-Klushyna, 2010).

Over several decades, M.A. Holubets conducted extensive research on the forest cover of the Ukrainian Carpathians and studied the dynamics of various forest indicators. He noted a significant expansion of spruce forests within the state forestry fund over 150-200 years, growing from 393 to 691 thousand hectares. Specifically, the area of pure spruce forests increased from 126 thousand hectares at the end of the last century to 325 thousand hectares in the 1970s, representing an increase of more than 2.5 times. Conversely, the area of beech forests within the restored cover initially totaled 680 thousand hectares. However, by the 1970s and 80s, it had decreased by 272 thousand hectares, marking a 40% reduction. For fir forests, the corresponding figures were 118 and 82 thousand hectares, respectively, representing a 30% decrease (Holubets et al. , 2001). The widespread cultivation of spruce (*Picea abies (L.)* H. Karst.) has been a prominent feature of forestry practices in most European countries over the past two centuries (Bilous et al. , 1975).

Due to the wide range of natural conditions, Zakarpattia exhibits both thermophilic forests containing Mediterranean species like white ash (*Fraxinus ornus L.*), silver linden (*Tilia tomentosa* Moench), fluffy oak (*Quercus pubescens Willd.*), and golden oak (*Q. dalechampii* Ten.), as well as boreal forests typically found in the taiga (Felbaba-Klushyna, 2010).

Virgin forest ecosystems dominated by European beech (*Fagus sylvatica L.*) hold exceptional value in terms of their functional significance and scientific importance, earning them a place on the list of the world's most treasured World Heritage sites. These forests are primarily concentrated within the protected regions of the Carpathian Biosphere Reserve, Synevyr National Nature Park, Uzhansky National Nature Park, and Zacharovanyi Krai National Nature Park. Among these, the largest tracts of such pristine forests are found in the Uholsko-Shyrokoluzhanskyi massif within the Carpathian Biosphere Reserve, which stands as one of Europe's most expansive virgin forest expanses (Pralisi..., 2003).

According to I. Fedurtsya and his colleagues (Fedurtsya and others, 1997), the forests of European spruce (*Piceetea abietae*) and white fir (*Abietea albae*) account for just 31.6% of the forested area in Zakarpattia. This figure is 7% less than the Ukrainian Carpathians as a whole. Forests of common oak (*Querceta roboris*) and rock oak (*Querceta petraeae*), which cover relatively smaller areas, make up around 8% of the forest composition.

Forests in Zakarpattia are distributed unevenly across different vegetation zones. The largest forested areas are concentrated at altitudes of 400-800 metres above sea level, within the lower forest zone. A somewhat smaller forested area belongs to the upper forest zone, found at altitudes between 800 and 1200 metres above sea level. Approximately 10% of the forested land is located in the floodplains of the Latorytsia, Borzhava, and Tisa rivers within the Zakarpattia lowland, encompassed by the Prytysyansky Regional Landscape Park. These floodplains exhibit variations in dominant forest species. For instance, in the floodplains of the lower Latorytsia River, one can find ash oak forests known for their high floristic diversity, predominantly situated along old streams, branches, and the riverbed itself (Kish et al., 2009). In the lower reaches of the Borzhava River, the forests consist of elm and ash trees, along with hornbeam oaks, common oak (*Quercus robur L.*), and narrow-leaved ash (*Fraxinus angustifolia Vahl.*). As reported by Kish and colleagues, these areas are considered to be one of the largest continuous expanses, covering 2500 hectares, of lowland floodplain forests in both Ukraine and Europe (Kish et al., 2009). In the lower reaches of the Tysa River, you can find willow-poplar and black poplar (*Populus nigra* L.) forests, with trees that are over 100 years old. Moreover, the floodplain alder forest of black alder (*Alnus glutinosa (L.) P. Gaertn.*) in the Ehresh tract stands as the largest in terms of area and one of the best-preserved alder forests in Zakarpattia (Kish et al., 2009).

In the lowest areas of the oak forests in the lower reaches of the aforementioned rivers, swampy alder forests have been preserved, hosting rare species such as the Kyiv nettle (*Urtica kioviensis Rogov.*), common ostrich fern (*Matteucia struthiopteris (L.) Tod.*), and sphagnum mosses. Some of these areas are protected within the aforementioned park, while certain tracts have been designated as forest reserves, including Silash (75.5 hectares, Berehove State Forestry), Ehresh (37.4 hectares, Vynohradiv Forestry), and Ostrosh (30.0 hectares, Mukachevo Forestry) tracts (Kish et al., 2009).

Within the lower-lying sections of the topography of some of these protected tracts, alder and ash forests, featuring tall grass bogs, have developed. Among them, small patches of sphagnum mosses, such as marsh sphagnum (*Sphagnum palustre L.*), central sphagnum (*S. centrale C. Jens.*), and sharp-leaved sphagnum (*S. capillifolium (Ehrh.) Hedw.*), can be found. It's possible that some alder forests emerged on the sites of former sedge-sphagnum or willow-sedge bogs following reclamation, a practice that was frequent in the lowlands during the postglacial era.

A significant proportion of forest vegetation syntaxons in Zakarpattia exhibit unique structural and species compositions not found elsewhere in Ukraine (Felbaba-Klushyna, 2010). Consequently, there is an observed decline in the extent of swampy alder forests.

A significant proportion of forest vegetation syntaxons in Zakarpattia exhibit unique structural and species compositions not found elsewhere in Ukraine (Felbaba-Klushyna, 2010). Consequently, there is an observed decline in the extent of swampy alder forests.

According to P.M. Ustymenko and colleagues, approximately 35% of Ukraine's rare forest phytocoenofond is found in Zakarpattia, with around 20% of these exclusive to the region (Ustymenko et al., 2007). Notably, these unique phytocoenoses are located in areas like Chorna Hora, Yuliyivska Hora, and Muzhiyivska Hora. The latest edition of the Green Data Book of Ukraine (2009) encompasses 308 associations within 72 forest vegetation formations in Ukraine. Among these, 28 occur in Zakarpattia, with 12 being exclusive to the region. Below, we provide a brief list and description of these unique forest phytocoenoses.

Additionally, the category of unique forest phytocoenoses includes swampy alder-lilac forests from the Alnetea (incanae) syringosa and Alnetea (glutinosae) syringosa formations. Syringa josikaeae J.Jacq.ex Rchb. is a Pleistocene relict that exclusively thrives in the Eastern Carpathians of Ukraine and Romania (Eastern Carpathian endemism). These communities, where it plays a dominant role in the undergrowth, are primarily situated on the southern slopes of the Ukrainian Carpathians within the upper reaches of the Latorytsia River catchment, with only one known location on the northern slopes of the Vododilnyi Ridge. To date, nine localities of Syringa josikaea communities have been recorded, whereas there were approximately 16 of them during the latter half of the previous century (Stoyko et al., 1980; Felbaba-Klushyna, 2005; Felbaba-Klushyna, Bizilya, 2006). Communities featuring grey alder Hungarian lilac and glue alder

Hungarian lilac forests are designated as rare within the Green Book of Ukraine (2009) (Felbaba-Klushyna, 2010).

In the Zakarpattia Oblast, forest cover exhibits variations across different floristic regions and altitudes. There is a prevailing trend of younger forests increasing in abundance while mature and old-growth forests are decreasing. Old-growth forests are primarily preserved within protected areas, and floodplain glue alder forests are notably scarce.

7.2. FUNCTIONAL IMPORTANCE OF FOREST COVER *(Hydrological and Soil Protection Role)*

Numerous studies have been dedicated to exploring the functions of forests in the Ukrainian Carpathians (Bilous et al., 1975; Blystiv, 2002; Holubets, 2010; Komendar, 1966; Oliynyk, 2008; Chubaty, 1968-1984). For the most recent insights into the functions of forests of various species and age compositions, one can refer to the works of V.S. Oliynyk (1996, 1999a,b, 2008).

In summary, the water protection function of forests can be assessed by their impact on total water reserves, as represented by the annual river runoff within a specific region (Rakhmanov, 1984). The hydrological role of forests is evident in the reduction of surface runoff in rivers and the increase in groundwater runoff. This phenomenon results in a decrease in unproductive flood runoff and a simultaneous rise in the more valuable groundwater runoff, which sustains and benefits national economic activities (Lvovich, 1963). The water-regulating function of forests is essential, as forest cover plays a significant role in protecting and conserving the water resources of a region by redistributing moisture across different biogeocenotic horizons and throughout the year (Mikhovych, 1986; Chubaty, 1984, as cited in Felbaba-Klushyna, 2010).

Numerous studies have examined the relationship between the hydrological and soil protection roles of forests and factors such as the species composition of forest coenoses, age category, relief conditions, altitude, the extent of forested areas, and forest management practices. For instance, the most substantial water protection impact is observed in mature and relatively mature beech forests and mixed beech-spruce-fir mountain forests. As mixed stands become more complex with age, they effectively utilise both underground and aboveground airspaces, enhancing their water protection functions compared to mono-dominant forest phytocoenoses. Therefore, to strengthen the water protection and conservation functions of forests for multi-purpose forest management, it is crucial to increase forest cover in watersheds and promote complex forests (Chubaty, 1968).

The water-regulating and water-protective roles of forests become more pronounced at higher altitudes due to increased precipitation, variations in the thermal regime, and the greater influence of mountain slope topography. Soils are a crucial functional component of forest phytocoenosis. In studies conducted by Chubaty in 1984, it was found that beech stand soils exhibited the highest infiltration rates and the lowest runoff rates. For instance, under similar precipitation intensity (62-75 mm per hour) and on slopes with similar steepness (20°-30°), the runoff in a mature beech stand was measured at 2.3-3.4 mm, with an infiltration rate of 95.5-96.6%. In contrast, a mature spruce stand showed runoff values of 14.1-57.8 mm, with infiltration rates ranging from 19.2% to 77.2%. In a pasture environment under these conditions, runoff levels were between 63.1-67.1 mm, and infiltration rates ranged from 11.7% to 16.3%. However, on slopes with a steepness of 100, runoff in mature spruce and beech stands was similar, at 3.6 mm, with an infiltration rate of 93.7%. Depending on weather conditions and the distribution of annual precipitation, underground runoff in mature beech stands varied from 61 to 553% of surface runoff for this period, while under spruce stands, it ranged from 45 to 347%. This demonstrates that the increased water-regulating influence of beech stands is attributed to their heightened moisture cycling intensity (Felbaba-Klushyna, 2010).

Forest functions are influenced by the method of logging and skidding. Clear-cutting and ground felling, for example, result in the complete removal of the forest floor and a significant portion of the topsoil on 60-90% of the logged area. In mountain forests, particularly in valley floors, soils exhibit very high water permeability, reaching up to 4000 mm per hour. In contrast, meadow communities dominated by compacted whitebark (Nardus stricta) have water permeability 10-15 times lower. Furthermore, after rainfall, runoff in forests starts several days later compared to meadows and fields. This means that water from the forest enters the riverbed when most of it has already drained from the meadows and fields, a crucial factor in flood prevention. In the Carpathian region, where 75% of river runoff is flood runoff, the primary function of forest cover lies in redistributing the total volume of runoff and reducing the potential for destructive floods (Felbaba-Klushyna, 2010).

Following clear-cutting, the annual runoff volume from the studied catchment in the beech stand increased significantly, rising from 39.1 to 406.3 mm when compared to control conditions without clear-cutting.

Forests universally serve the essential functions of soil protection and soil formation, as the nature and type of soil are intricately linked to forest cover in conjunction with climatic factors. A comparison of solid runoff (mudflows, landslides, avalanches) from catchments, both during the period when they were covered with forests and after harvesting for essential use, reveals that the maximum solid runoff occurs immediately after harvesting (Chubaty, 1984, as cited in Felbaba-Klushyna, 2010).

The pivotal factor that governs the state of water protection and water regulation functions of forests is the extent of forest cover within a given catchment. To uphold the water-regulating function of forests, it's imperative that their coverage within the catchments of Carpathian rivers remains at or above 70% of the total territory. Conversely, forest cover below 40% of the catchment area is regarded as inadequate for the stable operation of basin ecosystems (Blystiv, 2002; Oliynyk, 2008). Increasing the extent of forests in the region to 70% is a vital flood control measure, emphasising the need to expand afforestation in river basins with insufficient forest cover, while gradually replacing monocultures with mixed stands (Felbaba-Klushyna, 2010).

Chubaty has categorised the catchment basins in the Ukrainian Carpathians into four distinct groups:

1. River basins in the central drainage area of the southern megaslope of the Carpathians with an average annual precipitation of 1364 mm.
2. River basins in the upwind southern slope of the Polonynsky ridge, where the average annual precipitation is 1247 mm.
3. A group of basins on the southern and northern megaslopes, predominantly in the eastern part of the Pryvododilski Carpathians, with an average annual precipitation of 1156 mm.
4. Basins in the central and western parts of the northern megaslope of the Carpathians, partly in the Gorgan mountain range, and entirely in the Beskydy, where the average annual precipitation is 1008 mm (Chubatyi, 1984).

The findings of O.V. Oliynyk's research underscore the pivotal role of catchment forest cover in shaping river runoff. For instance, a 1% increase in the forested area of catchments across all studied groups leads to a river runoff increase of 9.4-11.9 mm (Oliynyk, 1996, 1999, 2008; Chubatyi, 1968). Mountain forests exhibit the capacity to retain approximately 25% of atmospheric precipitation. They reduce snow accumulation and the intensity of spring snowmelt by 1.5 times, enhance soil permeability by 2-10 times, lower soil moisture by 1.2 times, and decelerate the formation of surface water runoff by 3-4 times (Chubaty, 1968).

The main conclusion from these, and other relevant studies, on the role of forests is that, in addition to their climate-forming and soil-protective functions, forests play a crucial role as regulators of the hydrological balance in both mountainous regions and plains. This role becomes increasingly significant as concerns about water shortages grow (Felbaba-Klushyna, 2010).

Based on the results of the literature analysis, it can be concluded that unbalanced forest management in Zakarpattia has led to a disruption in the natural distribution of forests across altitude zones and age categories. Mature and overgrown forests are primarily found in high mountainous and remote areas, while young and middle-aged stands are situated at lower elevations, often near roads and settlements. Furthermore, young and middle-aged stands tend to be concentrated within certain river catchments, while mature and overgrown stands dominate others. This discrepancy is the primary cause of the environmental conditions that have resulted in water and energy imbalances and disruptions in river flows. For instance, in the basins of the Turya and Pynia rivers, located in the Skhidni Beskydy and low mountain meadows, extensive clear-cutting operations took place until the 1980s. Consequently, approximately 80% of their forested areas are now dominated by stands with a simplified vertical and horizontal structure, resulting in the loss of many water and soil protection functions. This has had a severely detrimental effect on the state of water resources. More than a quarter of a century ago, due to human activity, the Beskydy region lost about 460 million m^3 of water annually, and the absorption of solar radiation by the forests was reduced by 2.8 x 1015 kcal/year, representing a 3.4% decrease compared to the original biogeocenotic cover (Holubets, 2010, as cited in Felbaba-Klushyna, 2010).

Moreover, the forest cover of the Carpathian Mountains significantly influences the moisture content of air masses both over the Carpathians and in neighboring regions. This influence arises from the substantial moisture retained by the Carpathian forest canopy and subsequently evaporated into the air, resulting in an annual enrichment of the region's atmosphere by an average of 2.5-3 km^3 of water (Chubatyi, 1984, as cited in Felbaba-Klushyna, 2010).

Mountain forests in the Carpathians are recognized for their essential roles in water and soil protection, although these roles may vary in different geomorphological regions of the mountains, on different types of soils, and, as previously mentioned, depending on the species composition of forest phytocoenoses.

In accordance with the zonation of Carpathian mountain forests based on their water protection significance, these forests are categorized into the following groups (Chubaty, 1972, as cited in Felbaba-Klushyna, 2010):

I. Watershed mountain forests of paramount water protection importance, which play a critically significant role in supplying water to mountain rivers on both the southern and northern macroslopes. These forests are situated in zones characterised by maximum atmospheric moisture and a cold to cool climate, which has resulted in the formation of the densest hydrographic networks. Within this category, three sub-districts have been identified: I a. Chornohora-Maramorosh-Chyvchyn, I b. Horgansky, and I c. Beskydsko-Verkhovynsky. In Zakarpattia, mudflows most frequently occur in the upper reaches of the Chorna Tisa and Bila Tysa rivers, Tereblya, Teresva, and Rika, all of which are located within the district. On steep, rocky slopes, heavy rainfall can trigger soil erosion. In the Pryvododilni Horgany region, during the first half of the last century, devastating landslides destroyed approximately 50 hectares of forests, including over 20 hectares of pine forests. In certain cases, when water saturation is particularly severe, forest cover may not withstand landslides. Nonetheless, intact forests that haven't been significantly altered by human activities generally serve as a natural defence against the development of landslides and mudflows.

II. Water protection forests of the southern macroslope of the Polonynski Carpathians. The unique orographic features of the Polonynsky ridge have a significant impact on the distribution of moisture within the water balance elements. The water-regulating influence of the forests in this area combines moisture accumulation and nourishment of mountain streams and rivers, which are water protection elements. Conversely, it leads to increased moisture consumption through total evaporation compared to riparian water protection forests. This increased evaporation contributes to a somewhat reduced water storage capacity of these forests. Sub-areas within this category include: IIa. Svydovets-Krasnyansky, IIb. Borzhavsky, and IIc. Western Polonynsky.

III. The Zakarpattia lowland area with forests of water regulation and protection value coincides with the territory of the Volcanic Carpathians, encompassing the Solotvyno Basin in the eastern part. The significance of forest cover lies, firstly, in its ability to consolidate and stabilise the banks of mountain rivers, and secondly, in its role in regulating the hydrological patterns of the soil, ensuring high productivity for both forests and agricultural land. In this context, the water conservation role of forests, namely their influence on increasing water resources, is counterbalanced by the moisture consumption through total evaporation. This occurs in a relatively less humid and warmer climate. Thus, the widespread forests in this area create optimal hydrological conditions for the soil cover, with their water protection role being of secondary importance.

IV. The Carpathian lowland area of forests with water regulation importance. These forests share some similarities with the forests in the previous district regarding their role in water regulation and protection. This category comprises two sub-areas: IVa. The External Carpathian lowland and IVb. Pokutsko-Bukovyna lowland. The forests in the first sub-area serve the functions of both water protection and water regulation, while the forests in the second sub-area contribute to moisture accumulation and river nourishment. Additionally, they aid in stabilising river and stream banks and collectively enhance the hydrological conditions in both forested areas and adjacent agricultural lands.

Floodplain forests are not isolated as a separate region; instead, they are dispersed above the forest belt of the first two regions and form a transitional zone with the subalpine belt. Nevertheless, they are classified as forests with specific importance in water protection and water regulation (Chubaty, 1972). Foothill forests, in conjunction with thickets of mountain pine (Pinus mugo Turra) (coppice) and green alder (Duschekia alnobetula (Ehrh.) Pouzar) (larch), play a particularly crucial role in hydrological and erosion control.Вони поглинають величезну кількість води, яка стікає з полонин. For instance, graystone soil is capable of absorbing rainfall in just 23 seconds, whereas in white-tailed deer, it takes 7 minutes and 56 seconds. Sphagnum in peaty soils exhibits an exceptionally high moisture retention capacity. To illustrate, the moisture capacity of grass plants typically ranges from 100% to 200%, green mosses exhibit a range of 300% to 500%, and sphagnum mosses reach an impressive 1500% to 3000% (or even up to 5000%) (Komendar, 1966). In alpine pine forests, the litter layer plays a particularly significant role, averaging 100 cm per hectare, while in spruce forests, it reaches 80 cm per hectare. Consequently, in dense spruce stands and coppice forests, even on slopes ranging from 20 to 25 degrees, surface runoff and soil erosion are nearly non-existent (Bilous, 1975). Foothill forests, situated adjacent to treeless meadows, are instrumental in redistributing snow cover, leading to a reduction in springtime floods.

V.I. Komendar (1966) underscored the need to protect all thickets of cedar and bramble in the Ukrainian Carpathians and advocated for the artificial restoration of damaged natural phytocoenoses.

In summary, the foremost priority for conserving and reinstating the core functionality of forest ecosystems entails expanding their coverage, optimising their structure, especially in the upper catchment areas of the primary tributaries of the Tysa River and in lowlands, and safeguarding and rejuvenating riverine and floodplain water protection forests. Consequently, the primary mission of contemporary mountain forestry revolves around enhancing the water protection role of forests.

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Chapter 8.

CHANGES IN THE BIODIVERSITY OF ZAKARPATTIA IN THE CONTEXT OF ANTHROPOGENIC PRESSURE

8.1. IMPACT OF ANTHROPOGENIC FACTORS ON THE MICROBIOTA OF NATURAL ECOSYSTEMS *(M.Kryvtsova, M. Savenko)*

Over the past decades, there has been an intensification of anthropogenic impact on natural ecosystems, which has led to significant changes in the functioning of microbial cenoses. Microorganisms react sensitively to changes in the environment and, accordingly, to the impact of anthropogenic pressure. Sources of environmental pollution include the use of pesticides, industrial emissions into the atmosphere, domestic and industrial wastewater, fuel industry, transport, liquid and solid municipal waste, and heavy metal deposits.

The dynamics of microbial communities is a sensitive bioindicator system that reflects not only the state but also the functioning of microbial communities, and to a large extent, the ecosystem as a whole.

Significant changes in the composition of the microbiota of aquatic ecosystems are reflected in the results of monitoring observations (Bilkey et al., 2018). In particular, monitoring observations of the Uzh River were carried out. The authors demonstrate the dynamics of the qualitative and quantitative composition of the surface waters of the Uzh River in several monitoring sites with different types of anthropogenic pollution: 1) the area of influence of the Perechynskyi Lisokhimichnyi Kombinat (Perechyn Forestry and Chemical Plant); 2) the areas where municipal wastewater from the city of Uzhhorod enters the river; 3) near the location of household plots and unauthorised landfills on the banks of the water body.

According to the results of spatial and temporal monitoring of microbiological indicators of the Uzh River, it was found that the total number of microorganisms (TNM) fluctuates widely. The main factor behind the change in bacterial contamination of water in these areas was the change in the river's intra-annual hydrological regime. Thus, the highest values of total TNM were recorded from February to March during the spring flood and summer low water, and the lowest in January. A similar trend is typical for the dynamics of the coli-index, however, a steadily increased level is observed during the summer. As for the fluctuations in the total number of microscopic fungi, an increase in early spring and a further decrease in summer can be observed. Such a trend may indicate the proliferation of micromycetes under favourable conditions, in particular, of an increase in temperature. The decrease in the concentration of microscopic fungi in summer can be explained by the increased exposure to solar radiation, which is known to be stronger in high mountainous areas and in surface waters with low flow levels. Bacteriological indicators of water quality increase significantly within 100 metres of the Domoradzh Stream. Throughout the year, the microbial count reaches above-normal values, decreases in winter, and gradually increases with the beginning of spring. In this case, the influence of chemicals on the change in the dynamics of the TNM can be observed. The change in the coliform index at this point indicates its dependence on the temperature factor and river water content, the highest values are recorded during the summer intermittent period and exceed the permissible values 24-28 times, in winter they decrease by half, exceeding the norms 10-15 times. The total number of microscopic fungi during the year was within the limits, which is insignificant given the increased content of biogenic matter and generally had a slight downward trend in winter. Outside of Perechyn, a similar trend is observed, but the level of both chemical and microbiological pollution slightly decreases, which is explained by the self-purification ability of the river in the mountainous part and the remote distance from the potential source of pollution.

The impact of dense urban development is reflected in the results of bacteriological pollution of the water body within Uzhhorod. This is most evident in changes in the coliform index. Water pollution by coliform bacteria is explained by the unregulated discharge of untreated or insufficiently treated wastewater. It can be also assumed that the increase in temperature and the nature of the water content of the water body, namely the shallowing of the river during this period, leads to an increase in the concentration of pollutants and the proliferation of saprophytic microflora under favourable conditions. The results of chemical and microbiological studies of the Bialka mountain river in Poland were similar, where the level of bacterial pollution increased in summer as a result of an increase in the number of tourists and was closely correlated with the content of nitrogen compounds.

An equally important factor is the river's transition to a flat type, which results in the transfer of pollutants to lowland areas. In the lower reach of the Uzh River within the village of Storozhnytsia, a tendency to increased microbiological indicators of water quality outside the village was detected, with maximum TNM values recorded in summer and autumn. Compared to the control point, the excess of the total microbial count outside the village of Storozhnytsia reaches thousands of times. In addition, it was found that the increase in the total number of microorganisms and microscopic fungi was caused by an an increase in the concentration of nitrates, nitrites and ammonium nitrogen, which is explained by the flow of nutrients into the water body, one of the main sources of which is agricultural wastewater and runoff from adjacent areas. It is also worth noting that in this area, the flow rate slows down and the riverbed becomes silted, which significantly reduces its natural self-purification mechanisms. The coli-index also reaches high values both before and after the village, which can be explained, firstly, by the transfer of pollutants from upstream areas, and, secondly, by the close proximity of the riverbed to buildings, in particular, to a number of small household farms, which serve as a source of faecal pollution.

The results of the study of the distribution of different groups of microorganisms in aquatic environments indicate qualitative and quantitative changes in the structure of microbial communities under the influence of anthropogenic pressure. In the areas of water bodies subjected to anthropogenic pressure, a decrease in autochthonous gram-positive groups of microorganisms and an increase in the number of allochthonous gram-negative microbes were observed. The number and ratio of microorganisms changes under the influence of chemical compounds. Excessive concentrations of heavy metals in water bodies inhibit the growth of myxomycetes, thereby upsetting the balance in the ecosystem. In turn, such dynamics of quantitative reduction of microscopic fungi can serve as an indicator of water body pollution.

The results of the study indicate an uneven distribution of microorganisms of different physiological groups depending on the territorial location. Comparative characteristics of the ratio and number of representatives of the microbiocenosis indicates that the most unfavourable environmental situation is typical for a technogenically transformed area, where under the influence of long-term pollution, an adaptive response of microorganisms to inadequate living conditions is observed, which leads to successive changes in the microbial cenosis. The area near the village of Storozhnytsia, which is in the zone of influence of agricultural activities, is also characterised by changes in the structure of the microbiocenosis, which indicates a continuous flow of pollutants into the water reservoir (Savenko and others, 2021).

Antibiotic-resistant microorganisms in technogenically transformed ecosystems. The real challenge of the 21st century is the problem of antibiotic resistance, which threatens the effectiveness of antimicrobial therapy in the fight against infectious diseases. According to the WHO, 37,000 deaths were recorded in Europe alone in 2016 as a result of microbial resistance to drugs. The use of antibiotics has long crossed the boundary of the clinical profile and is widely used in the agricultural and food industries, making it impossible to introduce controls over the rational use of antimicrobials.

One of the consequences of the irrational use of antibiotics is the growth of antibiotic-resistant microorganisms and their genetic determinants of resistance not only within hospitals but also in the environment. The results of scientific studies conducted over the past decade indicate a significant spread of poly- and multi-resistant microorganisms and resistance genes in surface water, wastewater and groundwater, drinking and bottled water, soil and food of the plant origin.

These results indicate the potential risks of antibiotic substances entering the human body through the food chain, as even the consumption of water of inadequate quality can lead to the development of resistance. Modern wastewater treatment facilities are not capable of completely cleaning water from genetic determinants, the largest source of which is known to be hospital wastewater and domestic wastewater.

We have conducted research to determine the relationships of the migration of antibiotic-resistant microorganisms in the system of human-aquatic environment and to assess the risks of resistance spreading. In particular, the level of antibiotic resistance of microorganisms isolates of the *Enterobacteriaceae* family isolated in the conditions of inflammatory processes of the oral cavity and bacteria isolated from surface waters (the Uzh River) was studied.

The high level of antibiotic resistance of microorganisms of the *Enterobacteriaceae* family both in aquatic ecosystems and the human body was established. The highest rates of antibiotic resistance were revealed for unprotected beta-lactams, tetracyclines, macrolides, and first-generation cephalosporins. The results of the study prove the possible role of aquatic ecosystems in the formation and migration of antibiotic-resistant microorganisms, both in the environment and on the way to the consumer. The data obtained substantiate the feasibility of introducing new indicators of sanitary and hygienic control over the spread of antibiotic-resistant microorganisms (Savenko et al, 2021; Savenko et al, 2020).

Microorganisms of technogenically transformed soils. The impact of transport facilities on the natural environment is caused by the construction of motorways, their operation, burning of significant amounts of fuel, pollution of adjacent areas by emissions, runoff, and waste, which disrupt the natural balance in ecosystems. These environmental impacts include disruption of the stability of natural landscapes by transport infrastructure through erosion and landslides; air pollution by exhaust gases; and a steady increase in soil contamination with oil, lead, and products of blowing and falling bulk cargo (coal, ore, cement). Toxic substances emitted by diesel engines include carbon oxide, nitrogen oxides, soot, hydrocarbon compounds, sulphur dioxide, and hydrogen sulphide. The exhaust gases also contain benzo(a)pyrene and polycyclic aromatic compounds, as well as heavy metals. These substances in increased quantities during intensive railway traffic undoubtedly have a negative impact on all components of the surrounding ecosystems, including the air. Railway transport is also a source of physical impact (noise, vibration, electromagnetic radiation) and biological pollution of the mainline biogeocenoses. At the same time, there is a spread and accumulation of harmful substances on adjacent fields and land areas, which is equally harmful to the environment and human health.

Microbiological and biochemical indicators allow us to determine the depth of anthropogenic impact at the early stages of ecosystem transformation and provide an integral assessment of soil condition.

Monitoring studies have been conducted on the impact of xenobiotics on soil microbial communities in the area affected by vehicles, motor vehicles, and industrial xenobiotics (Bobryk et al., 2012). Soils located in the immediate vicinity of railways have different qualitative and quantitative composition compared to technogenically transformed ecosystems. In particular, in the area affected by railway transport, a reduced content of ammonifiers, micromycetes, and *Azotobacter* bacteria was observed. At the same time, coliform organisms, oligotrophs, oligonitrophils, and spores were dominant in microbiocenoses, whose increased number indicates a disruption of the processes of natural self-purification of ecosystems and, consequently, a deteriorated ecological state. The analysis of the quantitative composition of microbiocenoses and phytotesting revealed a significant negative impact of railway transport on the adjacent ecosystems. Soils near railway tracks are characterised by reduced microbiological activity, which gradually increases at greater distances.

The impact of motor vehicles on the soil microbiota of the areas adjacent to the motorway has also been established. The studies conducted in Uzhhorod near the motorway at a distance of 0-50 m from the road showed a dramatic change in soil microbial cenosis, which was manifested in an increase in the number of ammonifiers due to opportunistic microbiota and spore microorganisms, a decrease in the content of micromycetes and the percentage of nitrogen-fixing microflora (Ihnatko et al., 2012).

Trends in changes in soil microbiota indicators near the source of anthropogenic load were also established in the study of soil microorganisms near the Perechynskyi Lisokhimkombinat (Perechyn Timber and Chemical Plant). The research revealed chemical contamination of the soils close to the plant, which is caused by an increased content of nitrates and heavy metals exceeding the MPC. In addition, there is a strong acidification of the soil in the pollution zone. The correlation analysis showed that the most sensitive groups to the content of pollutants in the soil are nitrogen fixers and oligonitrophils. The number of actinomycetes did not change significantly, and the dynamics of oligotrophs coincided with the increased content of heavy metals. Studies have shown the presence of chemical contamination of the territories adjacent to the plant (30 m) and, as a result, the restructuring of microbial cenosis (Kryvtsova et. al, 2017).

Thus, microbial communities are sensitive to anthropogenic load, changing the ratio of autochthonous and allochthonous representatives, which inevitably affects the functioning of the ecosystem as a whole.

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8.2. PROBLEMS OF FLORAL DIVERSITY PRESERVATION *(R. Kish)*

Zakarpattia, the westernmost region separated by mountains, is one of the most interesting, rich and original natural regions of Ukraine, where two biogeographical regions of Europe are represented simultaneously – the Pannonian, which includes the Transcarpathian lowland, and the Alpine, which includes the southern megaslopes of the Ukrainian Carpathians. The high diversity of natural conditions, from lowland to highland, as well as their mosaic characteristic of mountainous countries, results in the second highest diversity of flora here after Crimea – more than 50% of all species of vascular flora in Ukraine. However, today, due to historical reasons, global changes in recent decades, and mainly due to the effects of anthropogenic impact, primarily economic development of land and natural resources, an increasing number of plant species growing in the region are experiencing a rapid reduction in natural habitats, insularisation and population decline, many species are already endangered, and some species have already disappeared or may disappear in the coming years (Chervona knyha, 2009). Therefore, nowadays preserving the unique floral richness and diversity of the region and creating conditions for its restoration is one of the main prerogative environmental tasks.

The issue of preserving the floral diversity of the territory of Zakarpattia at the legislative level, especially at the state level, began to be a focus of attention rather late. The very first measures in this direction, launched in the early twentieth century during the Austro-Hungarian era, were the creation of nature reserve areas, mainly forest reserves, where the entire vegetation cover of the reserved area was protected. Later, during the Czechoslovakian period of 1919-1939, this practice of protection was continued, but in addition to forest reserves (mainly for the preservation of virgin forests), a number of highland reserves were created in Zakarpattia (Stoiko, 1957, 1991). In Soviet times, after a long break, the restoration of some of the old reserves and the formation of new ones continued only in the late 1960s.

For the first time, the issue of direct protection of rare species at the regulatory level arose only with the publication of the Red Books – the Red Book of the USSR (Krasnaia kniga SSSR, 1978) and the Red Book of the Ukrainian SSR (published in 1980) – which contained lists of rare and endangered plants and animals, brief information about them and the necessary measures for their protection. The Ukrainian Red Book included 151 species of vascular plants in the list of species to be protected, almost half of which – 69 species – are recorded to be located on the territory of Zakarpattia (some of them, in particular, *Crocus banaticus, Narcissus angustifolius* – only in this region). The publication of this collection, prepared by a team of scientists, was preceded by lists of rare plants of Ukraine compiled in the 1970s by V.I. Chopyk (63-88 species of vascular plants were proposed for protection), which included species of the Zakarpattia's flora (Chopyk, 1970, 1978). The next, second edition of the Red Book, "the Red Book of Ukraine", which appeared during the years of independence, in 1996 included 541 plant species, where 439 species were those of higher plants – almost three times more than in the first edition (143 species were listed for Zakarpattia).

Today, the Red Book of Ukraine (hereinafter also referred to as the Red Book) is the legal basis for the protection of rare and endangered species of flora, according to the Laws of Ukraine "On Flora" of 9 April 1999 (current version) and "On the Red Book of Ukraine" of 7 February 2002 (current version). The latest, third, substantially revised edition of the national Red Book was published in 2009. It includes 826 plant species, including 611 species of vascular plants, which is almost a third more than in the previous second edition. 207 species, more than a third of the list, are found in Zakarpattia, including 36 species that are exclusively found in this region.

The tendency to expand the national list of rare species is associated, on the one hand, with an information gain about the composition, current distribution, number and actual state of populations of vascular plants in Ukraine. On the other hand, for a significant percentage of species that were not threatened until recently, a decrease in population numbers, reduction of habitats due to the destruction or transformation of habitats of the corresponding type, etc. has been recorded since the first edition of the Red Book.

After Ukraine ratified the Berne Convention, species listed in Resolution 6 (1998) of the Convention are also under state protection. There are 52 species of vascular plants in Ukraine listed in Resolution 6, 12 of which occur in Zakarpattia (Sudynni roslyny..., 2017). Seven of them are also simultaneously included in the national Red Book, three species (*Adenophora liliifolia, Iris aphylla* subsp. *hungarica, Tozzia carpathica*) are included in the regional Red List (see below), but two species – *Poa deylii* and *Campanula serrata* – are protected exclusively by the Bern Convention.

At the same time, the list of species from the territory of the Zakarpattia Oblast included in the new edition of the national Red Book does not fully or only partially cover the species of the region's flora, which is currently threatened and in need of protection in Zakarpattia. Many species that are common in other parts of Ukraine are rare in Zakarpattia, and many of them are now on the verge of extinction and are often represented by several dozen individuals or even single specimens. In addition, given the modern concepts of protection, endemic plant species are of prior importance for the preservation of global phytodiversity as carriers of a special genotype with a limited distribution, so the vast majority of endemics require special attention and protection measures (Didukh, Tsarenko, 2003; Yena, 2003), in particular, regional ones.

The issue of protection of regionally rare species in Zakarpattia has been raised many times. Thus, S.S. Fodor (1973) compiled the first version of the regional red list, which included 364 taxa of vascular plants (including subspecies and varieties). Later, a list compiled by V.I. Komendar S.S. Fodor and V.I. Vainagiy (1987) was published, which included 213 taxa. The most detailed list today is the Red List of Endangered Vascular Plants of Zakarpattia, compiled by V.V. Krichfalushii and others (Krichfalushii, Budnikov, Myhal, 1999), which includes 485 taxa and became one of the first regional Red Lists in Ukraine in the modern sense. Several proposed editions of the lists of rare species of the Ukrainian Carpathians, including the territory of Zakarpattia (Stoiko, 1977; Komendar, 1988; Malynovskyi and Tsaryk, 1991; Kricsfalusy and Budnikov, 2007), or only its mountainous regions (Malynovskyi et al., 2002) are also worth noting.

Along with scientific publications in Zakarpattia, there were several legally enshrined editions of the regional red list of vascular plant species of special concern in the Zakarpattia Oblast, the first edition of which was approved by the Oblast Council in 1992. The list has been repeatedly revised, and new editions compiled by us together with Danyliuk I.M., D. Bi. Sci. (Institute of Ecology of the Carpathians of the National Academy of Sciences of Ukraine) and Prots B.H., Cand. Sc. Biology (State Museum of Natural History of the National Academy of Sciences of Ukraine) were approved in 2008 and 2011, after the publication of the new edition of the Red Book of Ukraine, which included 68 taxa from the previous list. The current version of the Red List is the 2015 edition – “List of vascular plant species subject to special protection in the territory of the Zakarpattia Oblast”, approved by the decision of the Oblast Council No. 1263 of 28.05.15 (Annex 2). It was edited by scientists from the Carpathian Biosphere Reserve, Uzhanskyi National Park, and Synevyr National Park. The latest version of the list includes 321 taxa of higher plants.

Thus, today in Zakarpattia, the total list of rare species of higher plants under protection includes 530 taxa, which is about a quarter of the natural flora of this region. This percentage generally reflects the actual current state of threats to the floral diversity of the region. A high percentage of rare plants is a characteristic feature of mountainous countries, including those in Europe, which are distinguished compared to the surrounding areas by increased phytodiversity, in particular, the presence of numerous endemics, relics, species with a disjunctive area, etc. For example, in Poland, the Carpathian region occupies only 7% of the territory, but it is home to about 85% of all higher plant species in the country, 80% of endemics, etc., while 20% of plant species do not occur outside this region (Czerwona księga.., 2008).

Another important reason is that, due to historical reasons or anthropogenic transformation, most of the specific habitats with high or original phytodiversity (xerothermic forests and meadows, bogs and marshes, rocky outcrops, most highland biotopes, etc.) in Zakarpattia are usually found in small areas, often in the form of fragments, and therefore a significant part of the natural flora species is concentrated in small areas, where it is represented by small, often isolated or solitary populations. It should also be noted that due to the location of Zakarpattia at the intersection of two particularly different biogeographical regions – the xerothermic Pannonian and the Carpathian-mountainous Alpine – many species are represented here by marginal borderline populations in several or even one locality, with plants growing here at the limit of their ecological ranges (capabilities), with reduced population viability.

Only a small percentage of rare or endangered species in Zakarpattia owe its current state to the direct destruction by humans. Among these species, we should firstly mention highly decorative flowering plants, in particular, spring ephemeral plants (*Erythronium dens-canis, Fritillaria meleagris*, etc.) or certain orchid species, legendary plants, such as edelweiss (*Leontopodium alpinum*), woody plants with valuable wood (*Sorbus torminalis*), etc. Some species have also been and continue to be actively harvested (mostly illegally) as medicinal raw materials (*Gentiana lutea, Rhodiola rosea*), which has led, as in the case of R. rosea, to a total decline in species populations and even the extinction of some of them.

In recent decades, environmental changes associated with climate change have become the leading limiting factor in the decline of some species. First of all, this refers to cold-loving highland arcto-alpine, usually stenotopic species, whose isolated relict populations have been preserved on the slopes, peaks and ridges of the highest ranges of the Ukrainian Carpathians (*Anthemis carpatica, Callianthemum coriandrifolium, Carex fuliginosa, C. rupestris, C. lachenalii, Dichodon cerastioides, Gentiana nivalis, Lloydia serotina, Oreochloa disticha, Pedicularis oederi, Primula minima, Salix herbacea, Saxifraga androsacea, S. carpatica, Saussurea alpina, Trifolium badium, Veronica bellidioides*, etc.) Due to the limited altitudes of the region's mountains, under current trends in climate change, primarily global warming, these species may be lost (e.g., *Oreochloa disticha, Veronica bellidioides*) in the near future due to the inability to migrate higher or the lack of suitable habitats above their current distribution area (Klimatohenni zminy.., 2016). The overgrowth of rocky habitats of the highlands with woody and shrubby vegetation as a result of the upward movement of the upper forest is also an indirect negative impact of climate change, which has already resulted in the loss of some microhabitats of rare species confined to rock crevices and shelves (in particular, the localities of *Lloydia serotina, Carex rupestris* on the rocks of Mt. Smotrych on the Chornohora ridge disappeared). The upward trend was recorded for the populations of most of the above cold-loving arctoalpine species – the studied populations of these species when comparing data on their current and past locations in the late nineteenth and early twentieth centuries, taken from the literature or from old herbarium collections, have made an altitudinal rise from several tens to several hundred metres, reaching in some cases (the microhabitat of the aforementioned *Veronica bellidioides* now on the top of Pip-Ivan Marmoroshskyi – 1930 m above sea level) the limit of their vertical advancement (Kobiv, 2017).

Additionally, for many species (*Carex bicolor, C. pauciflora, Lycopodiella inundata, Oxyccocus microcarpus, Saussurea porcii, Saxifraga aizoides, Scheuchzeria palustris, Viola uliginosa*), whose populations reduction and insularisation are mainly associated with changes in the hydrological regime caused by anthropogenic impacts, climate change has an indirect effect, reinforcing the negative impact (Klimatohenni zminy..., 2016).

However, one of the most large-scale and significant threats to the phytodiversity of Zakarpattia and rare species in particular is the loss or transformation of habitat, which is now coming to the fore in the global planetary scale. The irreversible consequences of such processes are most clearly manifested in interventions that lead to the direct complete destruction of the ecotope. In historical times, such detrimental anthropogenic impacts have occurred primarily in the economically developed Transcarpathian lowland. In particular, in the late nineteenth and mid-twentieth centuries, a powerful marsh complex in the Serne Mochar tract was completely drained. Here, in a gigantic drainless depression of an area of about 15,000 hectares, located between the towns of Mukachevo and Berehove, a marshland of the upland type with unique flora and fauna and habitats that are particularly rare for the Pannonian region has been preserved since the last glacial age. The drainage works that began in the late nineteenth century and continued in the twentieth century eventually led to the complete disappearance of the relict marsh ecosystems of the massif and their specific biodiversity in the 1950s and 1960s, and, as a result, one of the largest post-glacial refugia of natural biodiversity of past eras in the Pannonian region was destroyed. The habitats (sometimes the only ones) of numerous, now rare species of higher plants that still occurred on the territory of the tract in the 30s and 40s of the twentieth century and were recorded by researchers (Margyttai, 1923) were lost. In particular, after the drainage of Serne Mochar, the only localities of *Ludwigia palustris* in Ukraine disappeared. *Utricularia bremii* and the only locality of *Utricularia* *minor* in Zakarpattia, the latter two species being confined to lakes and dystrophic reservoirs among sphagnum peatlands. The habitats of numerous rare species included in the Red Book of Ukraine (2009), such as *Fritillaria meleagris, Iris sibirica, Narcissus angustifolius, Oxycoccus microcarpus*, and the regional red list of relict species *Comarum palustre, Carex limosa, Calla palustris*, etc. have also been lost.

However, large-scale processes of shrinking natural ecotopes have particularly affected the entire, now densely populated, plain Zakarpattia lowland. In the recent past (until the eighteenth and first half of the nineteenth centuries), the entire plain part of Zakarpattia lowland was almost entirely covered with forests – mainly floodplain oak forests, riverine willow and poplar forests, and alder forests. Significant areas were occupied by lowland bogs, marshes, numerous lakes, and old ponds. Nowadays, forest areas cover only about 10-12% of the previous area, but they are often forest crops with a changed composition, and most of the territory has been converted into agricultural land or buildings. Today, natural, lightly disturbed or even transformed forest areas remain only in the form of small islands on the plain, mostly in floodplains. For example, the once-dominant floodplain elm and ash forest habitat (Niklfeld, 1974) is now only preserved in the lower reaches of the Latorytsia and Borzhava rivers. An important refuge for the former natural phytodiversity of the plain (and the mountainous areas of the region) is the extensive use of meadow and pasture lands, which, however, have suffered a distinct degradation in recent times due to the decline and extinction of traditional management or changes in the way of use.

Another centre of concentration of natural phytodiversity in the Transcarpathian Lowland is the volcanic hills – the so-called volcanic hills. In historical times, it was also predominantly forested with oak woods in a combination of the rock oak and, less often, oak-beech and beech forests, a significant range of which, although in a somewhat transformed form, remains only on certain hills (in particular, on Chorna Hora, Shalankivskyi Helmets, Muzhiievski Hills, Yulivski Mountains). The most unique areas with high biodiversity are concentrated on the southern slopes of some hills, where, after development for agriculture, mainly vineyards, island areas of low-growing sparse xerothermophilous oak trees and, in the form of fragments, relict remains of Pannonian meadow steppes have been preserved.

All of the above-mentioned areas of remnants of natural ecotopes of Zakarpattia lowland are characterized by high phytodiversity, especially on the volcanic hills, but due to the island character and scarce areas of suitable ecotopes, many rare plant species are represented by few (*Euphorbia lingulata, Saxifraga bulbifera* (Red Book of Ukraine)), and often – by one

(*Doronicum hungaricum, Lathyrus transsylvanicus, Silene viridiflora* (all are listed in the Red Book of Ukraine), *Lathyrus lacteus*) small, mostly isolated from the main range by populations with low number of individuals, or even with single specimens (*S. viridiflora*). Populations of such species are constantly under a high threat of rapid extinction due to anthropogenic interventions, natural environmental changes, or the complex effect of adverse factors, and, on the other hand, due to their isolation, there is virtually no possibility of restoring populations from other localities.

The plain part of the lowland underwent the most dramatic changes in the twentieth century, when, in addition to a large-scale reduction in forest areas, especially floodplains, there was a total drainage of the territory and regulation of rivers – straightening and canalization of channels, limiting floodplains with dams. This has led to the complete loss of small rivers and streams, and the large-scale disappearance of small water bodies on the plains – isolated washes, oxbows and waterlogged areas – relict upland bogs, forest and non-forest mires, lowland bogs, floodplain and wet alder forests, etc. Paradoxically, at the beginning of the twenty-first century, not a single bog remained in the Transcarpathian lowland, a former region of impassable swamps, bogs and mires, and even one of the last ones, in the Touvar boundary, is now completely dry and degraded (Kish et al., 2009).

Therefore, as the results of recent studies show, for most species of rare phytodiversity, especially those that are particularly threatened, the advancing changes in the hydrological regime, reduction, drying up and transformation of the once dominant aquatic and waterlogged natural habitats (swamps, marshes, floodplain forests) of the plain part of the lowland have become the leading cause of population decline and habitat extinction (listed in the Red Book of Ukraine: *Iris sibirica, Leucanthemella serotina, Marsilea quadrifolia, Nymphoides peltata, Utricularia australis, regionally rare Buschia lateriflora, Crypsis alopecuroides, Cyperus michelianus, Elatine alsinastrum, E. triandra, Gentiana pneumonanthe, Juncus atratus, Schoenoplectus supinus, Senecio paludosus, Urtica kioviensis, Viola elatior, Viola pumila* and many others).

A similar trend can be traced for the mountainous part of Zakarpattia in general. It is significant that the vast majority of taxa that are now extinct from the region's flora (*Beckmannia eruciformis, Ranunculus lingua, the aforementioned Utricularia minor*, listed in the Red Book of Ukraine (2009) *Juncus subnodulosus, Gladiolus palustris, Hammarbia paludosa, Schoenus ferrugineus)* or from the flora of Ukraine (the already mentioned *Utricularia bremii, Ludwigia palustris*, and *Eleocharis multicaulis* are listed in the national Red Book as extinct as well as *Eleocharis multicaulis, Primula farinosa, Carex lachenalii, Sparganium angustifolium*, listed as endangered, but most likely extinct) have been lost due to the transformation of wetland habitats. Many species confined to aquatic and waterlogged habitats, which, according to old herbarium collections and reports, were common in the region relatively recently, have now, even in comparison with the recent past, drastically reduced the number of habitats and are known from a few isolated localities (*Calamagrostis canescens, Pycreus flavescens, Stellaria palustris, Thelypteris palustris,* etc.).

For the Carpathian-mountainous area of the region, as well as for its plain part, the most vulnerable fraction of rare flora is made up of species of waterlogged and aquatic habitats, as well as rocky coenoses of the foothills and highland belt. This is only to a small extent due to natural factors (in particular, the low representation of rocky habitats in the highlands), but is mainly due to anthropogenic transformation of landscapes in connection with the development of the territory.

For the forest zone of the mountainous part of Zakarpattia, the direct reduction of natural habitats, primarily due to deforestation and conversion of land to agricultural use, especially in the densely populated foothill zone, has had a significant impact on plant diversity and the reduction of habitats of rare species. At present, various types of forestry operations, including logging and related development and clearing of logging sites, timber skidding, and other activities carried out with the use of various machinery, pose significant risks of loss of rare species habitats. Its use leads to large-scale disturbance of the soil cover on forest slopes, direct destruction of micro-localities of many species of herbaceous layer growing under the forest canopy, in particular, orchid species (Kish, 2008) or rare species occurring in small clumps (such as *Festuca drymeja, Lathyrus laevigatus, Scopolia carniolica*, listed in the Red Book of Ukraine).

However, as in the plain part of the region, today one of the key negative factors affecting the rare component of the flora of the mountain forest zone is changes in the hydrological regime, primarily related to anthropogenic factors, in particular with the particularities of forest exploitation (a significant share of precipitation does not accumulate on the slopes and is transferred to underground runoff, but due to the unsatisfactory condition of forest roads, flows down them and directly into watercourses, causing powerful erosion and increasing the level of floods) and reinforced by climatogenic changes in recent decades. The general trend of such changes in the hydrological regime and their impact on the forests of the mountainous zone is on the initial stage of assessment, but even now there is an increase in the dry period of the low water season for many small streams, the complete drying up and disappearance of many of them, as well as forest springs. The first to suffer from these processes are plant species of waterlogged habitats, in particular, those near springs and coastal areas (banks of streams, mid-forest marshes, spring bogs, etc.), for which populations have been observed to be progressively reducing and disappearing, as well as the abovementioned habitats to be degrading (Klimatohenni zminy.., 2016).

Among the vascular plants and habitats of the mountainous zone (including the highlands), species confined to oligotrophic sphagnum bogs – peatlands – are currently under the highest threat. In the largest of them (Hlukhania bogs in the village of Negrovets, Chorne Bahno at the foot of Buzhora mountain, Andromeda in Yasinia village and a number of others) in the 1960s, reclamation drainage works were carried out by laying a system of drainage channels for water withdrawal for further economic use of the bogs – peat extraction or for livestock needs – grazing, haymaking (Bradis, Andrienko, Lykhobabina, 1969; Marsh ecosystems..., 2006; Vorontsov, Danylyk, Kanarskyi, 2011).

These measures, not economically motivated at all, had catastrophic consequences for marsh ecosystems and led to the gradual degradation and transformation of the vegetation of oligotrophic marsh habitats, and their successive replacement in large areas by meadow mesophyte communities. Today, despite repeated attempts to block and disrupt the drainage systems in these marshes (Bolotni ekosystemy..., 2006), they continue to drain and dry the remnants of the original marsh ecosystems. The negative impacts of drainage are exacerbated by climate change – the shortening of the cold and prolongation of the warm period, which has become drier and hotter in the last decade, causing summer droughts (Rozroblennia..., 2013). Such changes are turning the climate closer to the southern steppe and Mediterranean types, moving it away from the boreal type (Klimatohenni zminy..., 2016), which significantly affects the change in vegetation cover of the Carpathians and peatlands in particular. Transformational processes caused by climate change are currently observed in almost all peatlands of Zakarpattia, including those where no drainage measures have been taken, for example, in the highlands, but the rate and depth of degradation here is not comparable to that in reclaimed marshes.

In general, for most peatlands today, a progressive trend of mesophytisation can be clearly observed – the penetration and growth of meadow species on sphagnum massifs, an increase in the area of meadow vegetation due to the displacement of native species and communities, and processes of sylvatisation – succession overgrowth of trees and shrubs – are taking place on peatlands in the forest zone.

As a result, today most species of a small group of vascular plants with specific ecology confined to peatlands are rare and listed in the National Red Book (*Carex dioica, C. pauciflora, Lycopodiella inundata* (the only existing habitat in the region on the Hlukhania peatland), *Scheuchzeria palustris*), or regionally rare species known from several habitats (*Androm-*

eda polifolia, Calla palustris Carex limosa, Menyanthes trifoliata, Pedicularis palustris), or nowadays single specimens from one locality (*Ledum palustre, Comarum palustre, Viola uliginosa*), or already extinct (already mentioned *Carex lachenalii, Hammarbia paludosa, Primula farinosa, Schoenus ferrugineus*). In addition to the abovementioned threats to the biodiversity of dried peatlands in the forest zone, in recent years, a large-scale expansion of the blue moor grass (*Molinia caerulea agg.*) has become critical in terms of its destructive consequences. Today, most peatlands in the forest zone of Zakarpattia, in particular, all the large ones, suffer from aggressive overgrowth of this species. Different stages of this degradation process can be observed in different bogs or parts of them. Sizeable areas of some peatlands (for example, in the Chorne Bahno bog) are now completely transformed – covered with mono-dominant thickets of blue moor grass, whose powerful overgrown clumps and dead remains have displaced species of native vegetation, including cenosis-forming sphagnum mosses. Some peat bogs, such as those in the Hnyla boundary on the northern outskirts of Lumshory village and a series of small ones have already been lost, as their original vegetation, displaced by molinia, became extinct and underwent successional substitution by its mono-dominant community.

Given the full range of threats, most existing peatlands, especially those in the forest zone, require active management measures for conservation and restoration. Today, without the implementation of restoration and revitalisation measures, primarily the restoration of the natural hydrological regime, a significant part of relict oligotrophic marshlands, including large peatlands, have a discouraging prognosis – they may be lost within several decades.

A high proportion of the region's rare species is concentrated in the highlands. A big part of them is confined to individual peaks, rocky outcrops or slopes, especially in areas of limestone or carbonate rocks (for example, on Mt. Petros, Mt. Shpytsi, the Chornohora range, Mt. Blyznytsia, Drahobrat cliff, Hereshasky on the Svydovets range, the Nenieski rocks on the Maramorosh Alps, etc.), forming a kind of concentration nodes or "hot spots" of phytodiversity. As a rule, these are species with low competitive ability, represented by isolated small populations, many of which are stenotopic species, with a narrow ecological and cenotic amplitude, limited by specific environmental conditions, and their rarity is associated with the absence of ecotopes of the corresponding type in the highlands (*Aquilegia nigricans, Bupleurum ranunculoides, Dryas octopetala, Hedysarum hedysaroides, Minuartia pauciflora, Oreochloa disticha, Primula halleri, Ranunculus thora, Salix alpina, Saxifraga bryoides* listed in the Red Book of Ukraine and other abovementioned arcto-alpine species, narrow-range Carpathian endemics *Antennaria carpatica, Astragalus krajinae, Genista oligosperma,* which may have disappeared, *Ptarmica tenuifolia*, etc.) Such species are quite vulnerable, as even small interventions or damage to life environment lead to the rapid elimination of their habitats (Kyiak, 2013).

Over the past two decades, the rapid and chaotic development of the tourism and recreation industry has become a powerful factor of negative impact on the region's vegetation, which is getting more intense in terms of harmful effects. The construction of tourist facilities, development of adjacent territories, the coastal zone of reservoirs and watercourses for recreational purposes, the construction of new routes for the development of tourist infrastructure, etc. have become a new serious and powerful threat to the natural world of Zakarpattia and have already led to the loss or transformation of almost all types of natural habitats in the region – from southern plain xerothermic to highlands, and have caused the reduction or disappearance of habitats of numerous flora species, including rare ones. For example, as a result of the development and "clearing" of the recreational zone along the water's edge, the only habitat of the regionally rare halophilous species *Triglochin maritimum* was lost on the coast of salt water bodies in Solotvyno, near the reservoir at the foot of the eastern slope of Mt. Chorna Hora near the town of Vynohradiv. There was built a recreation complex, and localities of the forest grape (*Vitis sylvestris*) particularly threatened, endangered throughout Europe, which has been preserved in a few specimens in the region, were destroyed, etc.

In recent years, the highlands have been subjected to a particularly strong pressure and interference. Large-scale, uncontrolled development of tourist infrastructure, including recreation centres and towns, ski resorts, uncontrolled water extraction for their operation, and unauthorised construction of roads on the slopes, the huge unlimited and uncontrolled flow of tourists and recreationists and the associated pollution, devastation and transformation of natural areas have already led to significant changes and losses and today pose the greatest threat to the habitats and flora of the highlands. A vivid example of such processes is the devastation of the most extreme habitat of the Carpathian mountain tundra in terms of weather conditions – alpine dense short grass sod meadows, which now survive only on the peaks, saddles and placors of the highest mountain crests exposed to the winds. Nowadays, the highest habitat locality on the summit and surrounding areas of Mt. Hoverla, which is formed by the curved sedge (*Carex curvula*) community, has been virtually lost due to the excessive tourist visitation, and the summit itself is almost completely devoid of vegetation. For the same reason, the only microlocality of *Oreochloa disticha* in the Ukrainian Carpathians on the top of Mt. Turkul is now on the verge of complete extinction (Kyiak, 2013). Similarly, the process of devastation of alpine desert meadow areas with *Juncus trifidus* on peaty soils of the Svydovets range takes place, where they are often confined to the ridgelined areas of the range, which are also used for numerous mountain roads and hiking trails. Intensive tourist traffic, both for hiking and motoring, including powerful off-road vehicles, quad bikes, and motorised vehicles, and the construction of new road sections next to those that are already impassable and destroyed, have led to the irreversible loss of significant areas of desert meadows on the range, for example, on the way up to Mt. Blyznytsia along the gentle northern ridge crest, where a continuous strip of completely devastated vegetation and soil cover, in some places up to the exposure of skeletal rocks, reaches several tens of metres. Similarly, extensive areas of primary alpine shrub communities of blueberries (*Vaccínium uliginósum*), which are also confined to extreme ravine and peak areas and often form complexes with the aforementioned desert meadows, have already been lost on the Svydovets Range. Blueberries, together with rhododendrons (*Rhododendron myrtifolium*), are the least tolerant communities to poaching in the Carpathian alpine belt, which degrade rapidly even with moderate regular poaching (or grazing), being replaced by dense grass sod communities or eroded areas (Kyiak, 1998).

Excessive recreational pressure is affecting water bodies in the highlands, especially limited in numbers lakes. The massive influx of vacationists (on some days, up to several hundred people are simultaneously on the shores of popular lakes, in particular, near Lake Nesamovyte on Chornohora, Lake Gereshaska on Svydivka) has resulted in eutrophication and mineralisation of water bodies, damage, devastation or transformation of the vegetation of the coastal zone and adjacent areas (Ekosystemy lentychnykh vodoim Chornohory, 2014). Today, the only relict locality of *Sparganium angustifolium* in Ukraine has already been lost due to transformational processes, in particular, eutrophication in Lake Gereshaska (Red Book, 2009), and one of the few known habitats of the oligo-mesotrophic alpine plant *Potamogeton alpinus* in Zakarpattia is endangered. The degradation processes associated with recreational interventions have also affected the group of peat bogs adjacent to the lake with a series of rare, endangered species in the region – *Carex pauciflora, Scheuchzeria palustris* (both species are listed in the Red Book of Ukraine), regionally rare *Carex limosa, Juncus castaneus.*

Another factor that has had a powerful negative impact on the diversity of the region's flora, rapidly progressing in recent years in terms of the scale and depth of destructive processes, has been the degradation, overgrowth and, ultimately, complete transformation of large areas of non-forested grassland communities – meadows and pastures. Today, in Zakarpattia, as well as throughout Europe, meadows and pastures are an important component of the typical landscapes of many regions and an integral part of their history, while they remain valuable agricultural land for fodder production or grazing, and important places of rest and recreation. In the vast majority of cases, these grass communities are semi-natural, created by cutting down forest vegetation. They have emerged as a result of century-old traditional extensive farming and have been maintained through long-term use, mainly as hayfields and pastures (Ellenberg and Leuschner, 2010). At the same time, temperate grassland habitats are particularly rich in biodiversity and are one of the most important areas of concentrations of non-forest species of natural flora and fauna, including the habitat of numerous rare species (Duelli and Obrist, 2003; Wilson et al., 2012). Due to their natural value, many areas of land in the European Union have been designated as areas of national or European importance (Natura 2000). Unfortunately, in recent decades, Europe (and more recently, Ukraine and Zakarpattia) has seen an extensive degradation of grassland habitats and a decline in their biodiversity, and these ecosystems are undergoing global changes and have become one of the most threatened globally (Hoekstra et al., 2005). The main reason for these negative trends is the decline of traditional management (grazing, pastoralism, haymaking) – primarily in areas remote from settlements – and the change in the way they are used: insufficient maintenance or even complete abandonment of areas with grass vegetation leads to their gradual transformation and disappearance. This issue is particularly acute for areas that have a sozological status and, based on the commonly used paradigm of conservation areas protection in Ukraine, are completely withdrawn not only from traditional economic use, but also from any active intervention.

Today, in Zakarpattia, due to the abovementioned trends in management changes, there is a rapid and large-scale transformation of widespread lowland-foothill meadow-pasture and rare meadow-steppe areas, as well as large areas of meadows and pastures in the mountainous zone (mainly due to successive overgrowth of woody and shrubby vegetation). In addition, due to the decline of pastoralism and the conservation of large areas of the highlands, there is a gradual decline in subalpine pastures, primarily matgrass, and the restoration of native forest communities and shrubby crooked forests in their place. In addition, in the absence of pastoral impact, competitive displacement of light-loving grasses (mat grass (*Nardus stricta*) and other small species) by tall sod grasses, low shrubs (blueberries (*Vaccinium myrtillus*), cowberry (*Vaccinium vitis-idaea*)) and succession transformation of communities into floristically depleted communities of tussock-grass (*Deschampsia cespitosa*), reed grass (*Calamagrostis villosa*) and, mainly, shrubby wastelands of blueberry take place here.

At the present stage, in Europe, in order to preserve valuable areas of herbaceous habitats, primarily those with high biodiversity, management measures are increasingly being applied to such areas of nature conservation importance – various environmental management schemes have been developed, which incorporate the implementation of a set of factors that profile this type of ecosystems in an attempt to preserve all levels of dynamic and coenotic organisation of phytosystems in these areas (Andrews and Rebane, 1994; Managing habitats.., 1995; Hansson and Fogelfors, 2000; Habitat management.., 2007). This approach is focused on the maximum biotic and coenotic diversity, which is the key to dynamic stability, sustainability and time-unlimited preservation of grassland (meadow-pasture, meadow-steppe, alpine) ecosystems, and in the reserved areas it most fully meets the main sozological task – the conservation of biodiversity and natural ecosystems as standards of nature (Tkachenko, 2004). In Europe, the annexes of the European Community Habitats Directive (92/43/EEC) (Oselyshchna kontseptsiia..., 2012) regulate certain activities in priority areas, but the preparation of management plans reflecting national or regional conditions should be developed by specific member states. This problem is receiving increasing attention in the Carpathians, and the first scientifically based models of ecological management of valuable areas of meadow-pasture land have already been developed and effective measures for different types of grassland communities (including areas with different sozological status) have been proposed in the neighbouring countries of the Carpathian region (Schmotzer A, Vojtkó, 1996; Irányelvek.., 1997; Šefferová Stanová, Plassman Čierna, 2011). In particular, in Slovakia, management models for 20 types of non-forest habitats have been developed, which include information on the ecology of a particular habitat, its distribution, trends and threats, recommended active management, restoration management, and generalisation of management requirements for specific species of flora and fauna.

Considerable data on habitat management measures for the long-term conservation and reproduction of populations of these species for the Ukrainian part of the Carpathian region have been developed, based on the results of long-term studies of the populations' biology of numerous, mainly highly rare, endemic or relict species of flora, mainly alpine and mountain flora of herb communities (Stratehiia populiatsiy, 2001; Vnutrishniopopuliatsiyna.., 2004; Zhyliaiev, 2005; Zhyttiezdatnist..., 2009; Kyiak, 2013; Zminy struktury..., 2018, etc.). Research and development of management models for the maintenance, conservation and restoration of the meadow-pasture communities in the region are only at the initial stage (Menedzhmentovi modeli.., 2018). In particular, the team of the Scientific Research Laboratory for the Protection of Natural Ecosystems (Uzhhorod National University) has made an attempt to analyse the current state, main threats and possible development trends for the types of grassland ecosystems common in the Ukrainian Carpathians and important in terms of conservation: for dry (xerothermic) meadows and meadow-steppe areas – spread as island fragments, for widespread lowland and low-mountain mesophilic hay meadows and mat grass meadows (Naukovi osnovy.., 2011; Rozrobka.., 2014). For these habitat types, pilot developments of current and long-term management measures based on the latest data from Central European experience, national practices and long-term results of own data and observations are recommended.

A powerful threat to the floristic and coenotic diversity of the region (as well as to biodiversity in general) is the progressive biological pollution caused by the invasion of non-native species – a global problem that requires separate coverage, and therefore is discussed in a separate section.

Summing up the far from complete overview of threats and problems of phytodiversity conservation in Zakarpattia, we can state that the destruction or transformation of life environment, which lead to the loss of natural habitats, is currently the most large-scale, significant and destructive threat to all biodiversity, as is the case in the global planetary dimension. Therefore, the conservation of biodiversity, especially of the vast majority of rare species or communities, is directly linked to the conservation of habitats – characteristic biotopes. This concept of biodiversity conservation necessitates the development of new approaches to the development of practical conservation recommendations that would ensure the sustainability of environmental conditions in the face of the inevitable increase in anthropogenic pressure on the natural environment. The response to these challenges was the development of the ecological network framework based on the so-called habitat concept of biodiversity conservation, i.e. the idea of conserving certain types of habitats as life environment for species or their groups (Prots et al., 2012; Kahalo et al., 2012; Recommendations.., 2012; Kahalo et al., 2017). It is the ecosystem approach to biodiversity conservation, implemented through the habitat concept, that is currently considered a priority in the European environmental paradigm, as a kind of tool for unifying approaches to the protection of biotic and landscape diversity. In Europe, this task is being addressed through the implementation of the provisions of one of the basic environmental documents of the European Union – "Habitats Directive" (Habitats Directive 92/43/EEC) and the development of the concept of a habitat approach to identifying areas of ecosystem interest for biodiversity conservation, united in a network called Natura 2000. Instead, in non-European Union countries, the Emerald Network, which was initiated and coordinated by the Berne Convention (1979), is a tool for promoting nature conservation in a pan-European context. The Emerald Network has basically the same background and the formation purpose as Natura 2000, but operates outside the EU and, in a sense, extends EU environmental standards beyond its borders and prepares the environmental legislation of these countries for integration to the EU (Prots et al., 2012; Kahalo et al., 2012; Designing..., 2019). The basis of the environmental protection programmes stemming from this concept (Natura 2000, Emerald Network) is the principle of identifying areas of the earth's surface (sites) that are initially characterised by certain properties or characteristics: as vegetation areas or habitats of certain species of plants and animals, location of certain types of communities, ecosystems, etc. (Recommendations.., 2012).

The European integration processes currently taking place in Ukraine have significantly intensified the work on the formation of the Emerald Network and the adaptation of European environmental legislation. In 2019, the Standing Committee of the Bern Convention approved the updated list of officially accepted Emerald Network sites, which includes 377 sites in Ukraine, but the development of proposals for expanding the network continues (Territories.., 2020). One of the main elements of the beginning the Habitats Directive implementation and, similarly, the development of the Emerald Network is the compilation of national lists of habitat types and species that may be found in Ukraine, followed by the development of management plans for all these areas with detailed habitat mapping (Recommendations.., 2012; National Catalogue .., 2018).

One of the first steps in this direction was the inventory, mapping and compilation of the Natura 2000 habitat catalogue (based on Annex I of the Habitats Directive) of the Transcarpathian lowland (Kish, Andryk, Mirutenko, 2006). Subsequently, a team of authors prepared the "Catalogue of Habitat Types of the Ukrainian Carpathians and Transcarpathian lowland" adapted to regional conditions (Prots, Kahalo, Kish et al., 2012), and developed and adapted the principles of sozological categorisation of habitats for Ukraine (Kish et al., 2012). The result of this process was the compilation of the National Catalogue of Habitats of Ukraine (2018), which, on the one hand, reflects the full diversity of habitat types in Ukraine, and on the other hand, is suitable for mapping the Emerald Network sites and is compatible with the habitat types of Resolution 4 of the Bern Convention and Annex I of the Habitats Directive.

However, at the national legislative level, the promotion of the concept of a habitat-based approach to biodiversity conservation in Ukraine is still at the stage of approving draft laws, which have been repeatedly postponed for revision. In this context, the precedent of an attempt to protect certain types of habitats and launch a habitat-based approach to biodiversity conservation at the regional level is encouraging. Thus, we prepared the first regional "red list" of habitats in Ukraine for the territory of Zakarpattia, based on the previously compiled list of habitats of the Ukrainian Carpathians and the Transcarpathian lowland, which was subsequently approved by the decision of the Zakarpattia Oblast Council of 28.05.2015, No. 1263 as the "List of Habitats (biotopes) Subject to Special Protection in the Territory of the Zakarpattia Oblast" (Regional Red List of Habitats) with the identified categories of threats and compliance with the habitat types of Annex I of the Habitats Directive (Annex 3). Today, this is technically the first list of habitats in Ukraine whose protection within the region is recognised and approved by law. As in the case of the regional “List of Invasive Plant Species of Zakarpattia Oblast" adopted for the first time in Ukraine (see section “Threats of Biological Invasions"), the "red list" of habitats will help to improve environmental protection and biodiversity conservation in the region by allocating areas of different priority levels in terms of protection status or nature management features, depending on the representativeness of rare or threatened habitats as potential centres of phytodiversity and rare flora.

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8.3. PROTECTION OF PHYTOCOENOTIC DIVERSITY OF ZAKARPATTIA *(L. Felbaba-Klushyna, V. Klushyn, L. Miklovsh)*

Living organisms in nature, as a rule, do not live in isolation, but form certain communities, which may consist of individuals of the same species, or their species diversity may be considerable. In botanical science, the aggregates of plant organisms in a certain area (forest, meadow, steppe, marsh) are called a plant community or phytocoenosis. A set of phytocoenoses forms vegetation (Felbaba-Klushyna, Komendar, 2001). The vegetation structure of certain regions contains communities that are endangered or are the standards of nature in a particular region and need to be protected. In particular, these are communities that arose in ancient geological epochs and are currently in a certain mismatch with environmental conditions (relict communities), or are at the limit of their range, or are being destroyed by anthropogenic impact, or are gradually transformed into communities of other types of organisation due to climate change and other factors. Such communities can be preserved in case of the right conservation regime. The first step towards their conservation is to identify them, map them and identify the negative factors that threaten their development.

In Ukraine, the first list of rare and endangered plant communities was published by S. M. Stoiko and concerned the Ukrainian Carpathians (Stoiko, 1977). He defined rare, unique and typical phytocoenoses, developed their categorisation and highlighted the reasons for their protection. The issue of protecting the phytocoenotic diversity of Ukraine was first raised at the national level in 1987, when the first Green Book of Ukraine was prepared (Zelionaia kniga..., 1987). It included plant communities that required protection at the state level. The Green Book is an official state document that summarises information on the current status of rare, endangered and typical plant communities that are subject to protection. It includes 127 rare, endangered and typical phytocoenoses of different syntaxonomic ranks. Of these, 50 communities (24 forest, 15 meadow, 4 marsh and 7 aquatic syntaxa) are found in Zakarpattia, which is about 40% of all the syntaxa to be protected in Ukraine.

In 2009, the second edition of the Green Book of Ukraine was published (Zelena knyha..., 2009). As it was already mentioned, in the new edition of the Green Book of Ukraine (2009), the number of syntaxa has increased significantly in the territory of Zakarpattia, and this refers primarily to marsh and aquatic vegetation.

Here is a brief description of plant communities included in the Green Book of Ukraine (2009).

Forest vegetation

Communities of yew beech forests *(Fageta (sylvaticae) taxosa (baccatae))* and fir-beech forests *(Abieto (albae)-Fageta (sylvaticae) taxosa (baccatae))*

Synphytosozological status: "rare"

Distribution in Ukraine: Zakarpattia, Precarpathia and Bukovyna.

Communities of beech forests *(Fageta (sylvaticae)* dominated by hart's tongue *(Phyllitis scolopendrium)* in the plant formation

Synphytosozological status: "rare"

Distribution in Ukraine: Ukrainian Carpathians (Uholskyi massif) Zakarpattia Oblast.

Communities of beech forests *(Fageta (sylvaticae))* dominated by perennial honest *(Lunaria rediviva)* in the plant formation

Synphytosozological status: "rare"

Distribution in Ukraine: Ukrainian Carpathians (Bukovynian Carpathians, Beskydy, Siansko-Stryiska Verkhovyna, Uholsko-Shyrokoluzhanskyi massif, Gorgany).

Communities of beech forests *(Fageta (sylvaticae)* dominated by scopolia *(Scopolia carniolica)* in the plant formation

Synphytosozological status: "rare"

Distribution in Ukraine: Ukrainian Carpathians (Zakarpattia Oblast (Eastern Beskydy, Volovets district; Tiachiv district, Shyrokoluzhanskyi massif); Ivano-Frankivsk Oblast, Lviv Oblast.

Communities of beech forests *(Fageta (sylvaticae))* dominated by wild garlic *(Allium ursinum)* in the plant formation

Synphytosozological status: "endangered"

Distribution in Ukraine: Ukrainian Carpathians (Bukovynian Carpathians, Skole Beskydy, Siansko-Stryi Verkhovyna), Western Podillia (Holohoro-Kremenets Ridge, Roztochia, Kamianets Prydnistrovia, Medobory).

Communities of mountain-ash-beech forests *Sorbeto (aucupariae) - Fageta (sylvaticae)*

Synphytosozological status: "rare".

Distribution in Ukraine: Zakarpattia Oblast, Uzhhorod district (Stuzhytsia forest massif, Mount Ravka, territory of Uzhanskyi National Nature Park)

Communities of rock-oak-beech forests *(Querceto (petraeae)-Fageta (sylvaticae))*

Synphytosozological status: "endangered"

Distribution in Ukraine: Marginal ridges of north-eastern (Ivano-Frankivsk Oblast) and southern (Zakarpattia Oblast, Volcanic ridge) macro-slopes of the Ukrainian Carpathians (Bukovyna Precarpathia) (Chernivtsi Oblast).

Communities of broad-leaved lime-beech forests *(Tilieto (platyphyllae)-Fageta (sylvaticae))*

Synphytosozological status: "rare"

Distribution in Ukraine: Ukrainian Carpathians, Uholskyi massif, Zakarpattia Oblast).

Communities of common oak forests *(Querceta roboris)* dominated by European ivy *(Hedera helix)*

Synphytosozological status: "endangered"

Distribution in Ukraine: Podillia and Volyn Uplands, Zakarpattia lowland (floodplains of the Tysa and Borzhava rivers), Precarpathia (Dniester valley).

Communities of fir and common oak forests *(Abieto (albae) – Querceta roboris)*

Synphytosozological status: "endangered"

Distribution in Ukraine: Precarpathia (Lviv Oblast, Ivano-Frankivsk Oblast), Zakarpattia.

Communities of Austrian-oak-rock-oak forests *(Querceto (australis)-Querceta (petraeae)*

Synphytosozological status: "rare"

Distribution in Ukraine: Foothills of the Vygorlat-Hutynskyi ridge (Yuliivska mountain, Gaborova Yanoch tract (Zakarpattia Oblast).

Communities of white-flowered ash-rock-oak forests *(Fraxineto (orni)-Querceto (petraeae)* and white-flowered ash-dalechampia-oak-rock-oak forests *((Fraxineto (orni)-Querceto (dalechampii)-Querceta (petraeae))*

Synphytosozological status: "rare"

Distribution in Ukraine: Foothills of Vyhorlat-Gutynskyi ridge (Chorna Hora (Zakarpattia Oblast))

Communities of dalechampia-oak-rock-oak forests *Querceto (dalechampii)-Querceta (petraeae)*

Synphytosozological status: "rare"

Distribution in Ukraine: Volcanic foothills of the Vyhorlat-Gutynskyi ridge (Muzhiivski Mountains, Yuliivska Mountain, Chorna Hora (Zakarpattia Oblast))

Communities of rock-oak forests *(Querceta (petraeae)* dominated by wood melick *(Melica uniflora)*

Synphytosozological status: "endangered"

Distribution in Ukraine: Krasna Polonyna mountain range (Zakarpattia Oblast).

Communities of rock-oak forests of sod *(Querceta (petraeae) cornosa (maris)*

Synphytosozological status: "endangered"

Distribution in Ukraine: Zakarpattia (Uzhhorod, Mukachevo districts), forest-steppe zone of Prydnistrovia (Khmelnytskyi, Ternopil, Chernivtsi, Vinnytsia, Odesa Oblasts), Mountainous Crimea.

Communities of pine-rock-oak forests *Pineto (sylvestris) Querceto (petraeae)*

Synphytosozological status: "rare"

Distribution in Ukraine: Southern Beskydy macro-slope (upper Latorytsia River) (Zakarpattia Oblast)

Communities of silver-lime-rock-oak forests *(Tilieto (argenteae) Querceta (petraeae))*

Synphytosozological status: "rare"

Distribution in Ukraine: Volcanic foothills of the Vyhorlat-Hutynskyi ridge (Yuliivska Mountain, Bihanska Mountain, Chorna Hora (Zakarpattia Oblast))

Communities of fir-rock-oak forest *Abieto (albae)-Querceta (petraeae)*

Synphytosozological status: "rare"

Distribution in Ukraine: Ukrainian Carpathians. Northeastern slope in Precarpathia (Hubychi tract, Lviv Oblast), southwestern slope in Zakarpattia (Kuziiskyi protected area of the Carpathian Biosphere Reserve).

Communities of cedar-pine forests *(Pineta cembrae)*

Synphytosozological status: "rare"

Distribution in Ukraine: Ukrainian Carpathians. North-eastern macro-slopes of the Gorgany and Zakarpattia (slopes of Popadia, Malyi Gorgan and Velykyi Gorgan, Tavpyshyrka)

Communities of Hungarian lilac European alder forests *(Alnetea (glutinosae) syringosa (josikaeae)*

Synphytosozological status: "rare"

Distribution in Ukraine: Ukrainian Carpathians (Volovets-Mizhhiria Verkhovyna, Watershed ridge of the upper Latorytsia river basin).

Communities of European alder forests *(Alnetea (glutinosae)* dominated by ostrich fern *(Matteuccia struthiopteris)* in the plant formation

Synphytosozological status: "endangered"

Distribution in Ukraine: Zakarpattia, Ukrainian Polissia (Rivne Oblast).

Communities of grey alder forests *(Alnetea (incanae)* dominated by ostrich fern *(Matteuccia struthiopteris)* in the plant formation

Synphytosozological status: "typical"

Distribution in Ukraine: Ukrainian Carpathians (Ivano-Frankivsk and Zakarpattia Oblasts).

Communities of grey alder *(Alnetea (incanae)* Hungarian lilac forests *(Alnetea (glutinosae) syringosa (josikaeae)*

Synphytosozological status: "rare"

Distribution in Ukraine: Ukrainian Carpathians (Watershed ridge, Polonynskyi Ridge, Siansko-Stryiska Verkhovyna, mountainous part of Zakarpattia and Lviv region: upper reaches of the Uzh, Latorytsia, Rika, Stryi rivers)

Communities of silver-lime forests *(Tilieta argentea)*

Synphytosozological status: "rare"

Distribution in Ukraine: Foothills of the Volcanic Vyhorlat-Hutynskyi ridge (Kosynski Mountains, Yuliivska Mountain, Zakarpattia Oblast).

Communities of broadleaf-lime forests *(Tilieta platyphyllae)*

Synphytosozological status: "rare"

Distribution in Ukraine: Eastern slopes of the spurs of the Volcanic Vyhorlat-Hutynskyi ridge (Kosynski Mountains, Yuliivska Mountain, Zakarpattia Oblast).

Communities of sycamore forests *(Acereta pseudoplatani)* dominated by perennial honesty *(Lunaria rediviva)* in the plant formation

Synphytosozological status: "endangered"

Distribution in Ukraine: Ukrainian Carpathians: Skole Beskydy – Slavske State Forestry (Lviv Oblast), Volovets and Velykyi Bereznyi State Forestry, Svydovets-Yasinia State Forestry (Zakarpattia Oblast); Bukovyna Carpathians (Chernivtsi Oblast), Prydnistrovia (Khmelnytskyi Oblast).

Communities of sycamore forests *(Acereta pseudoplatani)* dominated by wild garlic *(Allium ursinum)* in the plant formation

Synphytosozological status: "endangered"

Distribution in Ukraine: Ukrainian Carpathians: (Lviv and Zakarpattia Oblasts)

Communities of Polish larch-spruce forests *(Lariceto (polonicae)-Piceeta (abietis))* and Polish larch-cedar-pine-spruce forests *(Lariceto (polonicae)-Pineto (cembrae)-Piceeta (abietis))*

Synphytosozological status: "rare"

Distribution in Ukraine: Ukrainian Carpathians. Pryvododilni Gorgany (Kedryn tract, Zakarpattia Oblast), Skybovi Gorgany (Maniava tract, Ivano-Frankivsk Oblast).

Shrub and dwarf shrub vegetation

Communities of the herbaceous willow formation *(Saliceta herbaceae)*

Synphytosozological status: "rare".

Distribution in Ukraine. Subalpine and alpine zones of the Ukrainian Carpathians (Chornohora and Svydovets massifs).

Communities of the obtusifolious willow *(Saliceta retusae)* formation

Synphytosozological status: "rare".

Distribution in Ukraine. Subalpine belt of the Ukrainian Carpathians (Chornohora and Svydovets massifs) (Zakarpattia and Ivano-Frankivsk Oblasts).

Communities of the rowan-alder forest *Sorbeto (aucupariae)-Duschekia (viridis)* subformation

Synphytososological status: "rare".

Distribution in Ukraine. Mount Velyka Ravka (Zakarpattia Oblast).

Communities of the eightpetal mountain-avens *(Dryadeta octopetalae)* formation

Synphytosozological status: "rare".

Distribution in Ukraine. Subalpine and alpine belts of the Ukrainian Carpathians (Chornohora and Svydovets massifs) (Zakarpattia Oblast).

Communities of the alpine azalea formation *(Loiseleurieta procumbentis)*

Synphytosozological status: "rare".

Distribution in Ukraine. Alpine belt of the Ukrainian Carpathians (Chornohora massif) (Zakarpattia and Ivano-Frankivsk Oblasts).

Communities of the Eastern Carpathian rhododendron *(Rhododendreta kotschyi)* formation

Synphytosozological status: "rare".

Distribution in Ukraine. Subalpine and alpine belts of the Ukrainian Carpathians (Chornohora, Marmarosh, Svydovets massifs), (Zakarpattia and Ivano-Frankivsk Oblasts).

Meadow communities

Communities of the inermous fescue *(Festuceta inarmatae)* formations

Synphytosozological status: "rare".

Distribution in Ukraine. Subalpine belt of the Ukrainian Carpathians (Beskydy, Chornohora, Svydovets, Marmarosh, Chyvchyn massifs).

Communities of the Carpathian fescue *(Festuceta carpaticae)* formation

Synphytosozological status: "rare".

Distribution in Ukraine. Subalpine belt of the Ukrainian Carpathians (Chornohora, Svydovets, Marmarosh, Chyvchyn massifs) (Ivano-Frankivsk and Zakarpattia Oblasts).

Communities of rocky fescue *(Festuceta saxatilis)* formation

Synphytosozological status: "rare".

Distribution in Ukraine. Subalpine belt of the Ukrainian Carpathians (Marmarosh and Chyvchyn massifs) (Ivano-Frankivsk and Zakarpattia Oblasts).

Communities of the narrow-leaved daffodil *(Narcissieta angustifolii)* formation

Synphytosozological status: "rare".

Distribution in Ukraine. Transcarpathian lowland (Khust district), highland areas of the Ukrainian Carpathians (Svydovets and Marmarosh ranges) (Ivano-Frankivsk and Zakarpattia Oblasts).

Communities of the Dale hairgrass *(Poeta deylii)* formation

Synphytosozological status: "rare".

Distribution in Ukraine. Subalpine and alpine zones of the Ukrainian Carpathians (Marmarosh and Chornohora massifs) (Ivano-Frankivsk and Zakarpattia Oblasts).

Bog communities

Communities of the mountain-pine-sphagnous *(Pineto (mugi)-Sphagneta)* formation

Synphytosozological status: "endangered".

Distribution in Ukraine. Ukrainian Carpathians (mainly the Chornohora ridge), subalpine belt (Zakarpattia Oblast, Ivano-Frankivsk Oblast).

Communities of the depressed spruce-sphagnum formation *(Sphagneta depressipiceetosa)*

Synphytosozological status: "endangered".

Distribution in Ukraine. Forest belt of the Ukrainian Carpathians (Skybovi and Pryvododilni Gorgany) (Ivano-Frankivsk and Zakarpattia Oblasts).

Communities of the fuscum-sphagnum depressed common pine *(Sphagneta (fusci) depressipinetosa (sylvestris))* formation

Synphytosozological status: "rare".

Distribution in Ukraine. Northern part of Western Polissia (Volyn, Rivne, Zhytomyr Oblasts), upper forest belt of the Ukrainian Carpathians (Skole Beskydy, Gorgany) (Lviv, Zakarpattia, Ivano-Frankivsk Oblasts).

Communities of the Devell's sedge *(Cariceta davallianae)* formation

Synphytosozological status: "endangered".

Distribution in Ukraine: Western and Small Polissia, Roztochia, Volyn forest plateau (Volyn, Rivne, Khmelnytskyi, Lviv Oblasts). In Zakarpattia it occurs in the Eastern Beskydy (Volovets district).

Aquatic communities

Communities of the water caltrop *(Trapeta natantis)* formation

Synphytosozological status: "typical".

Distribution in Ukraine. Broad-leaved forest, forest-steppe and steppe zones (in floodplain water bodies and bays of the Dnipro, Prypiat, Teteriv, Desna, Ubort, Uzh, Latorytsia, Borzhava, Siverskyi Donets and Shatsk and Danube lakes).

Communities of the snowy water lily *(Nymphaeeta candidae)* formation

Synphytosozological status: "rare".

Distribution in Ukraine. Broad-leaved forest and forest-steppe zones (in lakes and floodplain water bodies of the Upper and Middle Dnipro, Desna, Teteriv, Uzh, Zdvyzh, Ubort, Horyn, Styr, Sluch, Turiia, upper reaches of the Southern Buh, Sula, Vorskla, Psel, Siverskyi Donets rivers, in Shatsk lakes). The southern border in Ukraine follows the Uzhhorod – Ivano-Frankivsk – Vinnytsia – Cherkasy – Poltava – Kharkiv line.

Communities of the four-leaved pepperwort (Marsileeta quadrifoliae) formation

Synphytosozological status: "endangered".

Distribution in Ukraine. Broadleaved forest and steppe zones. Floodplain reservoirs of the Latorytsia River (Zakarpattia Oblast), reservoirs of the Danube lakes (Odesa Oblast).

Communities of the fringed water lily *(Nymphoideta peltatae)* formation

Synphytosozological status: "rare".

Distribution in Ukraine. Broad-leaved forest, forest-steppe and steppe zones.

In the reservoirs of the Desna, Snov, Ubort, Southern Buh, Dnipro rivers floodplains, as well as the Kiliia delta of the Danube River and Danube lakes. Transcarpathian lowland, lower reaches of the Latorytsia River.

Communities of the Bremi's bladderwort *(Utricularieta bremii)* formation

Synphytosozological status: "rare".

Distribution in Ukraine. Sporadically in water bodies of the Ukrainian Carpathians and Zakarpattia (Zakarpattia Oblast) (Probably extinct community).

Communities of the Alpine pondweed *(Potamogetoneta alpini)* formation

Synphytosozological status: "rare".

Distribution in Ukraine. Very rare in the Ukrainian Polissia, Forest-Steppe and in the water bodies of the Ukrainian Carpathians (Sumy, Zhytomyr, Rivne, Khmelnytskyi, Zakarpattia Oblasts).

Communities of the long pondweed *(Potamogetoneta praelongi)* formation

Synphytosozological status: "rare".

Distribution in Ukraine. Water bodies of broad-leaved forest and forest-steppe zones. It is distributed on Synevyr Lake in Zakarpattia Oblast.

Communities of the arrowhead *(Sagittarieta sagittifoliae)* formation

Synphytosozological status: "rare".

Distribution in Ukraine. Broad-leaved forest, forest-steppe and steppe zones (in lakes, rivers, floodplain reservoirs, artificial reservoirs). In the Transcarpathian lowland it is common in the lower reaches of the Tisza and Latorytsia rivers.

Communities of the white water lily *(Nymphaeeta albae)* formation

Synphytosozological status: "rare".

Distribution in Ukraine. Broad-leaved forest, forest-steppe and steppe zones (in lakes, riverbeds, floodplain reservoirs, artificial reservoirs). In the Transcarpathian lowland it occurs in the floodplains of the Latorytsia and Tisa rivers.

Communities of the yellow water lily *(Nuphareta luteae)* formation

Synphytosozological status: "typical".

Distribution in Ukraine. Broad-leaved forest, forest-steppe and steppe zones (in lakes, rivers, floodplain reservoirs). In the Transcarpathian lowland it occurs in the floodplains of the Latorytsia and Tisza rivers.

Communities of the floating fern *(Salvinieta natantis)* formation

Synphytosozological status: "typical".

Distribution in Ukraine. Broad-leaved forest, forest-steppe and steppe zones (in lakes, bays, branches, river oxbows, artificial reservoirs). In the Transcarpathian lowlands, it occurs in the floodplains of the Latorytsia and Tisza rivers.

Thus, 28 forest, 6 shrub and dwarf shrub, 5 meadow, 4 marsh and 11 aquatic communities are found in Zakarpattia, which are included in the Green Book of Ukraine (2009).

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Fig. 8.3.1. Beech forests (Fageta (sylvaticae) dominated by perennial honest (Lunaria rediviva) in the plant formation (photo by L. Felbaba-Klushyna, 06.05.2023., Eastern Beskydy)

Fig. 8.3.2. Scopolia beech-sycamore maple forests (photo by L. Felbaba-Klushyna, 06.05.2023., Eastern Beskydy)

Fig. 8.3.3. Wild garlic beech forests
(photo by L. Felbaba-Klushyna, 06.05.2023., Eastern Beskydy)

Fig. 8.3.4. Rock-oak forests (Querceta (petraeae))) dominated by wood melick (Melica uniflora) in the plant formation (photo by L. Felbaba-Klushyna, 08.05.2023, Volcanic ridge)

Fig. 8.3.5 Communities of the Devell's sedge (Cariceta davallianae) formation (photo by L. Felbaba-Klushyna, 06.05.2023., Eastern Beskydy)

Fig. 8.3.6. Communities of the four-leaved pepperwort (Marsileeta quadrifoliae) formation (photo by L. Felbaba-Klushyna, (05.09.2021, Zakarpattia lowland)

8.4. INFLUENCE OF ANTHROPOGENIC FACTORS ON THE FAUNA *(F. Kurtiak, O. Mateleshko)*

It's hard to imagine a world without animals, a kingdom that accounts for more than a million species. Animals affect the lives of every human being, whether they like them, or dislike them, eat them, or, on the contrary, protect them. Animals have been of vital importance since the first time our ancestors went hunting, and the transition to meat eating has become one of the most important factors in human evolution. The importance of animals for humans and nature in general is much broader and more significant than it might seem at first glance. Most domestic animals provide humans with food, materials for clothing and footwear. For many centuries, animals have been helping people to do various jobs, they are used in sports and active leisure activities, for rehabilitation in case of various diseases, to accompany visually impaired and disabled people; they are used as rescuers when searching for people after avalanches in the mountains and under rubble after earthquakes. People get aesthetic pleasure from contact with animals in nature, and keeping and caring for pets is extremely important in fostering positive character traits in children. However, some species of animals cause many problems for humans and even harm agriculture; predatory insects and pests are used in biological control of harmful arthropods. Wild mammals are a source of diseases dangerous to humans.

But the main significance of animals is ecological, in that every life form plays an important role in the ecological balance on Earth. Predators control the number of herbivorous animals' populations, and animals that feed on carrion or excrement of other animals clean the surface of the earth and enrich it with mineral and organic substances and microorganisms. Insects and other invertebrates are important links in the food chain and form the basis of the diet of many species of birds, mammals, and fish. Insects and, to some extent, bats and birds are important pollinators of plants and are responsible for pollinating about 35% of the crops that provide food for humanity. Moreover, many species of flowering plants cannot exist at all without insect pollination.

Species extinction has always been a natural part of the evolutionary process. Throughout the history of the Earth, scientists claim that there were five stages of mass or major species extinction. The last and most well-known period of species extinction, believed to have been caused by an asteroid impact, occurred at the turn of the Cretaceous and Tertiary periods (~63-65 million years ago), when dinosaurs became extinct, enabling mammals to evolve.

According to many scientists, we are now in the early stages of the sixth period of species extinction (the Holocene extinction), which began about 50,000 years ago. This last great extinction was not caused by natural processes, but was directly or indirectly caused by humans. Animal species that in one way or another came into conflict with human interests were consistently slaughtered. The most recent extinction of species is associated with the development of new lands by Europeans in the 14th-16th centuries. Today, approximately 1000-1100 species of animals are endangered.

It is believed that the main and most threatening anthropogenic factor of species extinction is the degradation and fragmentation of animal habitats. The main causes of habitat degradation are agriculture, urbanisation, etc. The process of destruction of natural ecosystems occurs in stages. Sometimes, it may seem that a certain fragment of the natural landscape is not important for animals, but a combination of certain landscape elements or habitats may be vital for a particular species. This process is more insidious than direct destruction, because there seems to be no reason for the species to disappear, and yet it does. And, first of all, large animals (mammals, birds, etc.) disappear. Species with limited distribution (endemics) or rare, and species with limited ability to spread, as well as inhabitants of specific ecological niches (hollows of old trees, dead wood, caves), disappearing with the destruction of their habitats, are under the primary threat of extinction. Species that live in colonies or in complex social groups are threatened when their numbers fall to a certain critical level.

Other threats to species extinction include: 1) the trade in animals for pets and biomedical research, etc.; 2) climate change (the so-called global warming), which is predicted to cause the extinction of at least 20-30% of plant and animal species or 40-70% in the most unfavourable scenario; 3) high-intensity pollution; 4) introduced or invasive species destroying the habitats of native species, competing with them for resources and reducing their survival;

5) protection of farm animals by farmers; 6) isolated small populations lose the ability to exchange genetic material; 7) genetic pollution that is uncontrolled hybridisation or modification of the genome of natural species.

The scale of species extinction as a result of human activity is quite notable. Archival data and archaeological findings show that over the past 12 centuries, eight species of wild animals and more than 10 species of birds have been completely wiped out in the Carpathians. Nature conservation in the Ukrainian Carpathians has a long tradition and is described in the works of S.M. Stoiko (1991) and O.O. Haidukevych (2007). The initial stage was species protection, which accounted for caring for the conservation of hunting fauna; the stage of resource-based nature protection followed; territorial nature protection; and since the second half of the twentieth century, the environmental stage has been introduced in the nature protection concept and nature protection is now considered as a priority integral environmental, economic and social problem of international importance.

8.5. THREATS AND DECLINE OF AMPHIBIANS *(F. Kurtiak)*

Amphibians undoubtedly hold a significant position within the biocenoses of Zakarpattia. While the species composition of the amphibian fauna in this region is under ongoing clarification, and the number of amphibians is still a subject of study (Gasso and others, 2001; Shcherbak and Shcherban, 1980; Shcherban, 1976), analysing and comparing the available literature data on their population with their current status proves challenging. The available information is primarily limited to schematic estimates, classified as absent, very rare, rare, common, and frequent (Shcherbak and Shcherban, 1980).

Various factors influence the distribution and population size of amphibians within the region. Notably, abiotic factors such as temperature, humidity (particularly when they venture onto land), and the chemical properties of water and soil play pivotal roles in shaping amphibian habitats. Since amphibians are poikilothermic creatures, their body temperature and activity levels are contingent upon ambient temperature.

Given that amphibians possess exposed skin, maintaining a high level of humidity is imperative for their well-being. Rapid desiccation poses a significant threat, with even a 15% weight loss being fatal for these animals. Their skin is partially protected by a layer of mucus, serving to mitigate desiccation. In terrestrial amphibians, skin thickening and keratinization occur, reducing the potential for cutaneous respiration. This reduction is counteracted by an increase in the surface area of the lungs.

In conditions of inadequate ambient humidity, the skin of these amphibians becomes covered with a thin, dry, shiny film that is impermeable to water. The behaviour of amphibians also holds adaptive significance: most terrestrial species are active during dusk and nighttime, periods when humidity levels are at their highest.

It is important to note that amphibians cannot thrive in saltwater or on saline soils. Salts dissolved in water at concentrations exceeding 10% have detrimental effects on both larvae and adult amphibians.

In response to the climate changes observed in recent decades, our study focused on assessing shifts in the amphibian populations within Zakarpattia. The foundation of this research rests upon our own population counts, conducted from 1999 to 2021 in the Transcarpathian lowlands and foothills. These counts amounted to 1279 individual species counts in total and were executed utilising the route method (Novikov, 1953; Protasov, 2002). The route method was chosen because it had been employed by previous researchers when studying amphibian populations in Zakarpattia (Shcherbak and Shcherban, 1980; Shcherban, 1976). Furthermore, it is the most suitable and provides the most comprehensive data when studying this particular group of animals (Koly, 1979).

The length of the survey lines consistently exceeded 1000 metres, and the number of species was extrapolated to cover a 100-metre segment of the route. These surveys were carried out in 77 different habitats, which were distributed more or less evenly across the study area. Additionally, we analysed existing literature sources where quantitative data (a total of 227 counts for individual species) were provided alongside scoring (Shcherbak and Shcherban, 1980; Shcherban, 1976). Whenever possible, abundance counts were performed in habitats previously documented in the literature. This allowed us to compare contemporary data with the amphibian abundance recorded 30 years ago. The number of amphibians in this study is reported as "the number of individuals per 100 metres of the route."

In this study, “own data” pertains to the collections and surveys conducted by our team in the Zakarpattia lowlands and foothills from 1999 to 2021, while “literature data” refers to information on amphibian numbers in the same area between 1971 and 1980 (Shcherbak and Shcherban, 1980; Shcherban, 1976).

Based on our own collections and literature data, we compiled a database detailing the population of amphibians in the study area. This database was created and analysed using Microsoft Excel version 9.0. Additionally, a thematic map was generated using MapInfo version 7.0, a desktop cartography software package.

The main findings of the study are presented in Table 8.5.1, which includes quantitative data, percentages of individual species in the samples, and the classification scores proposed in the literature: – species absent, – + very rare, + rare, + + common, and + + + frequent (Shcherbak and Shcherban, 1980; Shcherban, 1976).

Analysing Table 8.5.1, we observe that the authors (Shcherbak and Shcherban, 1980) categorised very rare species as those with numbers per 100 metres of the route ranging from 0.50±0.03 *(L. montandoni)* to 0.59±0.12 *(M. alpestris)*. Rare species encompass those with numbers ranging from 0.60±0.07 *(R. dalmatina)* to 4.91±1.79 *(R. lessonae)*. Common species range from 4.72±1.55 *(R. dalmatina)* to 20.04±2.48 (B. variegata), while frequently occurring species range from 0.38±0.03 *(P. fuscus)* to 16.64±1.06 (*B. bombina*).

Upon examining the percentages of species in the samples, it becomes evident that the authors classified very rare species as those with percentages ranging from 2.88±1.41 *(M. alpestris)* to 8.57±0.00 *(L. montandoni)*. Rare species include those with percentages ranging from 1.16±0.38 *(R. dalmati-*

na) to 14.69±2.45 (P. lessonae), common species range from 1.16±0.38 *(R. dalmatina)* to 6.98±0.73 *(B. variegata).* Finally, species that occur frequently range from 0.14±0.09 *(P. fuscus)* to 5.99±0.69 *(B. bombina).*

Hence, based on the data presented in Table 8.5.2, we can quantitatively characterise the classifications of species occurrence employed by the authors in the 1971-1980 period (Shcherbak and Shcherban, 1980; Shcherban, 1976).

Comparing our data with literature data on average abundance (Table 8.5.1), we observe that the total number of all amphibian species in our data is 1.92 times lower than in the literature data.

Table 8.5.1.

Analysis of the number and percentage of amphibian species in the samples in the Zakarpattia lowland and foothills.

Species	Own Data		Literature Data		%, in the sample own data	%, in the sample literature	Score	
	average ± st. deviation	n	average ± st. deviation	n			lowland	foothills
Caudata								
Salamandra salamandra	5,29±2,61	31	3,67±0,70	13	2,49±1,23	0,90±0,17	–	+
Lissotriton vulgaris	6,09±0,68	127	16,16±7,47	23	2,87±0,32	3,96±1,83	+ +	+ + +
Lissotriton montandoni	1,06±0,06	12	35±0,00	1	0,50±0,03	8,57±0,00	–	– +
Triturus cristatus	2,66±0,42	31	8,88±1,62	15	1,25±0,20	2,17±0,40	–	+ + +
Triturus dobrogicus	5,43±0,82	144	9,52±2,48	13	2,53±0,38	2,33±0,61	+ +	–
Mesotriton alpestris	1,25±0,25	8	11,75±5,75	2	0,59±0,12	2,88±1,41	–	– +
Anura								
Bombina bombina	35,32±2,24	203	24,47±2,81	18	16,64± 1,06	5,99±0,69	+ + +	–
Bombina variegata	42,54±5,27	33	28,50±3,00	6	20,04± 2,48	6,98±0,73	–	+ +
Pelobates fuscus	0,81±0,07	82	0,57±0,36	21	0,38±0,03	0,14±0,09	+ + +	– +
Bufo bufo	11,15±1,41	91	28,88±7,60	8	5,25±0,66	7,07±1,86	+ + +	+ + +

Species	Own Data		Literature Data		%, in the sample own data	%, in the sample literature	Score	
	average ± st. deviation	n	average ± st. deviation	n			lowland	foothills
Bufo viridis	22,65±2,83	73	17,87±3,61	18	10,67± 1,33	4,37±0,88	+	+
Hyla arborea	7,05±1,63	64	9,84±1,09	16	3,32±0,77	2,41±1,98	+ +	+ + +
Pelophylax ridibunda	22,60±2,26	84	41,44± 10,59	8	10,64± 1,06	10,14±2,59	+ + +	+ +
Pelophylax kl. esculenta	37,36±7,34	122	67,71± 11,19	13	17,60± 3,46	16,58±2,74	–	–
Pelophylax lessonae	10,42±3,81	47	60,00± 10,00	7	4,91±1,79	14,69±2,45	+ + +	+
Rana arvalis	1,00±0,00	1	13,28±1,46	17	0,47±0,00	3,25±0,36	+	++
Rana dalmatina	1,28±0,14	95	4,72±1,55	13	0,60±0,07	1,16±0,38	+ +	+
Rana temporaria	0,98±0,16	31	26,23± 10,04	15	0,46±0,08	6,42±2,46	+	+ + +
Total	212,31± 31,35	1279	408,49± 88,32	227	100,00	100,00	22	25,5
Average	11,80±1,74		22,70±4,91		5,56±0,82	5,56±1,20		

Over the study period, there has been a shift in the dominance of certain species in the samples, with an increase in the representation of some species and a much smaller, nearly equal share of others. This shift clearly indicates a decrease in species diversity, as higher diversity is typically observed when the relative abundance of species is more evenly distributed [6]. Such findings are a cause for concern.

Table 8.5.2 presents a comparison of our data (1999-2021) regarding the number and percentage of amphibians in the samples with those from the literature (1971-1980).

It is worth noting that, according to our data, the number of salamanders increased by 1.44 times, while its percentage in the sample of typical habitats increased by 2.77 times. The number and percentage in the samples also increased for the common mudpuppy, by 1.44 and 2.78 times, respectively. Mountain newts, according to our data, showed an increase in both number and percentage in the sample, by 1.49 and 2.87 times, respectively. Garlic frogs and green toads in our samples increased by 1.42 and 1.27 times, and their percentage in the sample increased by 2.71 and 2.44 times, respectively.

Conversely, several species decreased in number and percentage in the sample based on our data compared to the literature data. The common newt decreased by 2.65 times in number and 1.38 times in percentage in the sample. The Carpathian newt exhibited a substantial decrease of 33.02 times in number and 17.14 times in percentage. Crested newts and alpine newts both saw reductions in number and percentage, by 3.34 and 1.74 times and 9.40 and 4.88 times, respectively.

Additionally, the number and percentage of grey toads in our samples decreased by 2.59 and 1.35 times, and pond frogs exhibited reductions of 5.76 and 2.99 times, respectively.

The number and percentage of all brown frog species in the samples exhibited a significant decrease. Sharp-toothed frogs decreased by 13.28 times in number and 6.91 times in percentage, nimble frogs by 3.69 times in number and 1.93 times in percentage, and grass frogs by 26.77 times in number and 13.96 times in percentage, respectively.

Conversely, some species experienced a decrease in numbers while showing a slight increase in percentage within the sample. The Danube triton decreased by 1.75 times in number and 1.09 times in percentage, frogs by 1.40 times in number and 1.38 times in percentage, lake frogs by 1.83 times in number and 1.05 times in percentage, and edible frogs (hybrid) by 1.81 times in number and 1.06 times in percentage, respectively.

Table 8.5.2.

The ratio of the number and percentage of amphibian species in the samples for the period 1999-2021 compared to the data for 1971-1980 in Zakarpattia lowland and foothills.

Species	Ratio of accounting data in 1999-2021 to data from 1971-1980.	
	by number of amphibians	by percentage in the sample
Caudata		
Salamandra salamandra	1,44	2,77
Lissotriton vulgaris	0,38	0,72
Lissotriton montandoni	0,03	0,06
Triturus cristatus	0,30	0,58
Triturus dobrogicus	0,57	1,09
Mesotriton alpestris	0,11	0,20
Anura		
Bombina bombina	1,44	2,78
Bombina variegata	1,49	2,87

Species	Ratio of accounting data in 1999-2021 to data from 1971-1980.	
	by number of amphibians	by percentage in the sample
Pelobates fuscus	1,42	2,71
Bufo bufo	0,39	0,74
Bufo viridis	1,27	2,44
Hyla arborea	0,72	1,38
Pelophylax ridibunda	0,55	1,05
Pelophylax kl. esculenta	0,55	1,06
Pelophylax lessonae	0,17	0,33
Rana arvalis	0,08	0,14
Rana dalmatina	0,27	0,52
Rana temporaria	0,04	0,07
Average	0,62	1,70

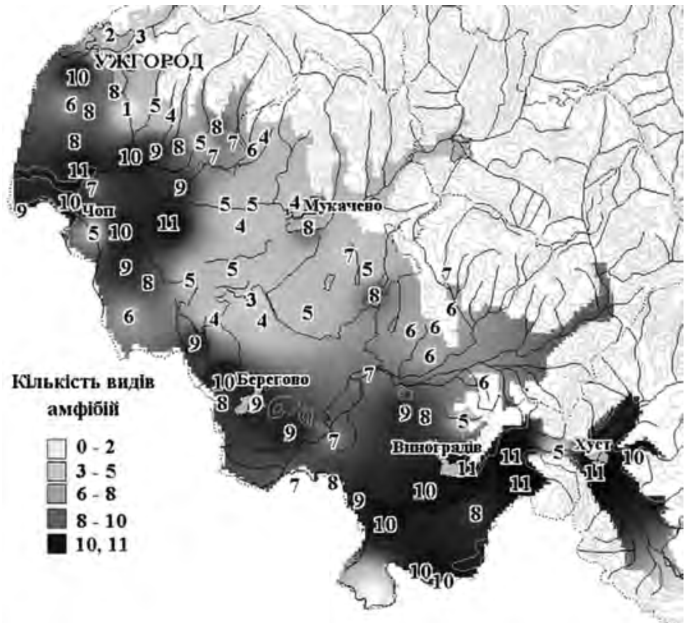

Fig. 8.5.1. Distribution of amphibian species richness in the Zakarpattia lowland and foothills.

At present, the distribution of amphibian species diversity across the study area is rather uneven (Fig. 8.5.1).

Based on the analysis of 77 localities that evenly cover the study area, reveals a clear association of the highest species diversity with the main waterways of the region, such as the Tysa, Latorytsia, Borzhava, and partially Uzh rivers. This may not seem obvious at first, as only one amphibian species (*P. ridibundus*) is found in these rivers. However, we attribute this distribution to the greater stability of riverine habitats.

Furthermore, this analysis of species richness distribution helps identify crucial areas for amphibian conservation, particularly in the southern part of Berehove, the central plain part of Vynohradiv, and the riverbed habitats of the Latorytsia River in Uzhhorod district. These regions exhibit high species diversity. On the contrary, the remarkably low distribution of amphibian species in the central and southern parts of Mukachevo district is noteworthy, likely due to habitat impoverishment, as the majority of the area is occupied by meadows and pastures [Kurtyak, 2004].

The distribution of amphibian species richness (Fig. 8.5.1) can provide a basis for designing programs for semi-natural breeding of amphibians with subsequent release into the wild, similar to some European regions.

Analysing the literature on this issue, it is evident that in recent decades, a significant decline in the populations of common and crested newts, as well as frogs, has been observed in the study area (Gasso and others, 2001; Shcherban, 1994). Despite the relatively recent nature of the data, quantitative estimates of the species' populations are notably lacking, except for crested newts, which are reported to be at 0.1-0.2 individuals per 100 m of the route (Gasso and others, 2001). Nevertheless, our observations align with the observed trend of declining numbers in these species, as reported in the literature.

Of particular interest is the increase in the percentage and number of *P. viridis* in the lowlands, which has also been documented by other researchers (Gasso and others, 2001). It is noteworthy that various European countries have reported a decrease in amphibian populations, including Poland (Zielinski and Klimkowski, 2003), France (Baumgart, 2003), Sweden (Claes and Goeran, 2003), Germany (Beckmann, 2003), Slovakia (Belansky, 2003), and others.

Therefore, the Zakarpattia Lowland region could potentially serve as a refuge for this species in the face of the overall negative impact of human activities. When studying the data obtained, it's important to acknowledge that the correlation between the number of species in the samples and their percentage representation during the study periods is 0.54.

The average percentages of species in the samples, despite significant differences in the numbers of individual species, were 5.56±0.82% in our data and 5.56±1.20% in the literature.

This decline in the number of species that are most commonly found in the lowlands suggests a significant impact of climate change on the amphibian populations of the region. It underscores the need to establish protected areas in these regions since human activity exerts a much greater anthropogenic pressure on the fauna, with approximately 90% of the area being utilized by humans. This pressure, combined with the region's higher species diversity, emphasizes the urgency of conservation efforts compared to mountainous regions.

8.6. CHANGES IN THE COMPOSITION OF THE ICHTHYOFAUNA *(F. Kurtiak)*

Significant changes have occurred in the ichthyofauna of Zakarpattia over the last century. These changes have been driven not only by shifts in the hydrography of our rivers but also by alterations in water management practices, the introduction of valuable commercial fish species, and environmental disasters such as water body shallowing and contamination with heavy metals.

A comparative analysis of fish species composition over the last hundred years is provided in Table 8.6.1.

Examining the data presented in the table, we can observe that V. Vladikov (1926) recorded 46 species of roundfish and fish in the region's rivers. E.K. Vlasova (1956) subsequently added two more species to this list: the bullhead (*Abramis bjoerkna*) and the American catfish (*Ictalurus nebulosus*).

I.I. Koliushev (1959) documented 49 fish species in the water bodies of Transcarpathia, including the addition of silver carp (*Carassius gibelio)* and lake trout (*Salmo truto m. lacustris*).

A notable increase in the species composition of fish in Zakarpattia occurred between 1959 and 1982. This expansion can be attributed to the initiation of active measures for acclimatizing commercial species, such as silver carp (*Hypophthlmichthys molitrix*), white carp (*Ctenopharyngodon idella*), Sevan trout (*Salmo ischchan*), char (*Salvenilus fontinalis*), Baikal brown trout (*Coregonus autumnalis migratorius*), and Chud River whitefish (*Coregonus lavaretus maraenoides*). Additionally, new species were discovered in Zakarpattia waters, including the European eel (*Anguilla anguilla*), burbot (*Sander volgensis*), Panonian roach (*Rutilus pigus*), Rodney's dace (*Gobitis aurata radnensis*), and bluegill (*Abramis ballerus*).

According to ichthyological studies conducted by Yu. Movchan (1993), the ichthyofauna of the Tysa River basin, encompassing all the rivers in the Zakarpattia Oblast, consists of 60 species and subspecies of roundworms and fish. New species reported by the author include oatmeal dace (*Leucaspius delineatus*), variegated silver carp (*Aristichthys nobilis*), and sunfish (*Lepomis gibosus*). Since 1998, two additional species have been discovered during ichthyological surveys: the rotan (*Perccottus glenni*) and the Amur sabrefish (*Pseudorasbora parva*).

The ichthyofauna of the study area currently consists of 62 species and subspecies of amphibians and fish, with 51 being native species, while 11 species have been acclimated or introduced into the water bodies of Transcarpathia in various ways. Notably, the ichthyofauna of the Tysa River basin is remarkable for Ukraine, as it encompasses numerous endemic species.

Over the period from 1926 to 2022, a total of 77 fish species and subspecies have been documented in the entire Tysa River basin, representing nearly half of the species diversity found in European rivers. Among these, 54 species are shared between the Ukrainian and Hungarian sections of the Tysa River and its tributaries. This disparity is likely due to variations in hydrological, hydrophysical, and hydrochemical conditions resulting from the river's course through diverse terrain.

As evident from the information provided above, two regions, specifically the trout and grayling habitats, are entirely situated within Zakarpattia. Owing to the absence of these habitats in Hungary, several species, including the Hungarian lamprey (*Eudontomyzon danfordi*), grayling (*Thymallus thymallus*), rainbow trout (*Oncorhynchus mykiss*), char (*Salvenilus fontinalis*), lake trout (*Salmo truto m. lacustris*), chub (*Phoxinus phoxinus*), barbel (*Nemachilus barbatulus*), andruff (*Leuciscus souffia agassizi*), Carpathian dace (*Gobio gobio carpathicus*), chub (*Cotus gobio*), and colourful dace (*Cotus poecilopus*), are either absent or occur as rare exceptions in this region. Additionally, species such as sturgeon (*Acipenser guldenstaedti*), thornyhead (*Acipenser nudiventris*), bluegill (*Abramis ballerus*), largemouth bass (*Micropterus salmoides*), baloney ruff (*Gymnocephalus baloni*), goby (*Proterorhinus marmoratus*), and chub (*Neogobius kessleri*) are not found in the water bodies of Zakarpattia.

Over the past century, significant qualitative and quantitative transformations have occurred in the fish fauna of Zakarpattia. Quantitative changes have led to a general decline in fish populations, both across the region and in specific water bodies. Species like sturgeon (*Acipenser gutdenstaedti*), beluga (*Huso huso*), spear (*Acipenser nudiventris*), and stellate sturgeon (*Acipenser stelatus*) have vanished from the fish fauna of Zakarpattia due to alterations in the hydrobiological conditions of the rivers (Turianin, 1982; Movchan, 1993). Notably, these species are migratory and were previously known to spawn in the lower reaches of the Tysa River, albeit they are more prominently associated with the Danube Delta.

The attempt to acclimatize Sevan trout (*Salmo ichari*), Chudskyi whitefish (*Coregonus lavaretus maraenoides*), and Baikal brown trout (*Coregonus autumnalis migratorius*) was unsuccessful, and the fate of the peled introduced into certain water bodies remains unknown (Movchan, 1993). Furthermore, the introduction of dwarf catfish (*Ictalurus nebulosus*), sunfish (*Lepomis gibosus*), oatmeal (*Leucaspius delineatus*), rotan (*Perccottus glenii*), and Amur chub (*Pseudorasbora parva*) into the region's water bodies occurred through various means.

In recent years, a decline in the populations of Hungarian lamprey (*Eudontomyzon danfordi*), sterlet (*Acipenser ruthenus*), chub (*Hucho hucho*), brook trout (*Salmo trutta m. fario*), grayling (*Thymallus thymallus*), vimba (*Vimba vimba*), sabrefish (*Pelecus cultratus*), elm (*Leuciscus idus*), and bream (*Abramis brama*) has been observed. We attribute this decline to several factors, including the general shallowing of rivers, degradation of water quality, changes in food supply, and more. The primary contributors to these phenomena are extensive deforestation and the discharge of various pollutants into riverbeds, originating not only from regional sources but also from abroad (notably, the substantial pollution of the Tysa River, the region's largest waterway, with heavy metals and cyanides from industrial facilities in Romania during 2000-2001).

Concurrently with the decline in fish stocks, there has been a notable increase in species diversity. Notably, between 1926 and 1993, the fish fauna of Zakarpattia was enriched by the addition of 14 species and subspecies of fish. Additionally, we believe that certain species such as the black American catfish (*Ictalurus melas*), balloon ruff (*Ictalurus melas*), bluegill (*Abramis ballerus*), and Panonian roach (*Rutilus pigus*), which are found in the lower reaches of the Tysa River, may also exist in the water bodies of Zakarpattia.

We propose three possible means through which these species could have entered Transcarpathian water bodies:

1. Accidental introduction during planned acclimatisation efforts for other species.
2. Introduction of eggs by migratory waterfowl.
3. Introduction as aquarium fish.

All of the above observations suggest that the ichthyofauna of Zakarpattia is not inherently stable, and there exists a lack of consensus among researchers regarding the taxonomic classification of specific species. In light of this, it is imperative to conduct a comprehensive inventory of the ichthyofauna in Transcarpathia, exploring the region's water bodies in greater detail, and working to enhance the number of individual fish species. This endeavour should also encompass efforts to develop methods for preserving the genetic diversity of the ichthyofauna, even in the face of recurrent pollution of the Tysa River with heavy metals and cyanides, which has led to increasingly severe consequences.

8.7. THE INFLUENCE OF ANTHROPIC FACTORS ON THE ENTOMOFAUNA OF MAIN BIOTOPES *(O.Mateleshko)*

The influence of anthropic factors on the entomofauna of various biotopes is a topic of great significance. Based on extensive long-term observations and the analysis of collection materials, it is evident that human economic activities have a pronounced impact on the distribution and abundance of various insect groups and taxa.

The primary anthropogenic factors that exert significant effects on insects include:

- Deforestation
- Land reclamation
- The development and establishment of agrocenoses
- The use of pesticides
- Pollution of water bodies
- Degradation and destruction of aquatic environments
- The practice of habitat burning
- Grazing of livestock
- Human recreational activities

Furthermore, it is essential to recognize that this impact and the underlying reasons for the decline in insect populations may vary across different types of ecosystems.

Alpine meadows and heathlands

Fig. 8.7.1. Alpine belt of the Chornohora massif, Hoverla (photo by O. Yu. Mateleshko)

The entomocomplexes found in these areas encompass a significant representation of arctic-alpine and European montane elements, along with numerous endemic and relict species, and subspecies. Notably, these ecosystems are home to rare indicator species, including *Carabus fabricii, Carabus silvestris transsylvanicus, Carabus hampei incompsus, Nebria transsylvanica, Chrysolina carpatica,* and *Erebia manto*. It's essential to recognize that alpine habitats, in particular, face a heightened vulnerability due to the prevalence of substantial anthropogenic pressures, including recreational activities and pastoral practices, which are concentrated in relatively small areas.

Subalpine scrub-meadow complexes

Moving to subalpine scrub-meadow complexes, the entomocomplexes here exhibit a diverse composition, combining Holarctic and Palearctic boreal and boreal-montane, Arctic-alpine, and European montane elements. Among their distinguishing features are the presence of rare species such as *Oreina plagiata, Oreina viridis, Parnassius mnemosyne, Pieris bryoniae,* and *Erebia manto*. These habitats, however, face their own set of challenges, including vulnerability due to fragmented distribution and significant anthropogenic pressures arising from recreational activities and grazing practices.

Fig. 8.7.2. Subalpine meadows of the Polonynsky Ridge, Polonyna Runa (photo by O. Yu. Mateleshko)

High-mountain reservoirs

Fig. 8.7.3. Temporary lake in Chornohora, Breskul (photo by O. Yu. Mateleshko)

The entomocomplexes include Holarctic and Palearctic boreal and boreal-montane, arctic-alpine, and European montane elements: *Somatochlora alpestris, Hydroporus longicornis, Agabus solieri,* and *Crenitis punctatostriata.* Habitats of this type are extremely vulnerable due to their small size and excessive anthropogenic pressure, primarily recreational (pollution and destruction of coastal areas).

The upper forest belt

The entomocomplexes have a relatively rich species composition, including Holarctic, Palearctic, boreal, boreal-montane, and European montane species. Indicator species in this habitat type include *Carabus irregularis, Quedius transsylvanicus, Lacon lepidopterus*, and *Pseudogaurotina excellens*. This habitat type is moderately widespread in the region and has a moderate degree of transformation. The primary negative impact on this habitat is due to the reduction of old natural forests.

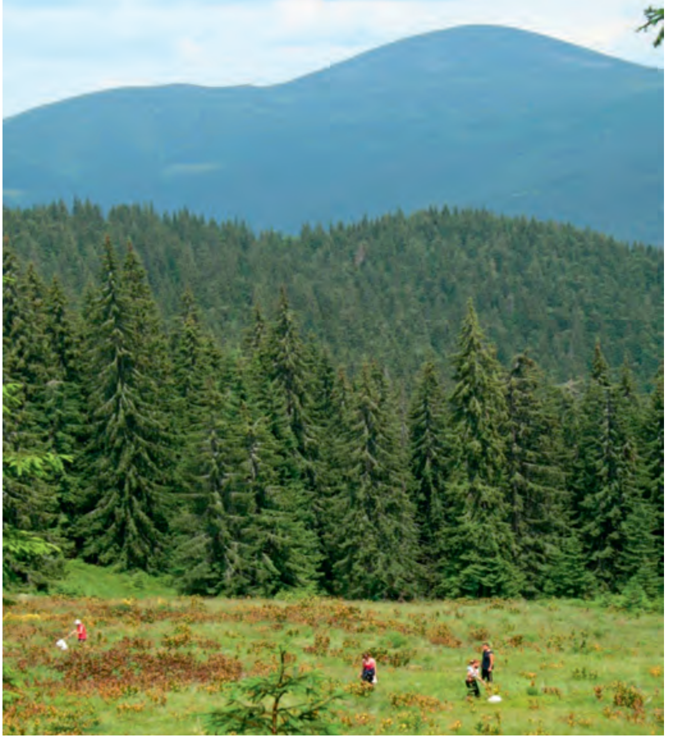

Fig. 8.7.4. The upper forest belt in Chornohora, Menchul (photo by O. Yu. Mateleshko)

The beech forest belt

The beech forest belt is characterized by a species composition dominated by temperate and non-temperate Palaearctic, European-Siberian, Western Palaearctic forest elements, and a significant presence of European montane species. Characteristic species in this habitat include *Carabus intricatus, Carabus irregularis, Lucanus cervus, Rosalia alpina, Cucujus cinnabarinus, Ludius ferrugineus, Eurythyrea austriaca, Apatura iris, Limenitis populi, Lopinga achine, Aglia tau, Endromis versicolora, Catocala fraxini, Catocala sponsa,* and *Phlogophora scitha.*

Fig. 8.7.5. Beech forest of the Volcanic Ridge, Makovytsia massif (photo by O. Yu. Mateleshko)

It is one of the most widespread habitat types in the region, which is generally characterised by a medium degree of transformation. The main factors of negative impact are the destruction of natural habitats of the species due to the reduction of old natural forests.

Thermophilic oak forests

The entomocomplexes exhibit a diverse species composition, featuring Western Palearctic non-moral, European-Siberian forest-steppe, and Mediterranean-Pontic species. Characteristic species include *Calosoma sycophanta, Lucanus cervus, Eurythyrea quercus, Cetonischema aeruginosa, Cerambyx cerdo, Purpuricenus kaehleri, Brintesia circe, Hipparchia fagi, Marumba quercus, Arctia villica, Catocala sponsa,* and *Catocala conversa.* These habitats, primarily found in the Volcanic Carpathians, are highly fragmented, possess a substantial degree of transformation, and face a significant risk of extinction due to the reduction of old oak forests.

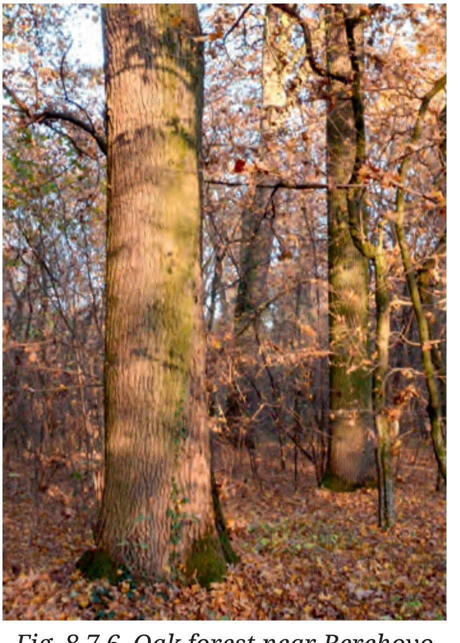

Fig. 8.7.6. Oak forest near Berehovo (photo by O. Yu. Mateleshko)

Floodplain and valley leafy forests

The entomocomplexes are characterized by a rich species composition, predominantly composed of temperate and non-temperate Palaearctic, European-Siberian, and Western Palaearctic forest elements. Rare species that stand out in these complexes include *Carabus clatratus, Osmoderma eremita, Aromia moschata, Apatura iris, Limenitis populi, Nymphalis vaualbum, Euphydryas maturna, Lopinga achine, Catocala fraxini, Catocala sponsa, Eudia pavonia, Saturnia pyri,* and *Endromis versicolora.* Habitats of this type have limited distribution, a high degree of anthropogenic transformation, and a significant risk of further degradation due to the lowering of the groundwater level, deforestation, and development.

Fig. 8.7.7. Oxbow in Berehivsky district, Zakarpattia lowland (photo by O. Yu. Mateleshko)

Forest-steppe complexes

Forest-steppe entomocomplexes boast a rich species composition, with a significant presence of thermophilic Western Palearctic nemoral and Mediterranean-Pontic steppe elements. Notable rare species within these complexes include *Poecilimon schmidtii, Saga pedo, Cetonischema aeruginosa, Protaetia fieberi, Purpuricenus kaehleri, Libelloides macaronius, Iphiclides podalirius, Colias myrmidone, Melitaea britomartis, Brintesia circe, Hipparchia fagi, Hamearis lucina, Proserpinus proserpina, Hemaris tityus, Eudia pavonia, Saturnia pyri, Eriogaster catax, Pericallia matronula, Ammobiota festiva, Arctia villica,* and *Rhyparia purpurata*. These habitats are fragmented and subject to substantial anthropogenic pressure due to livestock grazing, grass burning, and artificial afforestation.

Fig. 8.7.8. The southern slope of the Berehovo Volcanic Hills, Muzhievo (photo by O. Yu. Mateleshko)

Bog and peat meadows

These habitats form a unique hygrophilous complex within the entomofauna, featuring both zonal temperate and non-temperate as well as boreal faunal elements. Notable among the species found here are *Euphydryas aurinia, Boloria eunomia, Coenonympha hero, Lycaena helle, Maculinea alcon, Maculinea teleius, Maculinea nausithous,* and *Diachrysia zosimi.* Habitats of this type are under significant anthropogenic pressure, primarily due to drainage reclamation and grazing.

Fig. 8.7.9. Swamp meadow in the valley of the Uzh River, Nevitske (photo by O. Yu. Mateleshko)

Springs, streams and their banks

Mountain springs and streams, along with their banks, host a diverse and unique entomofauna. Notable rare species found in these ecosystems include *Cordulegaster bidentata, Leistus baenningeri, Nebria jokischii, Nebria fuscipes, Nebria reitteri, Deltomerus carpathicus, Oreodytes borealis, Ditylus laevis*, and more. The primary threat to these species and their habitats is the destruction caused by skidding felled timber along the streams.

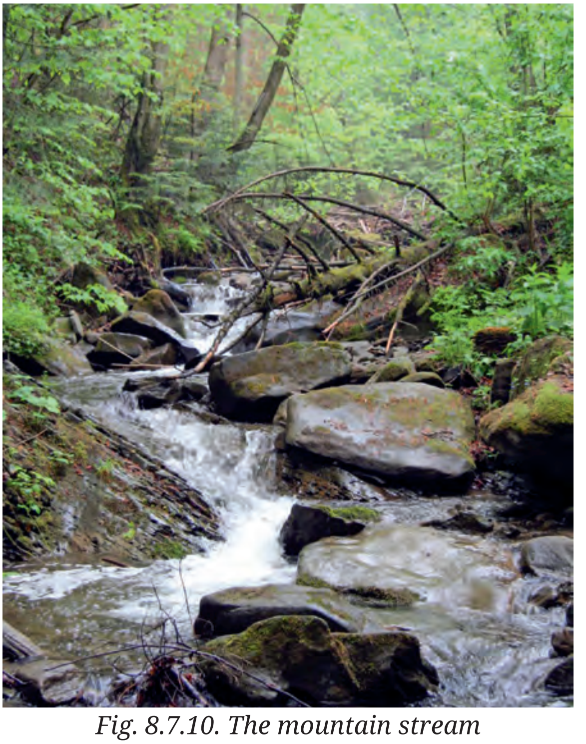

Fig. 8.7.10. The mountain stream of the Poloninsky ridge, Zhornava (photo by O. Yu. Mateleshko)

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8.8. THREATS OF SPREAD AND IMPACT OF INVASIVE SPECIES *(R. Kish, Yu. Shpontak, D.Tomenchuk, V. Mirutenko, I. Besehanych)*

Among the environmental threats in Zakarpattia Oblast, it is essential to highlight a problem that, in terms of its impact and irreversible changes in biodiversity, particularly phytodiversity, is now considered one of the most powerful destructive factors affecting native ecosystems globally. This issue pertains to the invasion of non-native organisms, often referred to as 'adventitious' or 'alien' species. Notably, it includes invasive plants and the associated biological pollution. These invasions pose threats of a planetary scale, as they have spread to all continents, affecting even the most remote corners of the Earth. In addition to the direct damage caused to agriculture and human health by invasive species, their environmental impact is substantial. The environmental cost of invasive alien organisms is already evident in the irreparable damage inflicted upon natural species, habitats, and ecosystems. In terms of the depth of the impact on destructive processes, especially in the context of biodiversity loss, it can be likened to the complete destruction and irreversible loss of habitat. This issue represents the second most significant threat to the planet's biodiversity, following the destruction of natural habitats. The economic losses associated with invasive species are considerable. Direct and indirect losses related to introduced species, including the loss of benefits, amount to billions of dollars annually in many countries.

Invasive plants comprise non-indigenous species with biological characteristics and efficient mechanisms for rapid and extensive colonisation of new regions. They can establish themselves not only in areas disturbed by human activity but also within natural vegetation, such as forests, meadows, and riverbanks, leading to a reduction in biodiversity. Climatic changes in recent decades have disrupted the structure of natural ecosystems, creating new niches in the vegetation cover. This, in turn, significantly enhances the opportunities for the establishment and naturalisation of such invasive species (Protopopova and Shevera, 2019).

The issue of alien invasions has reached a global scale, drawing the attention of not only specialists but also national and international institutions. It has been a topic of discussion at events such as the UN International Conference on Sustainable Development (Rio de Janeiro, 1992) and the UN International Conference on Non-Native Species (Trondheim, 1996). These discussions culminated in the development of the Global Strategy for the Problem of Invasive Non-Native Species (McNeely and others, 2001) and the European Strategy for the Problem of Invasive Non-Native Species (Genovesi and Shine, 2004). According to the core tenets of these strategies, countries were mandated to formulate National Strategies for the Prevention and Control of Invasive Species. Furthermore, they were directed to compile regional listings or 'Black Lists' of invasive plant species that account for regional nuances.

In Ukraine, as in other European countries, the issue of adventitious flora is exceptionally pressing. The country's adventitious flora fraction now comprises over 830 species, which accounts for approximately 14% of the total flora species count, a figure consistent with the European average (Protopopova, Mosyakin, Shevera, 2002). This fraction continues to expand yearly, with the addition of several taxa. Particularly perilous are highly invasive species with expansive distributions, often referred to as 'transformer' species. These species have already surmounted reproductive and cenotic barriers and possess the potential to unify and reshape ecosystems (Protopopova and Shevera, 2005). They exhibit a high degree of naturalization, rapid and effective dissemination, and a broad ecological range. The menace posed by invasive transformer species is particularly pronounced due to their penetration and naturalization in native habitats. In these habitats, they often establish themselves as a stable component of the community and can rapidly assume dominance, displacing indigenous species. This process leads to substantial losses in biodiversity and can result in the complete and often irreversible transformation, or even disappearance, of the habitat. During the historical period, Ukraine has seen the spread of approximately 42 to 64 species (depending on the interpretation), including *Ambrosia artemisiifolia, Acer negundo, Amorpha fruticosa, Helianthus tuberosus, Fallopia japonica, Heracleum mantegazzianum, Phalaris arundinacea, Solidago canadensis*, among others. Some of these species, such as *F. japonica, H. mantegazzianum, S. canadensis*, and several others, tend to form mono-dominant communities, particularly in disturbed areas, often covering extensive areas.

Currently, there exists a substantial body of research material and numerous reports detailing the distribution and degree of naturalization of various adventive and highly invasive plant species in different regions of Ukraine. Measures to prevent, counteract, and combat the spread of non-native species have been developed, but their implementation is hampered by a lack of systematic and practical government support (Protopopova, Mosyakin, Shevera, 2002; 2003). For instance, the M.G. Kholodnyi Institute of Botany at the National Academy of Sciences of Ukraine has formulated a working version of the National Strategy for the Control of Non-native Plants in Ukraine, proposed amendments to existing legislative acts, identified priority areas for the Concept, outlined measures for managing phytoinvasions, and strategies for restoring the native flora fraction. Unfortunately, these proposals have not been put into practice (Protopopova, Mosiakin, Shevera, 2002).

In the Transcarpathia, despite the extensive natural areas, many of which have conservation status, the invasion of non-native plant species presents one of the most significant threats to the region's floral and coenotic diversity.

In recent years, there has been a concerning trend of non-native plant species, including invasive ones, encroaching upon the region's nature reserves. This has led to alterations in the flora's species composition and, in some cases, its overall structure. For example, within the flora of Synevyr National Nature Park, the adventitious fraction consists of 104 vascular plant species, with 11 of these classified as invasive. Notably, *Phalacroloma annuum (Erigeron annuus), Impatiens parviflora, Salix fragilis*, and the introduction and initial expansion of Mantegazzi hogweed (*Heracleum mantegazzianum*) pose the most significant threats to biodiversity (Protopopova, Tiukh, Shevera, 1999; Shevera et al., 2019). Uzhanskyi National Nature Park records 118 adventitious plant species, including *Acer negundo, Ambrosia artemisiifolia, I. glandulifera, Echinocystis lobata, Helianthus subcanescens, Heracleum sosnowskyi, Fallopia japonica*, and more.

Many of these species were intentionally introduced and cultivated for ornamental, medicinal, fodder, or honey purposes. Notably, Sosnovsky's and Mantegazzi's hogweed, originally from the highlands of the Caucasus, were initially introduced as ornamental plants and later as fodder plants, which are also valuable as honey plants. Mantegazzi hogweed was first introduced in the 1960s by S.S. Harkevych to the Central Republican Botanical Garden of the USSR Academy of Sciences. From there, it made its way to Zakarpattia Oblast, initially to the Botanical Garden and the biological base of Uzhhorod State University in the Polonyna Rivna. Subsequently, it was extensively cultivated in collective and state farms within the region ("Climatogenic changes…", 2016; Protopopova, Shevera, 2005).

By the 1970s, the first feral plants of this species began appearing, primarily in the areas where it was cultivated. In the 1990s, a massive expansion of the species commenced. Currently, the species is prevalent in anthropogenic ecotopes, forming part of synanthropic plant communities. It continues to spread rapidly along roads and riverbanks, encroaching upon riverine floodplain habitats and wet meadows. At times, it establishes extensive mono-dominant communities. The dense thickets of hogweed, which outcompete native vegetation, significantly diminish the biodiversity of natural habitats. Additionally, these plants pose a risk to human health as they can cause severe burns when touched in sunny weather.

Today, the penetration and naturalisation of adventive and highly invasive plant species are facilitated by the region's geographical position on the borders of several countries and at the intersection of important Central European routes. The area boasts diverse environmental conditions, a dense river network, a tradition of cultivating numerous species for ornamental purposes, and, more recently, vast expanses of long-term or periodically uncultivated agricultural land, primarily in the most developed lowland and foothill regions. These disturbed, abandoned areas of anthropogenic origin, where competition from native flora species is absent or reduced, serve as starting points for the establishment, naturalisation, accumulation of diasporas, and subsequent expansion of adventive and, particularly, invasive plant species into neighbouring territories, including natural habitats.

An important factor contributing to biological pollution is the absence of a legislative framework and a well-developed control system, along with mechanisms and means to implement control measures for invasive species at the state or regional level. According to the latest estimates, 31 species of vascular plants have attained the status of invasive species in Zakarpattia Oblast. These include, in addition to the aforementioned species, *Asclepias syriaca, Echinocystis lobata, Impatiens parviflora, Rudbeckia laciniata, Salix fragilis, Solidago gigantea*, and others. Numerous studies have demonstrated that invasive species have infiltrated nearly all types of natural habitats in the Transcarpathia, spanning the entire altitudinal gradient from the plains to the highlands. These invasive species have significantly altered the structure and functioning of these habitats. According to the data we have gathered, forest habitats, particularly those in lowland and riverine areas, have been most affected by the spread of invasive species. For instance, floodplain willow-poplar gallery forests in the lower reaches of rivers harbor colonies of 11 invasive species. In riverine ash and alder forests, nine species have been identified, while floodplain elm and ash oaks in Zakarpattia's lowlands have been impacted by eight invasive species. In the forests of the Sub-Pannonian hornbeam oak habitat, a key component of the lowland forest tracts, seven invasive species have been observed. In total, 17 invasive plant species have been identified in the forest habitats of the Transcarpathia (Klimatohenni zminy ..., 2016; Shevera et al., 2017). In certain areas, these species can achieve total dominance, completely covering the grass layer and shrubby undergrowth with a continuous canopy. This is particularly evident in several forest tracts in the plains, where Vitis riparia thickets have expanded in some regions of elm and ash oaks. As a result, the global consequence of invasive plant species establishing themselves in natural plant communities is a reduction in species diversity and disruption of their structure, potentially leading to significant alterations in the region's most vulnerable ecosystems.

One of the initial steps in the development and organisation of measures to control phytoinvasions in the region and to address the issue at the state level is the creation of the first regional 'List of Invasive Plant Species of the Zakarpattia Oblast.' This list was adopted by the Zakarpattia Oblast Council, approved by decision of session No. 721 on 23 March 2017, and subsequently published (see Annex 4; Shevera et al., 2017). The list encompasses 31 species of invasive vascular plants subject to monitoring and control. It is anticipated that this list will form the foundation for ongoing monitoring efforts in the region and will contribute to the development and implementation of effective control measures for invasive plant species.

Today, similar lists have been compiled for several other regions of Ukraine, but their approval has been delayed for various reasons. These lists, along with locally developed action plans, could serve as the foundation for a national program to combat invasive species in Ukraine. It is also imperative to adopt a National Strategy for the Prevention and Control of Invasives, along with a comprehensive set of documents to establish a legislative framework for monitoring, research, methods of invasion prevention and control, the study of bio-ecological features at the regional level, and the subsequent development of an action plan to address the challenge of invasion protection. These are urgent tasks that should involve various research and environmental institutions. Neglecting or postponing the development and implementation of an action plan to prevent, control, and protect against invasions can lead to highly detrimental and unpredictable consequences for public health and the environment, particularly for natural ecosystems.

Invasive animal species also pose a significant threat to ecosystems. As previously mentioned, the region's location at the confluence of several countries' borders makes cross-border movements of goods and the importation of planting materials (such as fruit and ornamental plant seedlings) the primary pathways for invasive animal species to enter.

In recent years, there has been a rapid increase in the number of invasive invertebrate species, including the Spanish slug (*Arion vulgaris*), harlequin ladybird (*Harmonia axyridis*), western corn borer (*Diabrotica virgifera virgifera*), boxwood moth (*Cydalima perspectalis*), chestnut moth (*Cameraria ochridella*), *Phyllonorycter robiniella, Phyllocnistis vitegenella, Scaphoideus titanus*, and several others (Mirutenko et al., 2023).

Most of these species, with the exception of *Harmonia axyridis*, are phytophages. Their feeding activity leads to damage in agricultural, forest, and ornamental plants, resulting in significant losses for agricultural enterprises and local communities.

Harmonia axyridis, on the other hand, is a predatory beetle from the Coccinelidae family. It competes quite aggressively with native predators and contributes to the decline in native species in ecosystems, impacting the region's biodiversity as a whole. Numerous vertebrate invasions have also been reported in the region.

In particular, invasive fish species have been identified in the region, including sunfish (*Lepomis gibbosus*), variegated silver carp (*Aristichthys nobilis*), rotan (*Perccottus glehni*), Amur chub (*Pseudorasbora parva*) (Bondar and Kurtyak, 2017; Kurtyak, 2018), black catfish (*Ameiurus melas*), brown catfish (*Ameiurus nebulosus*), and others (Görner and others, 2014). In the case of reptiles, the red-eared turtle (*Trachemys scripta*) (Kurtyak and Kurtyak, 2013; Hleba, 2016) has also been identified, and among mammals, the marsh muskrat (*Ondatra zibethicus*) (Görner and others, 2014) is of concern.

The introduction of these vertebrate invasive species likely occurred through various means. Some may have been introduced accidentally during the acclimatisation of other species, while eggs of certain fish species could have been introduced by migratory waterfowl. As for the red-eared turtle, it is evident that this species was initially introduced for ornamental purposes. However, over time, individual terrarium owners may have released them into natural reservoirs.

The impact of invasive species on the environment primarily stems from changes in biodiversity. These invasive species exert competitive pressure on native species, leading to a decline in native populations and disruptions to local ecosystems. Many invasive species trigger chain reactions within ecological communities and can affect both biotic and abiotic components of ecosystems.

Invasive species can also alter ecosystem services by influencing populations, communities, ecosystem processes, and causing specific abiotic changes. Virtually all ecosystem services can be negatively impacted by invasive species.

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Chapter 9.

THE IMPACT OF CLIMATE CHANGE ON THE ECOSYSTEMS OF ZAKARPATTIA AND ADAPTATION MEASURES

(O. Stankiewicz-Volosianchuk)

The most noticeable consequence of climate change for our region is not the gradual warming, although low-snow warm rainy winters have already become obvious. The most observable are unusual or anomalous weather and atmospheric phenomena – heat waves, «tropical nights», hail, gusty winds, prolonged droughts, very heavy rains, extremely hot days. In the future, the oblast will expect more frequent floods and high waters, which will alternate with droughts. Therefore, the main task for minimizing the consequences of climate change is the implementation of complex measures aimed at detaining rainwater in natural, agro- and urban ecosystems.

Adaptation to climate change is the adaptation to existing or expected risks caused by climate change. Timely adaptation measures create additional opportunities and save costs for combating the consequences of climate change. Roughly speaking, investing in adaptation to climate change saves a third of the costs of eliminating the consequences in the form of natural forest fires, devastating floods, landslides, mudflows, the need for energy resources and food, health care and treatment of people (Adaptation to climate change, 2015; Didukh, 2009).

Urban Environment

The main negative consequences of climate change, which are manifested in cities, include: 1) long «heat waves» (periods during which the maximum daily air temperatures for more than 6 consecutive days exceed the average maximum air temperatures for a specific settlement in a specific season); 2) the appearance of days with «tropical nights» (a phenomenon when the air temperature does not drop below + 25 0C after sunset) (Safranov et al., 2021; Shevchenko, Vlasiuk, 2015); 3) underflooding as a result of torrential rains or floods; 4) hurricanes, squalls, hail (Kirbi, 2020); 5) degradation and reduction of green areas; 6) deterioration of the quality of drinking water and its shortage; 7) spread of previously rare infectious diseases and allergic reactions, etc.

All this has a negative impact on the state of the environment in populated areas, especially when it comes to cities where many people live, where there are blocks of high-rise residential buildings, roads, and transport interchanges. Cities become *more energy-dependent* especially in the summer period, when for comfortable living it is necessary to air condition the premises, additionally moisten the streets and install cuvettes with drinking water. Heat waves are very difficult to tolerate for people with cardiovascular diseases, frequent visits to polyclinics, hospitals, as well as deaths are sometimes the consequence of such weather conditions. Extending the growing season of allergenic plants common in urban landscapes also causes problems for allergy sufferers.

All these negative consequences can be mitigated, while at the same time significantly improving the habitat of people. A strategy and plan for the implementation of measures aimed at adapting to climate change should be developed for each city. This will determine not only the local climate policy, but also the specific steps that the city should take, based on the conditions and problems relevant to it. At the same time, there are events that are universal for every city. These measures are aimed at: 1) increasing the area of green spaces; 2) preservation of rainwater in city ecosystems; 3) development of distributed renewable energy power generation (Stankiewicz-Volosianchuk, 2021); 4) optimization of the use of drinking and technical water; 5) development of public transport.

It is not always possible to increase the area of green spaces for each city, especially in the historical city centres, in the blocks of high-rise residential buildings or industrial blocks. However, there is an equally effective solution, which consists in vertical greening of the urban environment. Vertical landscaping can be successfully used both in existing parks, squares, gardens of private estates through hedges, pergolas (Fig. 9.1), etc., and in areas of dense residential or office buildings or industrial zones through green facades (Fig. 9.2), green roofs, parklets (Fig. 9.3.).

Vertical greening of the urban environment achieves several goals: air purification and reduction of the amount of carbon dioxide in the air, production of oxygen, cooling of surfaces due to water evaporation. It has been proven that in the sun, concrete, ceramic or asphalt surfaces heat up above 50 0C, and covered with greenery – up to 27-28 0C. Vertical gardening not only improves significantly the microclimate and atmospheric air quality in cities, but also eliminates the need for air conditioning in buildings. Rainwater storage in cities, which during heavy rains often leads to the collapse of the city sewage system and flooding of the city, can be solved in another way (Kravčik et al., 2010). In particular, these are: 1) creation of water-permeable surfaces in car parking places, on paths in parks, squares, playgrounds; 2) creation of rain gardens and ditches (Catalogue of

Green Solutions, 2021), which can absorb and retain up to 90% of stormwater; 3) preservation of miscellaneous herbs on lawns; 4) collection of rainwater from roofs into natural and artificially created reservoirs or into aboveground/underground containers (reservoirs).

Fig. 9.1. Pergola with extensive green facade and hedge in Eberswalde, Germany (Photo by the author)

Fig. 9.2. Extensive and intensive green facade in Brno, the Czech Republic (Photo by the author)

Fig. 9.3. Green roof in the city of Brno, the Czech Republic (photo by the author) and a parklet in the city of San Francisco, the USA (photo from the Internet)

Fig. 9.4. Parking lots with water-permeable surface and a rain ditch (Photo from the Internet)

Fig. 9.5. Miscellaneous herbs on lawns (photo from the Internet) and the lake created by rainwater from the roofs of high-rise buildings in the city of Novy Liskovec, the Czech Republic (Photo by the author)

All these measures will retain rainwater in the city, creating a healthy microclimate during the drought (Fig. 9.4.-9.5.). During heavy rains, water will not accumulate on asphalt and concrete surfaces, clogging the drains of the sewage system, but will penetrate the soil and accumulate in the created micro-ecosystems (Kravčík et al., 2007). Replacing mowed lawns with lawns of miscellaneous herbs that imitate natural meadows aims not only to achieve an aesthetic effect, but also to reduce the temperature on the surface (the mowed lawn does not evaporate enough water for cooling and burns out without additional watering) and preserve biodiversity.

The development of local renewable energy power generation networks in settlements allows not only reducing the energy dependence of communities on central power grids, but also achieveing energy passivity of budgetary institutions and housing fund. In addition, small (with a capacity of up to 1 MWt) and residential rooftop solar power stations (up to 30 kW) allow one to cover large areas of the surfaces of flat roofs and roofs with a small slope covered with ruberoid or metal plastic, which overheat by absorbing solar heat. These areas can be used for electricity generation (Fig. 9.6).

Fig. 9.6. Creating shade and electricity generation at the airports of the city of Medford, the USA and the city of Tbilisi, Georgia (Photo by the author)

Water Management

It is often emphasised that adaptation in the field of water resources is the basis of climate change adaptation policy (Masey, 2012). At the same time, no measures in this field can be developed, ignoring a comprehensive approach, which will include issues of forestry and agriculture, industry, housing and communal sphere, and preservation of biodiversity. Zakarpattia will face the problem of floods and long droughts in the near future. Therefore, protecting the population from the destructive force of floods, as well as providing them with quality water in all seasons, is the main task.

What can, thus, be done to make sure that the oblast remains with water all year round and does not suffer from destructive floods? The construction of dams and reservoirs is the last one in the list of measures, since these hydrotechnical structures do not eliminate the causes of the increase in surface runoff into the rivers during precipitation, but only temporarily mitigate the consequences. Moreover, due to creating an additional base of erosion and a change in the natural hydrological regime, they lead to the further degradation of river ecosystems and the loss of biodiversity (Merezhko, Khimko, 1999; Stankiewicz-Volosianchuk, 2017). Therefore, it is necessary to start with an analysis of the causes of river shallowing and the lowering of undergroundwater level, in particular, the draining of swamps, uncontrolled intake of gravel-sand mixture from riverbeds, improper maintenance of amelioration canal systems, construction of floodplains, disturbance and compaction of soils on mountain slopes as a result of the operation of heavy machinery under time of logging and uncontrolled jeeping in forests and meadows, etc.

Brooks and streams, as tributaries of rivers of the last order, are negatively affected by trawling equipment during logging and motorised transport, in particular jeeping in the mountains. However, it is in mountain forests and meadows that the river flow is formed, so the integrity of these ecosystems is important for the stability of the entire river regime. The destructive force of a flood in the lower reaches is directly proportional to the hydrological state of the upper reaches (Klymenko, 2010). Therefore, measures to mitigate the impact of floods should not apply to the lower reaches of the river, where most of the settlements of the oblast are located, but, first of all, to the upper reaches, in particular the water catchment areas, where the runoff is formed. These measures should be aimed at preventing an increase in surface runoff as a result of soil destruction. Rainwater and meltwater should remain on meadows and forests, forming an underground aquifer, accumulating in upland lakes and forest reservoirs, marshes, swamps (Kravčík et al., 2007). Such measures should be based on an integrated approach to water management and reflected in *the Tysa River Basin Management Plan.*

The main measures should be aimed at the revitalization of swamps, floodplains and river meanders, where possible. In Zakarpattia, the majority of mountain rivers are free-flowing and this is an advantage for adaptation to climate change. Integrated river ecosystems are better able to adapt to any climatic changes. It is not without reason that within the framework of the implementation of the EU Biodiversity Strategy for 2030, EU countries plan to restore the free flow of 25,000 kilometers of rivers in order to guarantee normal water supply to the surrounding areas. In the context of implementing this strategy, in December 2021, the European Commission approved the Methodical Guide for the elimination of dams for the restoration of free-flowing rivers, which interprets the term «*free-flowing rivers*» as rivers or other surface water bodies (for example, lakes), which are not damaged by artificial barriers and are not disconnected from their floodplain (Guidance on Barrier Removal for River Restoration, 2021).

Therefore, when developing a plan of measures within the framework of the Tysa River Basin Management Plan, it is necessary, where possible, to avoid water regulation measures. This refers to the construction of hydraulic structures such as retaining dams, which segment the river and slow down its natural flow, as well as dams along the riverbeds, which artificially separate the channel from the floodplain of the river (Catalogue of Nature-oriented Solutions, 2021).

Each settlement in the oblast, in accordance with the Water Code of Ukraine, must also have *maps of threats of flooding the territory* (showing the territories that may be flooded due to flooding with a low, medium and high probability) and *the risks of flooding the territory* (showing the potential negative consequences related to flooding with a low, medium and high probability), and in accordance with them spatial planning should be carried out.

It is also necessary to gradually move to circular economy: to contribute to the reduction of water consumption in industry, energy, agriculture and everyday life through the application of subsidies, taxes and fines. For instance, it is necessary to encourage both business entities and household owners to collect and use rainwater, install systems of purifying water from wash basins and further use it as technical water. In this way, it is possible to reduce the use of drinking water for technical needs or irrigation.

Forest Management

Almost half of the territory of Zakarpattia oblast is covered with forests, the major part of which is mountainous. This means that almost all the water flow to the river is formed in the upper reaches of forest areas (Chubatyi, 1984; Hudyma, 2019). The integrity of the soil and forest floor in the forests, as well as the vegetation cover on the slopes is the key to the water regulation function of the forest (Buksha, 2002; Buksha et al., 2000). Forests affect the climate and at the same time climate change affects the forests.

Today, in the oblast there is a problem of the withering of spruce monocultures planted in the place of beech trees, as well as significant withering of forests on the plain and in the foothills. The problem of spruce withering is related to general warming and the spread of pests and diseases in spruce monocultures. This problem is solved by the use of combined felling systems aimed at the formation of native plantations of various ages, which are more resistant to climate changes. The situation is much more complicated with the grooves of the foothills and plains of Zakarpattia. It is related to the water regime of rivers.

In recent decades, there has been an increase in surface water runoff in the mountains and the rapid formation of floods during heavy rains, although the afforestation area of the territory is relatively high (more than

70%), in particular in the Uzh River basin (Barka et al., 2015) and in the upper reaches of the Tysa river. Despite this, the forests of the Carpathians are rapidly losing water.

We are talking about a very dense and branched network of forest roads, in particular, temporary and trailing roads on wood-cutting areas, which segment the forest landscape, compact the soil and «meliorate» forest massifs (Fig. 9.7).

It is these forest roads that play the role of «channels» along which water flows in streams during rains and during snowmelt. Damaged by heavy forest machinery the compacted soil cannot absorb water. This is how the forest loses water and how flood waves are formed, which destroy everything in their path (Fig. 9.8). The larger the area of such compacted soil, the lower the role of forests in water regulation. As a result, the loss of water by the forest can lead not only to the replacement of dominant species, but also to the reduction in the annual growth and productivity of the Carpathian forests.

Fig. 9.7. Network of forest roads and trails on wood-cutting areas where continuous felling was carried out in the vicinity of Huklyvyi village, Zakarpattia (Photo by the author)

The solution to this problem is achieved through measures or restoring forest roads and trails after the closure of the tree felling. Such works are also done with the use of heavy equipment, particularly, a bulldozer. The purpose of such works is to loosen the soil in order to increase its water permeability and form the necessary microrelief on slopes of various steepness, which will allow rainwater and meltwater to be directed to the undisturbed forest floor and/or to accumulate it in the created forest microreservoirs (Fig. 9.9). The same thing happens in primeval forests – uprooted old trees form a characteristic microrelief. In the depths where the roots were, moisture accumulates and various biological organisms live and develop – from fungi to vertebrates (Stankevych-Volosianchuk et al., 2022). Such micro-reservoirs are a breeding ground for yellow-bellied (*Bombina variegate L.*) or alpine newt (*Ichthyosaura alpestris L.*), which are listed in the Red Book of Ukraine. These also attract for feeding, e.g., the black stork, also a red book species, which today suffers a lot from the dehydration of forests. Thus, restoration of forest roads allows not only to preserve water in the forest, but also the biodiversity of forest species.

Fig. 9.8. Transporting felled trees along forest roads and water flows along these roads in the wet season, State Enterprise «Brusturianske Forest and Hunting Enterprise» and State Enterprise «Yasinianske Forest and Hunting Enterprise» (Photo by the author).

Other measures to retain water in the forest relate to the construction of forest roads, which are practically not built by forestry enterprises today. The technology of construction of forest roads involves the construction of lateral drains with a system of wells, where water flows and is discharged into the forest through a pipe under the road surface. Water culverts are built along the road from wood or concrete, which also divert water into the forest and prevent road erosion.

To retain surface runoff in the forest, in erosion ravines or temporary streams, a cascade of barrages is built from wood, stone or concrete (Fig. 9.10). This allows water to be retained during the heaviest downpours, preventing the formation of powerful flood waves. With such measures, it is possible to stop the erosion processes of the soil and turf its surface. Over time, the terrain in such places becomes even, and a forest appears in the place of ravines.

Fig. 9.9. Restoration of forest roads and trails after felling operations in the Czech Republic (photo from the site www.aqua-inova.com)

Fig. 9.10. Cascade of barrages in forest ravines, resulting from soil erosion, and in temporary streams of Slovakia (Photo by the author)

Owing to such measures, rainwater and meltwater enter the rivers gradually. They have time to saturate the soil and underground horizons with water and filter through.

Some forestry enterprises in the EU countries practise collecting rainwater from forest felling areas where reforestation has recently been carried out and from forest roads into specially created forest reservoirs. Such measures are quite expensive, so not every forestry enterprise can afford them. These reservoirs can also be used as a source of water in case of forest fires (Fig. 9.11).

Fig. 9.11. A forest reservoir created by rainwater on the territory of a forestry enterprise in Slovakia (Photo by the author)

In the U.S., the Clean Water Act requires forestry companies to carefully plan felling cycles in forests, taking into account all forest watercourses. This is the so-called integrated water catchment principle of forest resource management, the purpose of which is to increase the hydrological role of forests (Best Management Practices for Forestry, 2005).

A water catchment area is all the land and water bodies from which water flows to a certain point. It is possible to determine the catchment area for a lake, stream, river. Catchment areas range in size from a few acres (for a small stream) to hundreds of hectares (for a large river). During the planning of felling, hydrologists of forestry enterprises in the United States investigate where water comes from and flows out of the catchment area where felling operations are planned. The area of felling and road construction at high elevations can affect the amount and timing of runoff at lower elevations within the same water catchment. When it becomes clear where, when and how much water flows in the felling area, hydrologists determine the best location of roads and skidding trails with minimal damage to the environment.

After felling with consideration of the characteristics of watercourses within the catchment area, reclamation works are carried out at the felling area in American forestries. After a year, the achieved result is monitored and evaluated.

Agriculture

Climate change also affects agriculture. On the one hand, the lengthening of the vegetation season and even milder winters enable growing fruits previously exotic for our climate in Zakarpattia, such as figs, kiwis, and persimmons. On the other hand, agriculture needs drip irrigation systems, means of pest and disease control, due to the instability of usual varieties to new conditions. Sudden natural disasters also become a challenge for agriculture, as it significantly affects the harvest. For Zakarpattia, climate change may also become noticeable because of winemaking. For instance, Europeans were the first to experience climate change at the household level, because French wines, which were considered benchmarks for centuries, are rapidly changing their properties (quality) along with climate change (Adamenko, 2019).

Not only climate affects agriculture, but also vice versa. Manufacturing agricultural products leads to the emission of three types of greenhouse gases: carbon dioxide, methane and nitrogen oxide. Agriculture accounts for almost half of the global emissions of two types of the most powerful greenhouse gases after carbon dioxide: nitrogen oxide and methane. Nitrogen oxide is formed during microbiological and chemical transformations of organic matter, both in oxidation (nitrification) and reduction reactions (denitrification). The amount of emissions depends on the type of soil, humidity, temperature and tillage system. Methane is formed as a result of anaerobic processing of organic matter by microbes in the digestive tract of ruminants and other animals (intestinal fermentation), during storage of organic fertilisers, as well as during all transformation processes in conditions of lack of oxygen in the air.

Measures to adapt agriculture to climate change should encompass the following: 1) search for opportunities to produce and use renewable energy sources in the economy (heat and electricity generated with the help of wind, sun, biomass, biogas). This is especially important for livestock farms or farms that grow poultry. Accumulated livestock waste should become the basis of biomethane production; 2) cultivation of low-growing plants and plants that retain biogenic elements, so that after harvesting the soil does not remain bare; 3) cultivation of perennial herbs as part of crop rotation; 4) reduction of plowing, application of the system of zero tillage (No-Till) and other restorative agricultural practices; 5) giving preference to organic fertilizers (humus and compost); 6) prevention of water erosion; 7) cultivation of ground cover crops (radish, mustard), which clean the soil from nematodes, wireworms and pathogenic microorganisms, enrich the soil with a complex of useful substances and are antagonists of wheatgrass. They reduce soil erosion caused by heavy rains and floods, help to better retain moisture in the soil during drought; 8) giving preference to local varieties of crops that are less picky about the climate and more resistant to diseases. For example, in some European countries (Switzerland, the Czech Republic), farmers have returned to the cultivation of spelt – a less productive type of wheat, but which is a more stable crop in conditions of climate change. Small farms in Zakarpattia and Lviv oblast also grow spelt.

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Chapter 10.

DEVELOPMENT OF NATURAL AND TECHNOGENIC PROCESSES IN ZAKARPATTIA OBLAST

10.1. GEOLOGICAL AND GEOMORPHOLOGICAL EXOGENOUS AND TECHNOGENIC PROCESSES *(N.Kablak, M. Nychvyd, I. Kalynych)*

In recent decades, the Carpathian region has seen an increase in the number of environmental disasters. Territories with observed deformations of the earth's surface (geotectonic movements, landslides) are found in relatively densely populated areas, in industrial, agricultural, urban recreational areas, as well as in landscapes with different levels of nature protection. Any surface movements due to dangerous processes can destroy structures of various types on the earth's surface, threaten human life and property, and seriously affect environmental protection. Due to climate change, the Carpathian region is increasingly threatened by sudden and severe meteorological events (heavy precipitation, snowfall, landslides and mudslides), causing severe floods that threaten the population and the economy.

Exogenous Geological Processes (EGPs)

The territory of Zakarpattia oblast covers the mountainous part of the Ukrainian Carpathians (~70%), which is characterised by the highest dynamics of the geological environment, and the flat part of Zakarpattia Lowland. The most accurate correlation of the relief with the structural plan is observed in the Outer Carpathians, where the alternation of mountain ridges and basins, their heights, the nature of dissection and the direction of extension are associated with a series of covers that have a significant influence on the direction and structure of river valleys, which, in turn, form regional conditions for the development of landslides, mudslides and other dangerous engineering and geological processes [10]. Among all exogenous geological processes developing in the territory of Zakarpattia oblast, landslides are one of the most common (Table 10.1.1).

Table 10.1.1.

Distribution of EGPs in the territory of Zakarpattia oblast

Type of EGP	Distribution area, km ^{2}	Number of manifestations	Damage, %
Landslides	385,21	328	3,0
Karst (sediments capable of karstification)	2680,0	24*	21,0
Mudflow-prone watercourses	1822,0	276	14,3
Underflooding	1,0	4**	0,01
Lateral erosion	159,94	519	

* – karst phenomenon
** – settlement

Landslides on the territory of Zakarpattia oblast develop in Quaternary clay eluvial-deluvial deposits on river slopes and in the weathering crust of volcanic rocks. According to the type of displacement – these are landslides-flows and landslides-block slides. The main characteristics of landslides: absolute marks 409-471 m, longitudinal steepness, small dimensions: length 270-419 m, profile width 19,5 – 25,0 201-348 m, average capacity 6,7-16,0 m [7].

More than 20 types of geological processes of natural, natural-technogenic and technogenic origin, as well as the density of the network of rivers (0.8-1.6 km/km ^{2}), where often floods are formed and lateral erosion and a humid climate develop, significantly affect the occurrence of emergency situations. Underground water is the main destructive force of these processes. In particular, the level of underground water in Zakarpattia Lowland from the late 60s of the last century to the early 90s decreased by approximately 2 m, and since the mid-80s the average annual air temperature as well as the amount of total atmospheric precipitation have tended to increase, which is, to a certain degree, a result of climate change. Fig. 10.1.1 presents the classification of factors of the occurrence and development of landslide processes, highlights factors-conditions and factors-processes that determine various types of influence on the stability coefficient and mode of landslide slopes stability [9].

A total of 21 active landslides with a total area of 0.592841 km ^{2} were recorded on the territory of Zakarpattia oblast in 2020, of which 9 are newly formed (total area – 0.032500 km ^{2}), and 12 are activated partially or fully the previously mapped ancient or modern landslides (total area 0.560341 km ^{2}).

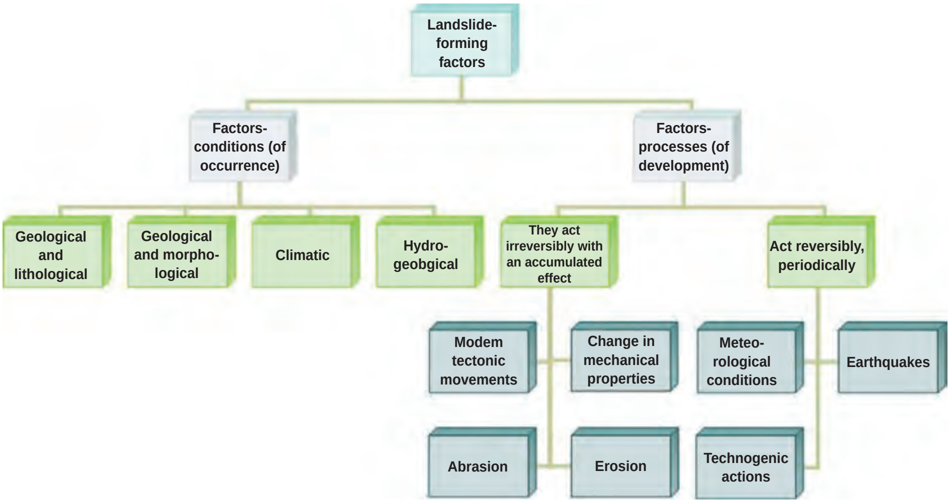

Fig.10.1.1. Classification of factors of occurrence and development of landslide processes

The activation of lateral erosion in 2020 was noted in the basins of the Chorna Tysa and Rika rivers, and to a lesser extent in the Teresva river basins in 20 areas, of which 12 were newly formed, and 8 were mapped in previous years. The length of individual newly formed areas of lateral erosion varies from the first tens of metres to 1.5 km, the total length of 12 newly formed areas is 3.7 km.

In total, in 2020, in the territory of the oblast, the descent of mudflows along 3 watercourses was recorded, the total area of whose basins is 16.13398 km^2.

The System of Monitoring the Geological Environment of Zakarpattia Oblast

Adverse climatic conditions led to the catastrophic activation of dangerous exogenous geological processes (DEGPs) in the autumn of 1998 – spring of 1999, spring of 2001, and summer of 2008.

One of the most dangerous within the Carpathian region is the territory of Zakarpattia oblast, where 3,288 landslides with an area of 385.21 km^2 were registered in 2021, which is 18% of the total area of landslides in Ukraine, as well as 24 karst sinkholes with a total area of 0.224 km^2, 519 sections of lateral erosion of watercourses with a total length of 159.94 km, 276 mudflow-prone watercourses with a total area of 1822 km^2 [6]. More than 900 residential buildings were in the dangerous zone of influence of exogenous geological processes (EGPs). In addition, there is a potential threat of destroying more than 1,750 residential buildings that are in the area of influence of the DEGPs.

The abnormal amount of atmospheric precipitation observed in Zakarpattia oblast in the spring and early summer of the current year led to the intensification of landslides in the territory of Rakhiv, Khust, Tyachiv and Uzhhorod administrative districts.

In particular, on June 28, 2020, in the village of Lopushne of Khust district, an ancient landslide became active over almost the entire site measuring 530×250 m (area 0.1234 km^2) as a result of overwetting of rocks on the slope after an intense downpour, which was preceded by almost daily rains in late spring and early summer.

The area of landslide activation covers almost the entire slope with an average steepness of about 22-25°, the lower and middle parts of which are mainly occupied by grass vegetation, and the upper part by young forest and shrubs. On the lower and middle parts of the slope, numerous glacier-like subordinate landslides were formed – flows ranging in size from 20×10 to 70×20 m with walls of detachment from the first tens of centimetres to 2.0–2.5 m in height. Higher up the slope on the body of the ancient landslide, numerous cleavage cracks with an extension of 5-10 cm and a vertical displacement of up to 20 cm were formed, which can be traced along the 50-70 m stretching. The thickness of the deformed rocks varies from 1-1.5 to 2.5-3.5 m, they are composed of deluvial-sliding clays and loams of the Quaternary age and sedimentary rocks (neogene flysch). Most of the landslide material of flowing consistency (including trees and bushes) moved to the foot of the slope, piling up the floodplain of the Branyshche stream, where 6 residential buildings are located. The thickness of the accumulated landslide material under the walls of buildings is from 0.2-0.3 to 2.5-3.0 m. One residential building was completely destroyed by the landslide material, other houses were damaged to one degree or another.

On the territory of the same settlement, 7 new small in size (from 30×20 to 170×100 m) and depth of laying (3-5 m) landslides with a total area of 0.0298 km^2, laid in deluvial-colluvial clays and loams of the Holocene, formed. The walls of 2 residential buildings were covered with landslide material, and 5 more buildings were in the hazardous zone of landslides.

In Tiachiv district on January 5, 2022, in the village of Nimetska Mokra, Maria Theresia Street and in the village of Tarasivka, Shevchenko Street due to waterlogging, a landslide occurred and hit the houses. And on December 17, 2022, a landslide took place on the mountain near the village of Pidplesha, Neresnytsia community of Tiachiv district. The landslide occurred as a result of prolonged rains.

In Rakhiv district, the activation of landslides was noted in the village of Yasinia and village of Lazeshchyna. The largest in terms of manifestation scale is the area of activation of the ancient landslide with a size of 830 × 250 m and an area of 0.1218 km^2, located in the urban-type village of Yasinia.

The landslide intensified on June 25, 2020, due to overwetting of the rocks on the slope after an abnormal amount of precipitation in the form of intense torrential rains. At the head of the landslide, a wall of detachment with a height of up to 20 m can be traced, near which a drainless depression of 20×15 m in size (depressed part of the landslide), filled with water, has formed. The thickness of the deformed rocks reaches 25-30 m, they are represented deluvially – by sliding clays and loams and sedimentary rocks (Paleogene flysch), the horizontal path of the landslide masses down the slope reaches 25-30 m. On the body of the landslide, there are numerous cleavage cracks, intermediate walls of detachment from 1.0 to 3.0 m high, with an extension of up to 0.5 m. 50 m higher up the slope from the main wall of detachment there were recorded numerous arch-shaped cleavage cracks and detachment walls with a height of 1.0 -1.5 m, up to 50-70 m long. In the tongue part (place of confluence of two temporary watercourses) and on both sides of the landslide, extrusion shafts with a height from the first tens of centimeters to 3.0-4.0 m were formed. Directly on the landslide body, down the slope from the main detachment wall, there are two residential buildings that have moved down the slope for a distance of about 30 m. The buildings are significantly damaged and are not suitable for living. In the area affected by the landslide, at a distance of 30 to 120 m from the side parts of the active landslide, there are 5 residential buildings that are not damaged. At the time of examining, there was no threat of their destruction due to the landslide process. Thus, on June 26, 2020, a powerful landslide occurred in the tract of Robsha, Yasinia settlement, Rakhiv district. Cracks appeared in the house, which divided it in two halves. The landslide was due to overwetting of the soil.

On December 18, 2022, in Rakhiv district near the Kuzii tract a slide of soil and stones over a retaining wall occurred on the road of state importance H-09 Mukachevo – Rakhiv – Ivano-Frankivsk – Lviv. Soil masses partly made it difficult to move on the roadway.

In addition, 11 more active landslides measuring from 30×20 to 170×100 m with a total area of 0,193120 km^2 have been mapped on the territory of Rakhiv district, of which 2 are newly formed (total area of 0,002700 km^2), and 9 are ancient ones mapped in previous years or modern years (total area 0,19042 km^2). There are seven damaged residential buildings in the area affected by the landslides, and one of them is uninhabitable. The roadside of the Mukachevo-Rohatyn highway was covered with landslide material at a distance of about 50 m, there is a threat of destroying the support of the railway bridge.

Activation of the landslide process was also noted in the village Novoselytsia, Uzhhorod district, where in 2008 a 40 × 80 m landslide formed. In the following years, the landslide temporarily stabilized, and in the spring of the current year, it became more active on a much larger area (0.114828 km^2). The edges of the village road was partially blocked by the landslide tongue up to 5 m high. Directly on the body of the landslide, in its tongue part, there are 10 residential buildings that are damaged to one degree or another (despite the fact that most of the buildings have been repaired, their walls and foundations have through cracks ranging from hair cracks to cracks 1,5-2,5 cm wide).

A new landslide occurred on January 19, 2023 in the village of Abranka, 20 km from Volovets. As a result of the landslide, two buildings were destroyed.

A total of 21 active landslides with a total area of 0,592841 km^2 were recorded in the oblast this year, of which 9 are newly formed (total area of 0,032500 km^2), and 12 are activated partially or fully, previously mapped ancient or modern landslides (total area of 0,560341 km^2).

The activation of *lateral erosion* in 2020 was noted in the basins of the Chorna Tysa and Rika rivers, and to a lesser extent in the Teresva river basins in 20 areas, of which 12 were newly formed, and 8 were mapped in previous years. The length of individual newly formed areas of lateral erosion varies from the first tens of meters to 1.5 km, the total length of 12 newly formed areas is 3.7 km. In the areas of lateral erosion, which were mapped in previous years, only the erosion width increased, while their total length remained unchanged (2,405 km). The total length of the areas of activation of lateral erosion is 6.105 km.

The bank fortifications were destroyed by the lateral erosion of watercourses, auto and communal roads were washed away along the distance from the first dozens to 250 m in the villages of Lopushne (Fig. 10.1.2), Svoboda and Synevyrska Poliana of Khust district, as well as the urban-type village of Yasinia and villages of Bilyn, Kvasy and Lazeshchyna of Rakhiv district. In Tiachiv district, there are no economic facilities in the zone affected by lateral erosion.

As of January 1, 2021, 531 areas of lateral erosion of watercourses with a total length of 163.64 km (159.94 km + 3.7 km) have been recorded in the territory of Zakarpattia oblast.

Mud-and-stone landslides and debris flows in the territory of the oblast were recorded in 2020 in the basins of the Rika and Teresva rivers in Khust and Tiachiv administrative districts. In the basin of the Rika river, debris flows came down near the village Pidchumal and in the village Lopushne of Khust district as a result of the downpour that occurred on June 28, 2020 (Fig. 10.1.2). In the first case, the debris material covered the surface of the Khust–Mizhhiria highway along the distance of about 30 m, and in the second case – the private plots of 4 households.

Fig. 10.1.2. Road in Lopushne village, destroyed by the lateral erosion

Such factors as lithological-stratigraphic, engineering-geological, geomorphological, tectonic, landscape, meteorological, technogenic factors influence mudflow formation. The analysis of the data based on the long-term monitoring of EGPs shows that, all other things being equal, the main reason for their massive activation is the climatic factor, primarily the increased amount of rain precipitation and rapid snowmelt, which leads to overwetting of the soil and the occurrence of floods [5]. Heavy rains that occurred in the spring and early summer of 2020 led to the local activation of EGPs in the territory of Khust, Rakhiv, Tiachiv, and Uzhhorod administrative districts of Zakarpattia oblast. In summer and autumn, the intensity of precipitation practically did not differ or was less than the statistical average for a long period. Activation of EGPs was not noted against this background.

In the basin of the Teresva river, the mudflow descended along the right unnamed tributary of the Mokrianka river after a downpour at the end of June of the current year (the exact date has not been established) and was discharged in the floodplain of the latter. There are no economic facilities in the area affected by the mud. The volume of debris carried along each of the mudflow-prone streams does not exceed the first thousands of cubic meters. In total, on the territory of the oblast in the current year, the descent of mudflows along 3 watercourses, the total area of whose basins is 16,13398 km^2, was recorded. Mudflows descended along two watercourses for the first time (total basin area 6,178794 km^2), and along one watercourse – also during the flood of 2001 (basin area 7,498798 km^2).

Thus, as of January 1, 2021 there were recorded 278 mudflow-prone watercourses in the territory of Zakarpattia oblast, the total area of whose basins is 1,828 km^2 (1,822 km^2 + 6 km^2).

On January 5, 2022, in the territory of Zakarpattia oblast, two mudflows descended on the road of regional significance P21 in the village of Nizhniy Bystryi of Khust district and on the highway of national importance H09 in the town of Rakhiv.

It should be noted that the data related to monitoring the spread and development of EGPs in the studied territory may be far from the real ones due to insufficient funding of the works.

Thus, the object-specific plan of the State Enterprise "Zakhidukrekolohiia" for the year of 2020 envisages the financing of works related to the object in the amount of UAH 150,0 thousand, while for the implementation of the geological task, the project implies the carrying out of a complex of field and laboratory works in the amount of about UAH 1445,0 thousand with subordinate works or UAH 1434,0 thousand – without the latter.

In view of the data obtained as a result of the study of the regime of EGPs at the observation points of the 1st category, it can be concluded that after the last massive activation of EGPs associated with the natural disaster on July 23-27, 2008, a temporary stabilisation of the process is observed. This trend is explained by relatively low amounts of atmospheric precipitation during these years.

A graphic image of landslides and mudflows in Zakarpattia is shown in Fig. 10.1.3.

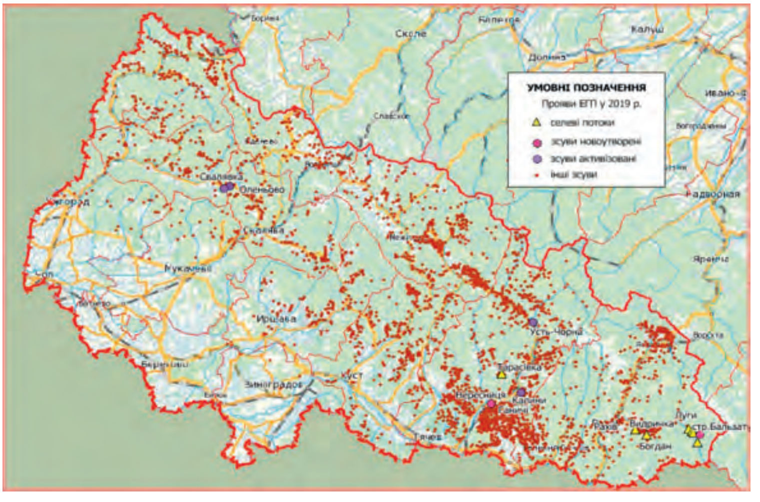

Fig. 10.1.3. Activization of landslides and mudflows on the territory of Zakarpattia oblast

The results of monitoring EGPs in Zakarpattia oblast for the period of 2020 are provided in the tables below (Tables 10.1.2.-10.1.4.).

Table 10.1.2.

The monitoring of landslide processes on the territory of Zakarpattia oblast

Total number of landslides in 2020	Area of landslides, km²	Number of the active ones	Area of active landslides, km²	Number of the active ones since 2019	Number of the newly formed ones in 2020	Number of landslides, identified within the period prior to studying the territory	In built-up areas				Number of household facilities in the zone of landslides
							Total number of land slides	Area of landslides, km²	Number of active landslides	Area of active landslides, km²	
3297	**385,803**	**21**	**0,593**	**12**	**9**	**0**	**0**	**0**	**21**	**0,593**	**37**

Table 10.1.3

The monitoring of karst processes in the territory of Zakarpattia oblast

Total number of karst manifestations in 2020	Number of surface karst manifestations (sinkholes) among them	Area of surface karst manifestations, km²
24	24	0,224

Table 10.1.4

The Monitoring of mudflows in the territory of Zakarpattia oblast

Number of mudflow hazardous watercourses in 2020	Area of mudflow- hazardous watercourses, km²	Number of mudflow forming loci	Total area of mudflow forming loci, km²	Mudflow-hazardous watercourse				Mudflow-hazardous basin			Number of household facilities in the zone of descending a mudflow
				Name of a watercourse	Date of a mudflow descent	Volume of the washed away material, m³	Number of cases of mudflow descents for the whole period of observations in 2020.	Name of the basin	Number of cases of mudflow descents	Number of cases of mudflow descents for the whole period of of observations	
3	16,13398	3	–	Unna med	06.2020	7500	1	Tysa	3	4	5
				Unna med	28.06.2020	1745	1				
				Vilkish ovyi	28.06.2020	750	1				

The sign “–” means that the source of the solid component of mudflows were loose sediments of the Quaternary age, accumulated on the bottoms of mudflow-prone watercourses, the exact distribution area of which is practically impossible to determine.

Technogenic processes under the influence of human activity within Zakarpattia oblast

According to the State Geological Service, more than 26,000 surface and underground karst manifestations have been recorded within the territory of Ukraine [2]. In the areas of mining operations and intensive technogenic load, the development of technogenic karst continues, sometimes with catastrophic manifestations of the process. This process has intensively developed in areas of salt minerals extraction (Solotvyno, Kalush, Novokarfahen, etc. deposits) within Zakarpattia, Ivano-Frankivsk, Lviv and Donetsk oblasts.

The Solotvyno rock salt deposit is located in the southeastern part of Tiachiv district of Zakarpattia oblast and is confined to the Upper Tysa (Solotvyno) depression of the Zakarpattia trough. The near-surface occurrence of rock salt formed as a result of post-sedimentation halokinesis – pressure on the salt rocks of the terrigenous strata that lie above, their transition to a plastic-flowing state and extrusion in the near-surface section area. Therewith he movement of plastic-flowing salt masses took place from the area of increased geostatic pressure to the area of its reduced values.

From the point of view of tectonics, the Solotvyno deposit is the stock of a salt diapir structure. Beneath the Quaternary sediments, the stock has a pear-shaped plan with a length of 1880 m and a width of 760 m. The long axis is oriented in the direction northwest – southeast. The salt stock has an asymmetric structure. The southwestern wing is steep (60–80°), and the northeastern one is gentler (up to 60°) [3].

From the point of view of geomorphology, the Solotvyno deposit lies within the wide valley of the Tysa river, in its right-bank part, in the areas of the spread of the second and partly the first terraces above the floodplain (Zaton area – old flooded mines, where salt lakes are located).

The deposit is located within the humid climate zone, where the amount of precipitation almost doubles the amount of evaporated moisture. The average annual rainfall is 873 mm, of which 45% falls in May-August, with a recorded maximum of 294 mm. Atmospheric water infiltration occurs in Quaternary sediments with flow into the lateral host rocks and up to the level of the salt mirror [4].

According to the archival data, the Solotvyno deposit has been developed underground for more than 245 years. Industrial development of the Solotvyno rock salt deposit began in 1778. During the development, 9 mines were built and exploited. The hydrodynamic equilibrium established in natural conditions at the Solotvyno deposit was disturbed at the end of the 18th – in the second half of the 20th century, when the construction of deeper mines began, compared to those that existed here in the Middle Ages. These are mines «Khrystyna» (1778), «Albert» (1781), «Kunihunda»

(1789 p.), «Mykolai» (1798), «Old Ludwig» – mine № 7 (1808), mine № 8 (1886) and mine № 9 (1975). The underground workings of the old mines that passed close to the surface became the places of penetration of suprasalt waters into the salt-bearing stratum. Today, all mines, except mine No. 9, are flooded. In mine No. 9, the brine level is maintained at the 60 m mark in conditions of the partially filled mine shaft [11].

All seven old mines were previously closed for economic and technical (emergency) reasons, and until recently their condition was defined as ecologically balanced, as they were timely conserved by backfilling or flooding (natural, artificial or combined).

The central part of the salt massif, in which the submerged workings of mine No. 7 are located, became the place where destructive processes developed. Mines No. 8 and No. 9 operated the longest. Allergological hospitals functioned in the workings of the salt mines, in mine No. 8 – the Oblast Allergological Hospital, in mine No. 9 – the Ukrainian Allergological Hospital. In fact, the development of an ecologically dangerous situation is connected with the activity of mines No. 8 and No. 9 [1].

The salt extraction at the State Enterprise «Solotvynskyi Solerudnyk» (the Solotvyno Rock Salt Mine) ceased at the beginning of 2007. In 2009, the enterprise stopped pumping mine water into the surface reservoirs. The working horizons of the salt mine and the underground departments of the oblast and the Ukrainian Allergological Hospitals were flooded. The territory of the Solotvyno Rock Salt Mine was declared an emergency zone in 2010. At the same time, the Expert Commission recognized the situation at the Solotvyno rock salt mine as an extraordinary state one.

The lack of funding for emergency repair works and technical re-equipment led to the destruction of the entire property complex, the activation of karst processes both on the territory of the enterprise and outside of it.

The ensuring of the movement of aggressive waters and the removal of saturated brines were the prerequisite for forming a large-scale karst. This role was played by the extensive drainage system, which was created in several levels in the salt massif itself to ensure the possibility of conducting mining works. However, frequent falls were recorded in tunnels and pits, blocking the water. Due to underfunding the Solotvyno salt mine, these falls were not eliminated in time. Artificial dams formed, which created the support of suprasalt waters and accelerated their infiltration into the salt massif in weakened zones, primarily in the area of Chornyi Mochar. This led to the catastrophic consequences that can be observed in the mine field today. Violation of the natural regime of suprasalt waters established in geological time led to the intensification of the dissolution of salts. The presence of an extensive system of drainage workings at the base of the Quaternary deposits and in the upper part of the salt body created zones of underground relief. This also expanded the zone of active water exchange to the zone of easily soluble rock salt and became the main reason for the intensive use of the territory. The flooding of mines No. 7 (Fig. 10.1.4) and No. 8 (Fig. 10.1.5) led to the appearance of new karst stream formations, the destruction of the waterproof cover (canopy) and the formation of sinkholes through which atmospheric water flows. The technogenically activated karst within the Solotvyno deposit has caused fundamental changes in the topography of the earth's surface, an increase in the runoff coefficient, changes in places of supplying and discharging groundwater.

Fig. 10.1.4. Pictures of some sinkholes in the Solotvyno salt mining area (photo by Ivan Prodanets). Flooded mine No. 7 (aerial photography materials as of 2020 was executed using the UAV – Tarot 680PRO Hexacopter)

In 2016, in order to assess the situation on the territory of the mines of the «Solotvynskyi Solerudnyk» enterprise, the European Union Civil Protection Team (EUCPT) Advisory Mission operated there. The mission's activities were implemented with the support of the Ministerial Commissariat for the EU Strategy for the Danube Region, the Ministry of Foreign Economy and Foreign Affairs of Hungary, the Ministry of Foreign Affairs of Ukraine, the Representation of Ukraine to the EU, the Zakarpattia Oblast Council and the Zakarpattia Oblast State Administration. The experts prepared materials for the Advisory Mission, which aimed to contribute to the establishment of a concrete plan of action to resolve the issue of the emergency situation.

Fig. 10.1.5. Pictures of some sinkholes in the Solotvyno rock salt mine (photo by Ivan Prodanets). Mine № 8 (aerial photography as of 2020 was executed using UAV – Tarot 680PRO Hexacopter

In addition, the rapid development of the salt karst prompted a number of neighbouring countries of the natural disaster zone – Hungary and Romania – to participate in joint planning of potential solutions to the problem. In 2015, the Ministry of Foreign Affairs of Ukraine, on the initiative of a number of state structures (the State Service for Emergency Situations, the Ministry of Agrarian Policy and Food of Ukraine, the Ministry of Ecology and Natural Resources, the Zakarpattia State Oblast Administration, the UN FAO, etc.) and Hungarian government and state organisations initiated an appeal to the EU regarding the involvement of an expert mission of the European Union to Ukraine to assess the threats and risks of the state-level emergency situation that has developed on the territory of the «Solotvynskyi Solerudnyk» State Enterprise.

The given data testify to the current critical and catastrophic state of the geological environment within the Solotvyno rock salt deposit, which is primarily related to the intensive development of salt karst in recent years. Violation of the natural regime of suprasalt waters, stable over geological time, led to the activation of salt dissolution. The presence of an extensive system of drainage workings at the base of the Quaternary sediments and in the upper part of the salt body became the main cause of intensive karstification of the territory.

In order to determine the dynamics of landslides and karst in the urban-type village of Solotvyno, aerial photography works were carried out in two stages: in the spring of 2020 and in the autumn of 2021. Based on the results of the aerial photography, there were created orthophoto maps and three-dimensional digital terrain models for predicting karsts and displacements (Fig. 10.1.6-10.1.8) [8].

Fig. 10.1.6. 3D karst scheme (Karst 1: mine №7)

Fig. 10.1.7. 3D karst scheme (Karst 2: Chornyi Mochar)

Fig. 10.1.8. 3D karst scheme (Karst 3: mine №8)

On the basis of the created cartographic materials, a study of karst manifestations on the territory of the urban-type village Solotvyno was carried out, with the comparison of the impact of destructive processes for the period of 2010-2021. Summarizing the fulfilled calculations, it can be emphasized that the processes of increasing the size of karst sinkholes are not linear in nature. The areas of the sinkholes at the site of mines No. 7 and No. 8 as of 2021 are 4,5518 hectares and 4,3711 hectares, respectively. The formed Chornyi Mochar lake has an area of 2.1487 hectares. This indicates the continued influence of ground water on salt deposits [8].

The current situation at the state enterprise the «Solotvynskyi Solerudnyk» is critical and requires the attention of the state in order to regulate negative phenomena, the development of which threatens the life and health of the residents of the urban-type village of Solotvyno. The existence of the research base on the subject of the issue indicates that endogenous processes continue to spread beyond the former mining area. It is necessary to carry out regular monitoring missions to track the dynamics of the development of destructive phenomena on the territory of the village. Admittedly, in accordance with the National Program No. 3 «Restoration of Clean and Safe Environment», measures for the ecological restoration of the Solotvyno Salt Mines are planned for 2026-2032.

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10.2. DANGEROUS AND SPONTANEOUS METEOROLOGICAL PHENOMENA *(R. Ozymko, M. Karabiniuk)*

Over time, the interaction between man and the forces of nature has not lost its significance, and to some extent, on the contrary, it has gained even greater scope. One frequently comes across information about terrible destruction of buildings, hydraulic structures, flooding of territories, damage to property and even human casualties. Dangerous and spontaneous meteorological phenomena belong to such destructive forces of nature. They are atmospheric phenomena by their nature that rapidly develop in space and time, which complicates their predictability. These phenomena cause great damage to various sectors of the economy of any country, disrupting its development. Total losses from them can reach tens or even hundreds of millions of hryvnias per year. Very often, such phenomena are observed in combination with other dangerous or natural phenomena, which increases their negative impact. For example, heavy rains are accompanied by thunderstorms, hail, and gusty winds; heavy snowfalls – by blizzards, sleet snow, strong wind, etc.

In the history of the hydrometeorological service of Ukraine, the criteria for dangerous and spontaneous phenomena have changed many times. New criteria for dangerous and spontaneous meteorological phenomena, adopted by the Ukrainian Hydrometeorological Center in 2019, are in effect today. Therefore, according to the new standards, the following definitions and concepts are applied (Regulations..., 2019):

1. *Dangerous meteorological phenomena of the 1st level of danger (DMP I)* – «weather phenomena that, based on quantitative indicators, duration and territory of distribution, create certain inconveniences for the population and the functioning of the economic complex of the country».

2. *Spontaneous meteorological phenomena of the 2nd level of danger (SMP II)* – «these are natural phenomena that, based on quantitative indicators, duration and territory of distribution, pose a threat to the population and disrupt the functioning of the country's economic complex».

3. *Spontaneous meteorological phenomena of the 2nd level of danger (SMP III)* – «these are natural phenomena that, based on quantitative indicators, duration and territory of distribution, pose a threat to people's

lives in large areas, lead to large-scale damage to the country's economic complex, and harm the environment».

The territory of Zakarpattia Region is characterised, in general, by a relatively favorable climate for the life and activities of the population. However, the natural-geographic features of the territory and the specifics of atmospheric circulation cause, compared to the flat part of Ukraine, a significant development of various modern dangerous and spontaneous meteorological phenomena and processes. The most dangerous and most common processes include significant, heavy and extreme precipitations (Spontaneous Meteorological..., 2006; Report on..., 2013; Semerhei-Chumachenko, Ozymko, 2019; Ozymko, 2020; Karabiniuk, Markanych, 2020), the criteria of which are given in Table 10.2.1.

We will focus our attention on atmospheric precipitations that meet the criteria of SMP II and SMP III, as those that have the most negative impact on the surrounding natural environment and human activities. Further, the characteristics of the spatio-temporal distribution of heavy and extreme precipitations in Zakarpattia Region during a typical climatological period (1990-2019) are presented.

Table 10.2.1.

Types of atmospheric precipitation according to the criteria DMP I, SMP II and SMP III (Regulations..., 2019)

Name of a phenomena	Criteria for DMP I (colour marking – yellow)		Criteria for SMP II (colour marking – orange)		Criteria for SMP III (colour marking – red)	
	quantitative indicator	duration	quantitative indicator	duration	quantitative	duration
Snow	significant snowfall 7-19 mm	≤ 12 hours	heavy snow 20-29 mm	≤ 12 hours	extreme snowfall ≥ 30 mm	≤ 12 hours
Wet snow	significant wet snowfall 15-49 mm	≤ 12 hours	heavy wet snowfall 50-79 mm	≤ 12 hours	extreme wet snowfall ≥ 80 mm	≤ 12 hours
Rain	significant rainfall 15-49 mm	≤ 12 hours	heavy rainfall 50-79 mm	≤ 12 hours	extreme rainfall ≥ 80 mm	≤ 12 hours
Rain in mudflow-prone areas	significant snow 15-29 mm	≤ 12 hours	heavy rainfall 30-49 mm	≤ 12 hours	extreme rainfall ≥ 50 mm	≤ 12 hours

Downpour	-	-	heavy downpours 30-49 mm	≤ 1 hour	extreme downpours ≥ 50 mm	≤ 1 hour
Prolonged rains	-	-	heavy prolonged rainfall 100-149 mm	> 12 hours ≤ 48 hours	extremely prolonged rainfall ≥ 150 mm	> 12 hours ≤ 48 hours

From January 1, 1990 to December 31, 2019, 33 stationary hydrometeorological observation points in Zakarpattia Region recorded a total of 3,104 individual cases of rainfall, wet snowfall, and snowfall of the SMP II and SMP III criteria, the long-term dynamics of which are presented in Fig. 10.2.1 (Ozymko, 2020). The figure shows considerable variation in the number of SMP between different and even consecutive years. The biggest difference is noted between 2000 and 2001 (157 individual cases), and the largest amplitudes of fluctuations are observed between the first (1990-1999) and second (2000-2009) decades. During the studied period, the maximum recurrence rate of SMP occurred in 1998 (222 individual cases), and the minimum – in 1990 (36 individual cases). In this way, the absolute amplitude of the multiannual course of the recurrence of SMP was 186 individual cases within 30 years.

On average, there are observed 103 individual cases of rainfall according to the criteria of the SMP, which is a high indicator and can be tentatively considered the average annual climatological norm in the territory of Zakarpattia Region. In Fig. 10.2.1 the trend of an increase in the recurrence of spontaneous precipitation for 1990-2019 was identified. If this trend continues, in the future, we should expect an increase in the number of SMP cases. Sharp interannual fluctuations in the recurrence of spontaneous meteorological phenomena can negatively affect their timely forecasting and adaptation to the consequences (Semerhei-Chumachenko, Ozymko, 2019).

Analysis of the distribution curve of multiannual variability of heavy and extreme precipitations (refer to Figure 10.2.1) reveals certain rhythms in recurrence, and given the multiannual period of the research – certain cycles. Rhythms are repetitions of certain atmospheric (or natural) processes or fluctuations in their intensity, as well as the associated fluctuations in the values of meteorological elements that are not strictly periodic in nature: the amplitude of fluctuations during rhythms is not constant, and the intervals between the occurrence of the phenomenon or between extreme values are not rigidly equal. Rhythms with large (multiannual) time intervals between repetitions of the process or extreme values of its intensity or between extreme values of the element are called cycles (International Meteorological..., 1992). The rhythmicity is traced regarding the recurrence maxima in 1992, 1995, 1998, 2001, 2004 (2005), 2007 (2008), 2010 and 2016 (2017). Thus, 3-year cycles of recurrence of heavy and extreme precipitations are quite clearly distinguished. The only exception is the period from 2011 to 2015. Of course, in quantitative terms, peaks of recurrence did not always coincide, but were above the average annual value.

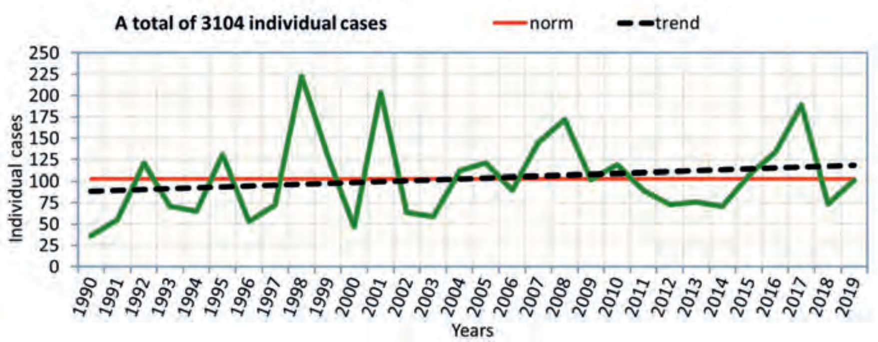

Fig. 10.2.1. Multiannual dynamics of individual cases of heavy and extreme precipitations in Zakarpattia Region (Ozymko, 2020)

In Fig. 10.2.2 the dynamics of heavy and extreme precipitation in view of the seasons is presented, which makes it possible to highlight interseasonal fluctuations and changes in the recurrence of precipitations that have met the criteria of SMP. Over the last three decades (1990-2019), there has been a sharp increase in individual cases of heavy and extreme precipitations in winter, as evidenced by the clear trend and rising amplitude of fluctuations. Admittedly, in the winter of 1991 and 1997, there was no individual case of heavy or extreme precipitation, and the maximum recurrence occurred in 2017 – 83 individual cases. It is obvious that it is at this time of the year that we should expect an intensive increase in the frequency of precipitations according to the criteria of the SMP and, respectively, a complication of weather conditions (Ozymko, 2020).

In the spring, the trend is almost steady, so the interannual amplitude of variation in the number of individual cases is more or less smoothed out relative to the average value (19 individual cases), although significant differences were recorded in some years with a maximum in 2001 – 92 individual cases and a minimum in 2012 – 1 individual case. In the summer, there is a slight positive trend in the frequency of individual cases. Two maxima stand out: 1998 (93 individual cases) and 2008 (112 individual cases). A third (997 individual cases) of all heavy and extreme precipitation was observed in the summer, which is associated with a significant number of heavy rains. The average annual recurrence of heavy and extreme precipitation is 33 individual cases. A slight negative trend in the recurrence of cases was observed only in autumn. Just as in summer, two peaks stand out: in 1992 (89) and in 1998 (109 individual cases). On average, 29 individual cases of heavy and extreme precipitation were recorded in autumn (Ozymko, 2020).

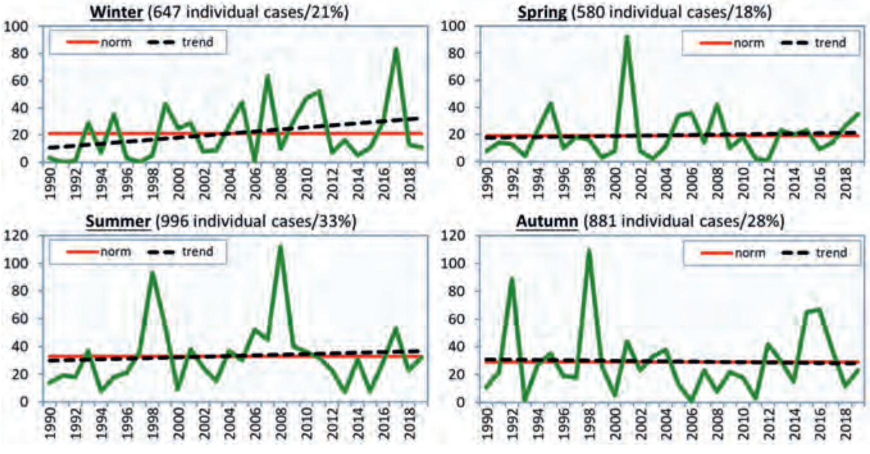

Fig. 10.2.2. Seasonal recurrence of individual cases of heavy and extreme precipitation in Zakarpattia Region (abscissa axis – years, ordinate axis – number of individual cases) (Ozymko, 2020)

Of all the seasons, only in winter there were years when heavy or extraordinary precipitation was not recorded. A sharp increase in the recurrence of individual cases of precipitation of the SMP criteria in winter is explained by an increase in air temperature in the cold period of the year, which led to a change in the structure of precipitation In Zakarpattia Region, there is a tendency of increasing the recurrence of days with rain and decreasing the number of days with snow, especially in winter, which has significantly intensified since the early 21st century (Balabukh, 2008; Balabukh, Lukianets, 2015). It can also be explained by more rapid climatic changes in this season of the year, among which there may be mentioned the restructuring of circulation mechanisms in the atmosphere. Significant interannual fluctuations in recurrence of heavy and extreme precipitation with a maximum difference of 80-90 individual cases prove the difficulty of making long-term weather forecasts and climate forecasts for the territory of Zakarpattia Region.

Recurrence cycles are also distinguished in terms of seasons (refer to Fig. 10.2.2). In winter, a 6-year cycle of recurrence maxima is clearly observed 1993 (29), 1999 p. (43), 2005 (44), 2011 (52) and 2017 (83 individual cases), which increases gradually. In spring, less clear 6-year cycles of recurrence maxima are observed in 1995 (43), 2001 (92), 2008 (42), 2013

(23) and 2019 (35 single cases). In summer, 10-year cycles of recurrence of maxima are distinguished in 1998 (93), 2008 (112) and 2017 (54 individual cases). In the autumn, unclear 6-year cycles of recurrence of maxima of fixed individual cases of SMP are observed in 1992 (89), 1998 (109), 2004 (38), 2012 (42) and 2016 (67 individual cases).

Hence, in Zakarpattia Region, in all seasons of the year, there is significant interannual variability in the recurrence of individual cases of heavy and extreme precipitation. The most noticeable changes in recurrence were recorded in winter and summer.

As can immediately be seen from Fig. 10.2.3, the major part accounts for heavy and extreme rainfalls (81%/2526 individual cases), much less – for snowfalls (11%/333 individual cases) and wet snowfalls – (8%/245 individual cases). The differentiation of the phase state of heavy precipitation (SMP II) practically corresponds to the general picture of the ratio. However, when comparing extreme precipitation (SMP III), twice as much volume accounts for wet snowfalls (16%/74 individual cases), a little less for snowfall (12%/58 individual cases) and, certainly, the major part of it – on rains (72%/333 individual cases). Such a considerable unequal distribution of precipitation phases is due to the climatic features of Zakarpattia oblast and the predominance of synoptic processes characteristic of the warm half-year, during which even in the cold period of the year it rains quite often (Ozymko, 2020).

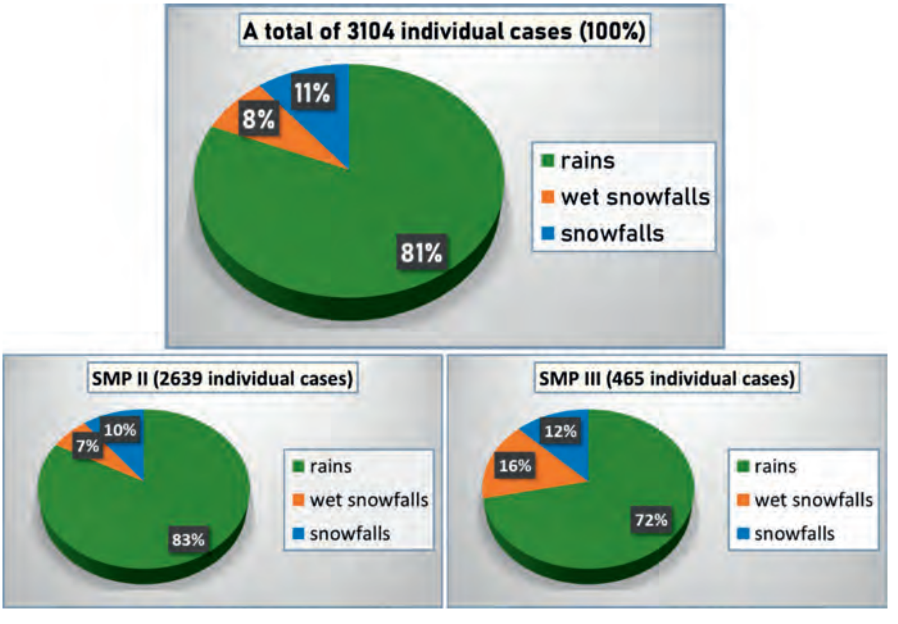

Fig. 10.2.3. The ratio of heavy and extreme precipitations in Zakarpattia Region by different phases during the period of 1990-2019 (Ozymko, 2020)

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Chapter 11.

ENVIRONMENTAL EDUCATION

11.1. FEATURES AND PLACE OF ENVIRONMENTAL EDUCATION IN OUR LIFE *(M. Vakerych, Ya. Hasynets, V. Mirutenko, M. Balazh, H. Popovych, A. Hiutler)*

The ecological situation on the planet stimulates the rapid restructuring of the thinking of world society, the formation of environmental consciousness and environmental culture. In this regard, environmental education and environmental awareness-raising activities are becoming a new priority area in education. The experience of the countries of the European Union shows that based on the principles of the country's environmental policy, a high level of environmental culture and an active position of society in nature conservation activities, it is possible to improve the state of the environment [4]. However, a high level of environmental culture is impossible without an appropriate level of environmental education, which must be provided on the basis of complexity and continuity. Increasing the level of society's education based on the integration of knowledge and modernization of the entire educational space with elements of sustainable development of society is urgent. In the countries of Western Europe and Japan, systematic environmental education begins from early childhood.

Modern environmental education is a systemic component of the national education system, which functions on the basis of the current legislation on education and the National Education Development Strategy of Ukraine for the period until 2021. The focus of modern environmental education lies in harmonizing the interaction of society and nature, solving issues of environment and sustainable development of society. The goals and objectives of environmental education are determined in view of the goals and objectives of the national environmental policy.

Environmental education today is a continuous complex process of forming an environmental outlook, environmental consciousness and culture of the entire society as a whole. Its foundation consists in the acquisition of a system of knowledge about the laws of functioning, vital activity and interaction of all living beings, the role of man in preserving the environment; the process of environmental education and environmental awareness training, development of professional knowledge, skills necessary for nature protection activities [5].

In the conditions of the transition to the «New Ukrainian School», special attention is devoted to environmental education of pupils, which is expressed in one of the key competencies «Environmental Literacy and Healthy Life». In the process of acquiring this competence, the learner must be able to use natural resources wisely and rationally within the framework of sustainable development, be aware of the role of the environment for human life and health, and must develop the ability and desire to follow a healthy lifestyle [2].

In the system of continuous education, preschool education is the first step. Here preschoolers form and consolidate hygienic habits, develop the simplest practical skills, and become aware of elementary environmental issues. The key element of the system of continuous environmental education and awareness-raising activities is obviously the comprehensive school.

In primary school classes, knowledge about the surrounding natural and social environment, acquired by schoolchildren in the family circle and preschool institutions, is consolidated and developed. Attention is paid to this in such a school subject as «I Explore the World» with the involvement of tasks on environment, games, as well as some types of practical communication with nature. At this age, the foundations of environmental culture, a holistic view of nature are laid, a scientific and conservation attitude towards the natural environment is formed, the need for its protection is realized, the norms of behavior in the environment and the skills of carrying elementary environmentally competent actions are learned. This also happens within the lessons of the Native Language, Fine Arts, Music, Labor Education, etc., where this aspect reveals natural history material in a new way, enriches and helps to develop communication skills with natural objects.

Currently, in secondary school it is through subjects «Biology» and «The Fundamentals of Health» that issues of environmental education are dwelled upon. Although new integrated courses «Getting to Know Nature», «Natural Sciences», «Environment» «Health, Safety and Well-being» are appearing in the conditions of the «New Ukrainian School», on which the main «burden» of responsibility of educating an environmentally conscious person will fall. During them «environmentalized» moral values are developed, accessible for perception of teenagers. The purpose of educating children of this age (11-14 years) is to form a positive attitude towards the environment. This also happens in the lessons of Geography, Literature, and Physics.

In senior classes, when studying such integrated courses within the framework of the «New Ukrainian School» as «Health and Environment», «Biosphere and Man», «Fundamentals of Ecology», «Human Ecology», «Nature and Culture», «Environmental Protection», the schoolers' moral orientation is consolidated and improved in their relationship with nature. Here the foundations of a dialectical understanding of the unity of nature and society are laid, yet nature protection is considered as part of the general and generally accepted human culture. At this stage, a modern worldview is formed, which is built on integrative knowledge about the surrounding world and is manifested in a responsible attitude based on the conviction of the need to protect the natural environment. The role of environmental practices is important.

Leading experts in school pedagogy are of the opinion that the teacher responsible for environmental education of pupils should always be aware of the super-task: the competence of the school graduate should correspond to the latest scientific achievements, which are closely correlated with environmental culture, with its humanistically integrated economic, legal, moral, aesthetic and practical attitude of man to nature.

It is important that school graduates enter adulthood with stable values of a careful attitude towards the environment. At the same time, the emphasis is put on understanding that their activity is indeed connected not only with the personal well-being and the well-being of their loved ones, but also with the whole of humanity.

The level of development of modern education in general and environmental education in particular depends on the introduction of new original and innovative methods and techniques of teaching and upbringing. This includes the widespread and continuous computerization of environmental education in schools. It is also necessary to proceed with the introduction of extracurricular activities, for example, «environmental summer camps» or starting with project lessons such as «Forest is my friend», «Nature and Art», etc. in primary school [1].

Environmental education is an organic and priority part of the entire education system, which gives it a new quality, which forms a different attitude not only to nature, but also to society and man.

Environmentalization of education means the formation of a new worldview and a new approach to activity based on the formation of noospheric humanitarian and ecological values [3].

Appropriate school education and upbringing, their modernity and advancement depend primarily on the orientation and quality of the teacher's professional training. Admittedly, the formation of a proper attitude towards the surrounding world is primarily connected with imitating those patterns and attitudes that are characteristic of people from the child's immediate environment. Parents, as well as teachers, provide the child with the first example of morality.

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11.2. SCIENTIFIC EDUCATION OF ENVIRONMENTAL ISSUES
(Ivana Slepakova)

The main intention of science education is to improve student's scientific literacy through activities that involve planning, measuring, analysing data, designing and evaluating procedures, systematic documentation and interpretation of results. Examples of such activities are those that allow pupils to engage in their own inquiry and discovery of science.

In the diagram (Figure 11.2.1), created by linking the Llewellyn (2009) research cycle and Wenning (2005) stages of research, is shown how the inquiry cycle is related to the stages of inquiry. In normal practical activities where the IBSE (inquiry based science education) method is not used, the teacher allows pupils to carry out mostly tasks where they follow only the instructions given in advance. IBSE requires interactivity, where students are forced to reason logically in Level I, engage practical skills in Level II, independently design a procedure in Level III, and formulate a research problem in Level IV. The highest Level V is open exploration, which allows students to discover the problem independently and work through the entire inquiry cycle.

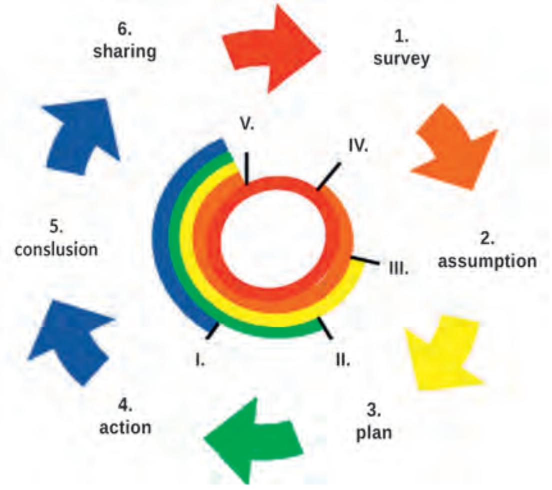

Fig. 11.2.1. Levels of inquiry (Slepáková, 2014).

Teachers should develop student's interest in science and motivate the younger generation to become active students of science and potential future scientists who can participate in solving global problems in the future. This vision may seem difficult to achieve, but on the other hand, it is probably one of the ways to change the attitudes of the younger generation towards global issues by giving them the opportunity to discuss them professionally with scientists at a young age and to sow the grains of knowledge, academic skills, enthusiasm and engagement.

The teacher's task is both to help pupils to understand the negative impacts of humans on their environment and to motivate pupils to actively participate in the protection of the environment, especially at the regional level. Pupils learn to fulfil this objective, for example, by investigating factors that affect the life of organisms and finding connections between them. Another objective of environmental education is to understand the principles of sustainable development and to critically evaluate the use of green technologies.

Environmental education is a global effort to raise awareness of the state of the environment and the need to protect it. The topics related to climate change are wide-ranging, but there is limited space for educational activities on these issues in schools. Time allocation in schools is almost impossible for detailed teaching of environmental topics. These are many times a cross-cutting theme of other subjects. If the implementation were to be entirely in the hands of the teacher, the quality is understandably lower and the teacher's capacity exhaustion higher. The preparation of a quality didactic approach involving the professional aspect of the studied is a challenging process. The ideas for environmental teaching should reflect current trends. One such themes are undoubtedly the teaching of the topic „Algae as biofuels“ or „Algae as biofilms“. Developing an educational concept for such a comprehensive topic is time-consuming and requires scientific knowledge on which to base pupils' inquiry activities.

Teaching environmental topics without scientific knowledge can't lead to the effective formation of a positive relationship to the environment and the need to protect it. In order for pupils to feel the need and willingness to approach natural resources responsibly, they need to know the laws of nature and understand ecological relationships. A good teacher influences pupils so that they acquire habits that are beneficial to the preservation of living conditions.

The development of scientific and ecological competences must be directly linked to outdoor education. Observing and monitoring natural objects and processes in changing natural conditions offers an ideal opportunity for variable approaches in education that maintain pupils' attention. The observation of living organisms in their natural environment provides an objective view to the laws of nature. Through manipulation with living material and learning the procedures for measuring and analysing data, pupils learn the basics of scientific work. Working with determination keys develops procedural analysis and synthesis skills. Changing environmental conditions and the variability of learning aids allow pupils to propose hypotheses and suggest experiments to verify them. Of course, outdoor teaching is not always possible, and moreover, the evaluation of the obtained data often has to take place at school.

Digital tools play an important role in the teaching of environmental topics, which cannot be absent in the modern school, because their use in the teaching of biology is related to the current trend of digital transformation. The process of digital transformation aims to improve a subject by inducing significant changes in its characteristics through a combination of information, computer, communication and connection technologies (Vial, G., 2021). Simply put, it is about improving the quality of a system (e.g. education) through the implementation of modern ICT or digital tools. An important role in digital transformation in schools is played by educational digital resources. These are, for example, simulations, animations, educational videos, quizzes, apps, software, programmes or websites that engage learners in learning activities and support the achievement of learning objectives. Digital resources are compiled from individual digital media – text, video, images, audio, etc. Research findings (Navaridas-Nalda F., et al, 2020) have shown that the influence of school principals is critical in digital transformation based on the integration of quality digital content, and this is mainly through open discussion that enables teachers to see the integration of digital content into instruction as an opportunity to improve student achievement rather than a problem to be eliminated. An example of such a digital resource for a wide range of outdoor activities supported by a virtual lab in the form of instructional videos or identification keys is the EFFUSE platform available on effuse.science.upjs.uk. For the young generation, the digital world is a normal part of life, so it is important to use the digital environment in the educational process.

The challenge in the implementation of inquiry activities and moreover directly in the field is the evaluation of the pupils' skills and the obtained knowledge. Given that outdoor education is rarely rather than often implemented in schools, it is necessary to approach the evaluation of such activities formative rather than summative. Formative assessment (assessment for learning or developmental assessment) comes from the Latin word formo (to modify, to reshape). The purpose of formative assessment is to help the pupil in the learning process. It involves activities related to gaining information about where the learner is in the learning process, where they need to be and how best to get there (Kireš et al., 2016).

There are several formative assessment tools as self-assessment card, summary, ticket upon departure, and other. We provide the prediction card as an example of an effective assessment of any thematic focus on example of topic related to algae – *Heterokothophyta* (Table 11.2.1). In prediction card pupils need to decide whether the statement is true or false, before and after lesson.

Table 11.2.1.

Prediction card, Heterokontophyta

Prediction card				
Topic: Heterokontophyta				
Before the lesson		**Statement**	**After the lesson**	
True statement	**False statement**		**True statement**	**False statement**
T	F	1. The algae of the *Heterokontophyta* have 2 equally long flagella and the storage substance chrysolaminarin.	T	F
T	F	2. Yellow-green algae, diatoms and green algae are characterized by open mitosis.	T	F
T	F	3. *Eustigmatophyceae* have a stigma deposited inside the chloroplast.	T	F

T	F	4. The cells of diatoms are divided into central and peripheral according to the shape of the dishes.	T	F
T	F	5. Diatoms have a unique type of cell wall, the frustule, which is encrusted with $CaCO_3$.	T	F
T	F	6. Brown algae have a cell algae composed of 2 parts-solid and amorphous.	T	F

The use of formative assessment tools helps pupils to analyse their own learning process and at the same time informs them about the gaps or misconceptions with which they comes to the lessons. Hands on science enables to remove misconceptions and replace inaccurate knowledge with correct knowledge.

Pupil's ideas about nature and its laws, which are as close as possible to reality, can be acquired by pupils if they have opportunity to work with real natural objects and, if possible, in their natural environment. This is the reason why it is necessary to support outdoor teaching „hands on science", which can be defined as pupils being given materials, carrying out experiments, investigating phenomena and trying out their ideas. One of the most effective way to apply „hands on science" is to teach science in a nature-based environment and thus form students to be interested in environmental sciences.

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E 45 **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.

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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.

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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

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89600, м. Мукачево, вул. Ужгородська, 26
тел./факс +380-3131-21109
Веб-сайт університету: www.msu.edu.ua
E-mail: info@msu.edu.ua, pr@mail.msu.edu.ua
Веб-сайт Інституційного репозитарію Наукової бібліотеки МДУ: http://dspace.msu.edu.ua:8080
Веб-сайт Наукової бібліотеки МДУ: http://msu.edu.ua/library/