
**ECOLOGICAL AND GEOGRAPHICAL FOUNDATIONS
FOR THE SUSTAINABLE DEVELOPMENT
OF NATIONAL NATURE PARKS
IN THE UKRAINIAN CARPATHIANS**

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INTRODUCTION

The current stage of civilizational development necessitates the integration of the sustainable development concept into all spheres of socio-spatial and economic activity. Given their heightened vulnerability to external factors and their key role in maintaining the ecological balance of continents, mountain regions require special attention in the context of spatial modeling and conservation management. The Ukrainian Carpathians represent a unique biogeographic region in Central Europe. A complex orographic structure, specific microclimatic conditions, and prolonged landscape genesis have resulted in a high concentration of endemic and relict flora and fauna, as well as the preservation of primeval forest ecosystems. At the same time, this specific mountain region is currently becoming an arena of intensive socio-ecological transformations.

The core problem is that the natural-territorial complexes of the Carpathians are experiencing intensive synergistic pressure. On the one hand, there is a spontaneous commercialization of the recreational and tourism potential, accompanied by chaotic infrastructure development, the expansion of the ski trail network, and the spread of motorized extreme tourism (jeeping, enduro), which cause irreversible degradation of the soil and vegetation cover. On the other hand, intensive, and sometimes illegal, logging continues, undermining the water-regulating and soil-protecting functions of forest ecosystems and provoking the activation of hazardous exogenous geomorphological processes – mudflows, landslides, and catastrophic floods¹.

¹ Круглов І. С. Трансформація ландшафтів Українських Карпат. *Український географічний журнал*. 2018. № 3. С. 14–22. DOI: 10.15407/ugz2018.03.014

The results of fundamental research in the fields of geoecology and biogeography convincingly demonstrate that expanding the network of Nature Reserve Fund (NRF) sites is the most effective tool for conserving landscape and biological diversity². Within the system of NRF categories, national nature parks (NNPs) are considered the most adaptive and balanced form of spatial protection. Their spatial structure, based on the principles of functional zoning, conceptually enables the harmonization of a strict protection regime in high-value areas with traditional natural resource use and regulated recreation in the remaining territories³.

However, the practical functioning of Carpathian NNPs demonstrates that the institutional establishment of protected status does not automatically eliminate the contradictions between the socio-economic interests of local communities and the imperatives of ecocentrism. The uncertainty and lack of boundaries demarcated on the ground, the chronic funding deficit for conservation measures, and outdated forestry and hunting management practices within the economic zones of the parks cause permanent spatial and resource conflicts. Overcoming these contradictions requires rethinking traditional protected area management paradigms and integrating innovative tools for geospatial analysis and adaptive management.

The aim of the study is to conduct a comprehensive analysis of the spatial and ecological-economic aspects of natural resource use within the national nature parks of the Ukrainian Carpathians in order to substantiate the scientific and methodological foundations for optimizing their functioning based on sustainability principles. In accordance with this objective, the subsequent subsections detail the scale of contemporary socio-geographical transformations of protected areas, assess the consequences of the recreational degradation of landscapes, and propose strategic vectors for the modernization of the ecological management of mountain ecosystems. Ultimately, the practical implementation of these recommendations is expected to harmonize biodiversity conservation with the socio-economic needs of local communities, ensuring the long-term resilience of the Carpathian natural heritage.

1. Formation and Current State of the National Nature Park Network in the Ukrainian Carpathians

The mountain landscape ecosystems of the Ukrainian Carpathians represent a unique natural complex that plays a crucial role in maintaining ecological balance, shaping the hydrological regime, and conserving the biological diversity

² Голубець М. А. Екосистемологія. Львів : Поліграфцентр, 2000. 316 с.

³ Стойко С. М. Охорона природи Українських Карпат та прилеглих територій. Київ : Наукова думка, 1980. 261 с.

of the region^{4, 5}. At the same time, the prolonged anthropogenic transformation of forest ecosystems and the intensive economic development of mountainous areas have significantly increased the risks of negative ecological processes, including catastrophic floods, soil erosion, and the loss of biotic potential^{6, 7}. Under these conditions, a need arises to develop a balanced system of natural resource use, where the territories and sites of the Nature Reserve Fund (NRF) serve as the key spatial framework^{8, 9}.

National nature parks (NNPs) hold a prominent place within the system of preserving conservation potential. Unlike strict nature reserves, the functional structure of NNPs enables the integration of natural heritage conservation objectives with meeting the recreational, scientific, and socio-economic needs of the local population¹⁰. The development of the national park network is viewed as a strategic direction for ensuring the sustainable development of mountainous areas, as it creates the conditions for a transition from resource-depleting forestry to the development of the recreation industry and ecotourism^{11, 12}.

The establishment and spatial development of the national park network in the Ukrainian Carpathians are based on the system of legislative acts of Ukraine. The fundamental legal framework is provided by the Law of Ukraine «On the Nature Reserve Fund of Ukraine» which defines the status, legal regime, and functional zoning of national nature parks¹³. The development of ecological corridors and the integration of fragmented protected areas into a unified spatial system were carried out in accordance with the Law of Ukraine «On the State Programme for the Formation of the National Ecological Network of Ukraine

⁴ Заповідні екосистеми Карпат / С. М. Стойко та ін. Львів : Світ, 1991. 248 с.

⁵ Мельник А. В. Українські Карпати: еколого-ландшафтознавче дослідження. Львів, 1999. 288 с.

⁶ Коваль Я. В., Антоненко І. Я. Значення гірських лісів у системі екологічної безпеки. *Гори і люди (у контексті сталого розвитку)* : матер. Міжнар. наук.-практ. конф. Ужгород : Патент, 2002. Т. II. С. 381–385.

⁷ Олійник В. С. Паводкорегулююча роль гірських лісів Карпат. *Екологічні та соціально-економічні аспекти катастрофічних стихійних явищ у Карпатському регіоні (повені, селі, зсуви)* : матер. Міжнар. наук.-практ. конф. Рахів, 1999. С. 257–260.

⁸ Про природно-заповідний фонд України : Закон України. *Відомості Верховної Ради України*. 1992. № 34. Ст. 502.

⁹ Заповідники і національні природні парки України. Київ : Вища школа, 1999. 232 с.

¹⁰ Кукурудза М. М. Менеджмент національних парків : навчальний посібник. Львів : Видавничий центр ЛНУ ім. Івана Франка, 2003. 127 с.

¹¹ Жук П. В., Кравців В. С. Рекреаційний потенціал Українських Карпат і перспективи його використання. *Українські Карпати: проблеми і перспективи* : матер. Міжнародн. наук.-практ. конф. Львів, 1993. С. 58.

¹² Рожко І. М. Рекреаційна оцінка гірських природно-територіальних комплексів для потреб туризму (на прикладі Українських Карпат) : автореф. дис. ... канд. геогр. наук : 11.00.11. Львів, 2000. 175 с.

¹³ Про природно-заповідний фонд України : Закон України. *Відомості Верховної Ради України*. 1992. № 34. Ст. 502.

for 2000–2015»¹⁴ and the Law of Ukraine «On the Ecological Network of Ukraine»¹⁵.

The legislative establishment of the functional zoning of NNPs (strict protection zone, regulated recreation zone, stationary recreation zone, and economic zone) allows the most valuable natural complexes to be excluded from intensive use, while simultaneously retaining opportunities for traditional land management and recreational activities¹⁶.

The contemporary network of national nature parks encompasses the main geomorphological and geobotanical regions of the Ukrainian Carpathians – from the low-mountain foothills to the high-mountain massifs of Chornohora, Gorgany, and the Beskids^{17, 18}. The recreational resource potential of mountain natural-territorial complexes serves as an important foundation for the development of hiking, educational, balneological, ski, and other types of active tourism¹⁹. At the same time, the continuous growth of tourist flows leads to intensified anthropogenic pressure on vulnerable mountain ecosystems, which necessitates appropriate monitoring.

For the purpose of systematization and comparative geographical analysis, Table 1 summarizes the key information regarding the main national nature parks of the region.

The formation and expansion of the NNPs network play a significant role in ensuring the ecological safety and sustainable development of the region across several main directions:

- *Water conservation and flood control functions.* Mountain forest ecosystems, excluded from intensive clear-cutting within national parks, act as natural accumulators of atmospheric precipitation, convert surface runoff into groundwater recharge, and significantly reduce peak flood levels in the Dniester, Prut, Tisza, and Cheremosh river basins^{20, 21}.

¹⁴ Про Загальнодержавну програму формування національної екологічної мережі України на 2000–2015 роки : Закон України. *Відомості Верховної Ради України*. 2000. № 47. С. 40.

¹⁵ Про екологічну мережу України : Закон України. *Відомості Верховної Ради України*. 2004. № 45. Ст. 502.

¹⁶ Кукурудза М. М. Менеджмент національних парків : навч. посіб. Львів : Видавничий центр ЛНУ ім. Івана Франка, 2003. 127 с.

¹⁷ Заповідні екосистеми Карпат / С. М. Стойко та ін. Львів : Світ, 1991. 248 с.

¹⁸ Мельник А. В. Українські Карпати: еколого-ландшафтознавче дослідження. Львів, 1999. 288 с.

¹⁹ Жук П. В., Кравців В. С. Рекреаційний потенціал Українських Карпат і перспективи його використання. *Українські Карпати: проблеми і перспективи* : матер. Міжнародн. наук.-практ. конф. Львів, 1993. С. 58.

²⁰ Коваль Я. В., Антоненко І. Я. Значення гірських лісів у системі екологічної безпеки. *Гори і люди (у контексті сталого розвитку)* : матер. Міжнар. наук.-практ. конф. Ужгород : Патент, 2002. Т. II. С. 381–385.

²¹ Олійник В. С. Паводкорегулююча роль гірських лісів Карпат. *Екологічні та соціально-економічні аспекти катастрофічних стихійних явищ у Карпатському регіоні (повені, селі, зсуви)* : матер. Міжнар. наук.-практ. конф. Рахів, 1999. С. 257–260.

Table 1

**Characteristics of the National Nature Parks
of the Ukrainian Carpathians**

Name of the National Nature Park	Geographical (basin) location	Main conservation and recreational features
Carpathian NNP	Ivano-Frankivsk Oblast, upper reaches of the Prut River basin	The first NNP in Ukraine; encompasses the high-altitude massifs of Chornohora (Mt. Hoverla); high level of recreational development and tourist infrastructure
«Synevyr» NNP	Zakarpattia Oblast, Tereblya River basin	Preservation of Inner Gorgany landscapes, high-mountain bogs, and Lake Synevyr; assessment and modeling of climate and tourism resources
Uzhanskyi NNP	Zakarpattia Oblast, Uzh River basin	Part of the trilateral East Carpathians Biosphere Reserve; protection of primeval beech forests and mountain ecosystems of the Beskids
«Skole Beskids» NNP	Lviv Oblast, Stryi and Opir River basins	Protection of silver fir and beech forests of the Eastern Beskids; significant recreational potential and availability of balneological resources
«Hutsulshchyna» NNP	Ivano-Frankivsk Oblast, Pokuttya-Bukovyna Carpathians	Combination of natural landscape protection with the preservation of ethnocultural heritage and traditional crafts of Hutsulshchyna
«Verkhovynskyi» NNP	Ivano-Frankivsk Oblast, Cheremosh River basin	Protection of high-mountain ecosystems of the Chyvchyny-Hrynyava Mountains; conservation of intact forest and subalpine complexes
«Boykivshchyna» NNP	Lviv Oblast, upper reaches of the Dniester River basin	Preservation of natural-territorial complexes of the Eastern Beskids and the distinctive cultural heritage of the Boyko region
«Korolivski Beskydy» NNP	Lviv Oblast, Dniester River basin	Formation of ecological corridors in the Carpathian foothills; protection of forest areas and recreation development

- *Biodiversity and landscape diversity conservation.* National parks ensure the protection of rare and endangered species of flora and fauna listed in the Red Data Book of Ukraine, as well as the safeguard of rare phytocoenoses (plant communities)^{22, 23}.

- *Socio-economic diversification.* The development of national park management stimulates the creation of new jobs in the service sector, research activities, park inspection, and guided tour services²⁴. The network of tourist and ecological trails, designed on a landscape-ecological basis, makes it possible

²² Заповідні екосистеми Карпат / С. М. Стойко та ін. Львів : Світ, 1991. 248 с.

²³ Заповідники і національні природні парки України. Київ : Вища школа, 1999. 232 с.

²⁴ Кукурудза М. М. Менеджмент національних парків : навчальний посібник. Львів : Видавничий центр ЛНУ ім. Івана Франка, 2003. 127 с.

to reduce unregulated recreational pressure on vulnerable high-mountain ecosystems^{25, 26}.

Thus, the development of the national nature park network in the Ukrainian Carpathians is a fundamental condition for ensuring sustainable development, preserving the unique natural and landscape heritage while simultaneously laying the groundwork for the socio-economic growth of local communities.

2. Ecological Risks and Anthropogenic Transformation of Mountain Landscapes

Forest and aquatic ecosystems of the Ukrainian Carpathians serve as the foundation for the region's ecological stability, providing climate-regulating, soil-protective, and water-regulating functions. However, over recent decades, they have been subject to high technogenic and economic pressure, which comes into systemic contradiction with the zoological tasks of biodiversity conservation, particularly within protected areas. The key factors of spatial-ecological degradation are depleting forest use (manipulations with sanitary fellings, illegal logging) and the expansion of small-scale hydropower in the mountain river basins.

Impact of unsustainable forest management on NNP ecosystems

Despite the protected status of the territories, forestry activities within the economic and regulated recreation zones of NNPs remain highly intensive. The widespread practice of assigning clear sanitary fellings causes particular concern among the scientific and conservation communities. While formally intended to improve the sanitary state of forests and eliminate foci of pest infestations (specifically the European spruce bark beetle, *Ips typographus*, in monocultures of secondary spruce forests), in reality, they often serve as a legalized instrument for extracting commercially valuable industrial timber²⁷.

These processes lead to a reduction in the area of old-growth forests and the spatial fragmentation of continuous forest massifs. The elimination of critical microhabitats (in particular, deadwood and defective trees) disrupts the life cycles of rare representatives of ornithofauna and entomofauna, as well as xylotrophic mycobiota.

²⁵ Рожко І. М. Рекреаційна оцінка гірських природно-територіальних комплексів для потреб туризму (на прикладі Українських Карпат) : автореф. дис. ... канд. геогр. наук : 11.00.11. Львів, 2000. 175 с.

²⁶ Романів А. С., Романів О. Я. Обґрунтування мережі туристичних маршрутів Національного природного парку «Синевир» на засадах ландшафтознавчих досліджень. *Фізична географія та геоморфологія*. 2004. Вип. 46, Т. 1. С. 243–250.

²⁷ Чернявський М. В. Проблеми збереження старовікових лісів та пралісів Українських Карпат. *Науковий вісник НЛТУ України*. 2016. Вип. 26.4. С. 120–128.

Illegal logging deepens ecological degradation, disrupting not only the spatial structure of biogeocenoses but also the physicochemical properties of the soil cover. Direct consequences of failing to comply with environmental logging regulations and utilizing heavy tracked machinery for timber skidding along stream beds include the loss of the water-regulating capacity of mountain slopes. This causes the intensification of surface runoff during heavy rainfall, the activation of erosion processes, and the formation of destructive floods in the lower reaches of river basins²⁸. The typology of logging and its geoecological consequences for mountain ecosystems are summarized in Table 2.

Table 2

**Typology of logging and its ecological consequences
in mountain ecosystems**

Type of Anthropogenic Intervention	Primary Ecological Risk	Impact on Structural Components of the Biogeocenosis
Clear sanitary fellings	Destruction of old-growth trees and microhabitats	Biodiversity reduction, alteration of microclimatic conditions, disruption of trophic chains
Illegal logging	Soil cover degradation and activation of erosion	Decline in the water-regulating capacity of slopes, increased risk of landslides and mudflows
Timber skidding along stream beds	Development of linear erosion. Mechanical damage to undergrowth and the hydrological network	Soil compaction, siltation of mountain rivers, destruction of fish spawning grounds

Ecological risks of hydropower development in mountain rivers

The second significant factor of destructive technogenic pressure is the mass construction of small hydropower plants. Starting in the 2010s, against the backdrop of promoting renewable («green») energy and introducing the «green tariff» mechanism, the intensive construction of diversion hydropower plants gained momentum in the Carpathian region. The operational scheme of such facilities involves damming the watercourse and diverting a significant portion of the river flow (up to 80–90%) into diversion pipelines over distances ranging from several hundred meters to several kilometers²⁹.

For mountain watercourses, which are inherently highly sensitive to transformations of the hydrological regime, such interventions have destructive consequences. On river reaches between the intake facility and the discharge

²⁸ Олійник В. С. Гідрологічна роль лісів Українських Карпат. Івано-Франківськ : НАІР, 2013. 232 с.

²⁹ Ковальчук А. А. Екологічні проблеми розвитку малої гідроенергетики в Українських Карпатах. *Гідрологія, гідрохімія і гідроекологія*. 2018. № 2(49). С. 56–65.

point (within the diversion reach), a critical decrease in water levels, disruption of the flow velocity profile, seasonal overheating of water masses during the summer period, and the emergence of a persistent dissolved oxygen deficit are observed. Hydrotechnical structures of SHPs form impassable mechanical barriers to the spawning migrations of rheophilic ichthyofauna species—specifically brown trout (*Salmo trutta m. fario*), European grayling (*Thymallus thymallus*), Danube salmon (*Hucho hucho*), and Balkan barbel (*Barbus petenyi*), most of which are listed in the Red Data Book of Ukraine and are protected under the Bern Convention³⁰.

The comprehensive impact of diversion small hydropower plants on the hydro-ecosystems of Carpathian rivers is summarized in Table 3.

Table 3

Impact of diversion-type small hydropower plants on the ecosystems of Carpathian rivers

Project Implementation Stage	Primary Factor of Negative Impact	Ecological Consequences for the Hydro-Ecosystem
Infrastructure construction	Alteration of the natural riverbed, operation of heavy construction machinery	Destruction of natural spawning grounds, sharp increase in water turbidity, destruction of riparian protective zones
Operation (water diversion into pipeline)	Critical reduction of water discharge in the natural riverbed below the dam	Degradation of hydrobiocenoses, disappearance of stenobiotic (rheophilic) species, shallowing of the watercourse
Construction of retaining dams	Artificial fragmentation of the integrated river system	Blocking of fish migration routes to spawning areas, disruption of sediment transport

The synergistic effect of depleting forest management in watersheds and the regulation of watercourses by diversion structures manifests in the comprehensive degradation of natural-territorial complexes. Instead of fulfilling their zoological functions and carrying out environmental monitoring, territories adjacent to national nature parks are transforming into zones of intensive economic resource exploitation. This highlights the urgent need to improve the environmental impact assessment methodology and optimize the functional zoning of protected area network entities. Specifically, this involves the regulatory implementation of environmentally safe basin-based nature management standards and the establishment of effective buffer zones around core reserve zones. Only such a systemic geoecological approach will allow for

³⁰ Снігурець О. В. Вплив гідротехнічних споруд на іхтіофауну гірських річок. *Біологічні студії*. 2019. Т. 13, № 1. С. 95–104.

the restoration of the self-healing potential of Carpathian landscapes and ensure their sustainable spatial development in the long term.

The formation of the modern spatial structure of the high-altitude landscapes of the Ukrainian Carpathians was long determined by traditional nature management, in which polonyna livestock farming holds a primary role. On the one hand, moderate livestock grazing historically contributed to maintaining the biodiversity of subalpine meadows by inhibiting processes of their successional afforestation. On the other hand, under contemporary conditions of spatial limitation and intensification of economic activities within national nature parks, traditional cattle farming frequently transforms into a factor of systemic environmental destabilization.

Ecological consequences of unregulated grazing on high-altitude meadows (polonynas)

A key problem of modern polonyna management is the local exceedance of ecologically permissible grazing capacity (overgrazing) in the most accessible high-altitude areas. High livestock density within restricted areas induces the development of pasture digression processes. The result is a destructive transformation of phytocoenoses: valuable forage species and rare endemic plant components are displaced by low-value digression species resilient to trampling – specifically tufted hairgrass (*Deschampsia cespitosa*) and matgrass (*Nardus stricta*).

Alongside this, excessive mechanical pressure on the vulnerable soil cover causes its severe compaction, destruction of the sod layer, and disruption of the water-air regime. This significantly reduces the infiltration capacity of the surface, driving the activation of sheet erosion and the formation of a network of erosion rills, which subsequently transform into linear erosion landforms³¹.

The intensification of these processes extends beyond mere soil destruction, impairing the water-regulating capacity of subalpine geosystems and the hydrological regime of Carpathian river basins. Long-term degradation of the plant-soil cover irreversibly reduces the biological productivity of polonynas, subsequently undermining the natural resource potential of traditional cattle farming itself. Under such conditions, the restoration of vulnerable high-altitude ecosystems requires the introduction of pasture rotation systems and the temporary withdrawal of the most severely degraded areas from economic use.

The sequence of these destructive processes, as well as the stages of pasture digression of polonyna landscapes and their diagnostic indicators, are summarized in Table 4.

³¹ Кияк В. Г. Дигресія високогірних екосистем Українських Карпат під впливом пасовищного навантаження. *Екологія та ноосферологія*. 2017. Т. 28, № 1–2. С. 45–54.

Table 4

Stages of pasture digression of polonyna landscapes and their indicators

Digression Stage	Characteristics of Vegetation Cover	State of Soil Cover
I (Initial)	Slight reduction in the proportion of sensitive species, dominance of typical grasses	Preservation of turf integrity, minimal compaction of the upper horizon
II (Moderate)	Disappearance of endemics, spread of inedible herbs (<i>Nardus stricta</i>), dwarf shrubs	Soil exposure on 15–30% of the area, reduced water permeability, emergence of livestock trails
III (Severe)	Formation of impoverished ruderal communities, degradation of vegetation cover	Mechanical destruction of turf on 50–70% of the area, active sheet erosion
IV (Catastrophic)	Complete loss of forage value, fragmented vegetation cover	Exposure of parent rock, development of deep linear erosion, scree slopes

Recreational digression and the impact of mass tourism

Another, no less significant factor in the transformation of natural-territorial complexes is the rapid increase in recreational pressure. National nature parks of the Carpathian region experience systematic pressure due to the growth of unmanaged recreational flows. Although the organization of public recreation is among the priority functions of national nature parks, the lack of effective visitor management and modern tourism infrastructure leads to substantial geoecological destruction of protected areas³².

The most common consequence of mass trekking is the expansion of recreational digression zones along popular routes (particularly on the Chornohora, Svydovets, and Gorgany massifs). In the absence of equipped and marked trails, hikers widen the transit zone to several dozen meters, causing complete destruction of the plant-soil cover. An extremely aggressive form of recreational nature use is the expansion of high-clearance off-road and motor vehicles (off-roading/jeeping, ATVs, and enduro motorcycles) beyond public roads. The movement of such vehicles along steep slopes and mountain riverbeds causes immediate and often irreversible damage to ecosystems: habitats of plant species listed in the Red Data Book of Ukraine are destroyed, bird nesting and amphibian breeding biotopes are disrupted, and a powerful acoustic disturbance factor is created³³.

Deep ruts left by heavy motor vehicles on treeless slopes transform into artificial channels that concentrate surface runoff during heavy rainfalls,

³² Смалійчук А. Д. Рекреаційна трансформація ландшафтів Чорногірського масиву: сучасний стан та шляхи оптимізації. *Фізична географія та геоморфологія*. 2019. Вип. 1(93). С. 78–86.

³³ Волощук М. Д. Ерозійні процеси в Українських Карпатах та вплив рекреаційної діяльності на їх активізацію. Ужгород : Карпати, 2015. 190 с.

triggering the catastrophic development of linear erosion and landslides. The systematic presence of high-speed transport causes the fragmentation of contiguous faunal habitats, forcing large mammals (specifically the brown bear, *Ursus arctos*, and the Eurasian lynx, *Lynx lynx*) to abandon their traditional home ranges. This problem is further compounded by the lack of demarcated boundaries of national parks in the field and low fine rates, which makes effective operational control over motor vehicle movement in remote mountain areas impossible. This drives an urgent need not only to establish strict enforcement against unauthorized access within protected areas, but also to localize and channel such recreational activities onto dedicated tracks outside protected boundaries.

Systematized forms of recreational impact, their spatial distribution, and corresponding consequences for the landscape structure of NNPs are presented in Table 5.

Table 5

Forms of recreational impact and their consequences for landscapes of national nature parks

Type of Tourism Activity	Primary Impact Factor	Ecological Consequences for Natural-Territorial Complexes
Mass Hiking / Trekking	Trampling, uncontrolled campfire lighting, littering	Expansion of erosion trails, damage to forest advance growth, localized solid waste pollution
Off-Roading (Jeeping) & Motor Tourism	Mechanical soil damage by heavy vehicles, noise stress	Deep linear slope erosion, destruction of rare species populations, wildlife disturbance
Tent Camping	Concentration of anthropogenic load on small areas	Soil compaction at campsites, pollution of adjacent water bodies with organic matter

Such trends in the transformation of mountain geosystems – both under the influence of traditional forms of nature use and under the pressure of emerging recreational practices—clearly demonstrate the imperfection of existing spatial management models. The cumulative effect of overlapping drivers within areas with relaxed zoological regimes highlights the urgent need to substantiate integrated functional zoning mechanisms capable of mitigating spatial conflicts between economic interests and ecological safety imperatives³⁴.

³⁴ Мельник А. В. Функціональне зонування національних природних парків як інструмент збалансованого просторового розвитку. *Вісник Львівського університету. Серія географічна*. 2020. Вип. 54. С. 112–123.

3. Optimization of Spatial Structure and Innovative Management of Protected Areas

The severity of ecological-economic conflicts in the Carpathian region convincingly demonstrates that the current system of spatial organization of national nature parks (NNPs) has exhausted its potential and requires systemic modernization. The traditional model of functional zoning, established in the late 20th century, has proven incapable of flexibly responding to contemporary challenges: the rapid commercialization of recreational nature use, the expansion of small hydropower, and global climate transformations. In many Carpathian NNPs, a predominant share of the territory (sometimes over 50–60%) is allocated to the economic zone and the zone of stationary recreation, which de facto neutralizes the zoological function of the conservation institution³⁵.

A key instrument for resolving resource use conflicts should be a scientifically grounded reorganization of the spatial structure of NNPs. The modern approach requires shifting away from formal (administrative) division in favor of a landscape-ecological concept. The primary task is a substantial expansion of the core reserve zone, which must fulfill the function of a stabilizing ecological core of the territory. It is imperatively necessary to include all identified clusters of primary forests, quasi-primeval forests, and old-growth forest massifs, as well as first-order drainage basins, into this core zone. This will prevent any types of logging (including sanitary logging) and the construction of hydrotechnical structures in the most ecologically sensitive areas.

At the same time, the formation of an integrated zoological framework requires the creation of reliable buffer zones and local ecological corridors designed to eliminate landscape fragmentation and ensure the spatial connectivity of core reserve zones. Furthermore, the zoning of recreationally developed territories should rely on strict calculations of the ecological carrying capacity of landscapes, with a clear delineation and infrastructure setup of local tracks for sightseeing or extreme tourism outside reserve boundaries. The practical implementation of such a geospatial model based on GIS technologies will allow for minimizing existing resource use conflicts and establishing the groundwork for the long-term sustainable development of the entire mountain region³⁶.

A systematized list of updated criteria and spatial parameters for optimizing the functional zoning of NNPs in the Carpathian region is summarized in Table 6.

³⁵ Гетьман В. І. Еколого-географічні основи територіальної організації національних природних парків України. Київ : Інститут географії НАН України, 2018. 245 с.

³⁶ Брусак Е. І. Функціональне зонування гірських природоохоронних територій: проблеми та шляхи вирішення. *Вісник Львівського університету. Серія географічна*. 2021. Вип. 55. С. 34–45.

Table 6

**Updated criteria for optimizing the functional zones of NNPs
in the Carpathian region**

Functional Zone of the NNP	Main Defect of the Existing State	New Delineation and Spatial Organization Criteria
Core Reserve Zone	Territorial fragmentation, insufficient area (often < 20%)	Coverage of no less than 30–40% of the park area; mandatory inclusion of primeval forests, subalpine/subnival zones, and river headwaters; formation of contiguous clusters
Zone of Regulated Recreation	Chaotic dispersion of tourists, slope digression (degradation)	Binding exclusively to marked trails; calculation of recreational carrying capacity; creation of «ecological corridors» for visitor transit
Zone of Stationary Recreation	Capital construction encroachment, violation of water protection zones	Concentration of infrastructure at the NNPs periphery; prohibition of construction closer than 100 m from riverbeds; implementation of eco-architecture
Economic (Utility) Zone	Intensive logging, overgrazing on mountain pastures (<i>polonynas</i>), soil degradation	Implementation of strict limits on livestock grazing (pasture rotation maps); transition to selective (close-to-nature) silvicultural systems

Implementation of innovative GIS technologies and remote monitoring systems

Effective spatial optimization and systematic control over compliance with the zoological regime are impossible without the integration of modern tools of Geographic Information Systems (GIS) and Remote Sensing (RS) technologies. The transition to a digital management paradigm for protected areas allows for minimizing the influence of subjective factors while ensuring high accuracy and objectivity in environmental auditing³⁷.

The use of high-spatial-resolution satellite data, radar scanning materials, and unmanned aerial vehicles (UAVs) enables national nature park administrations to regularly record spatio-temporal transformations of the landscape cover. Specifically, this is critically important for detecting hidden pockets of illegal logging in hard-to-reach mountain valleys and ravines, as well as for monitoring desuccesion processes and shrub expansion on high-altitude pastures (*polonynas*) resulting from traditional transhumance livestock farming.

The integration of multispectral satellite imagery and the calculation of vegetation indices (in particular, NDVI) allow for rapid, automated analysis of

³⁷ Проценко В. В. Використання ГІС-технологій у просторовому плануванні та моніторингу територій природно-заповідного фонду. *Екологічні науки*. 2019. № 2(25). С. 88–94.

defoliation and dieback in Norway spruce stands caused by climatic anomalies and pest outbreaks. Furthermore, the development of interactive Web-GIS geoportals based on cloud technologies ensures transparency in environmental protection activities, enables public involvement in monitoring violations, and serves as a tool for automated risk modeling of linear erosion or fire hazards. Concurrently, the implementation of mobile GIS applications for field ranger surveys-combined with automated pattern recognition algorithms-makes it possible to form an integrated spatial decision support system and transition from passive violation tracking to proactive geoeological management.

Key directions for applying GIS technologies and Remote Sensing (RS) methods in the geoeological monitoring of mountain landscapes are systematized in Table 7.

Table 7

**Application of Remote Sensing and GIS technologies
for spatial monitoring of NNPs**

Tool / Technology	Object of Ecological Monitoring	Expected Outcome of Spatial Management
Multispectral satellite imagery (Sentinel, Landsat)	Forest massifs, condition of <i>polonyna</i> vegetation cover	Detection of illegal clear-cutting, assessment of coniferous forest dieback scale, monitoring of pasture digression
UAVs (drones) with thermal imagers	Wildlife, hiking routes, fire hotspots	Wildlife population census without disturbance factors, control over illegal campfires, detection of poachers
Airborne Laser Scanning (LiDAR)	Topography, vertical forest structure, watercourses	Precise mapping of erosion processes and landslides, flood zone modeling during inundations, designing eco-trails
GIS modeling of migration corridors	Migration routes of large carnivores and ungulates	Designing transboundary ecological corridors (e.g., for brown bear or lynx), planning buffer zones

Any measures aimed at modifying functional zoning and strengthening the sozological regime inevitably face resistance from local territorial communities. The population of mountain settlements in the Carpathian region has historically depended on logging, non-timber forest use (harvesting wild berries, mushrooms, and medicinal raw materials), and high-altitude pasture livestock farming. For this reason, the spatial optimization of NNPs must necessarily incorporate effective mechanisms for compensating socio-economic losses and creating alternative sources of self-employment³⁸.

³⁸ Смалійчук А. Д., Мельник А. В. Соціально-економічні аспекти функціонування природно-заповідних територій в умовах децентралізації. *Часопис соціально-економічної географії*. 2022. Вип. 32. С. 45–56.

A conceptual solution to this problem lies in establishing special buffer «collaboration zones» (partnership zoning) at the boundary between protected sites and the lands of local communities. Within these areas, priority should be given to the development of sustainable nature management models: certified harvesting of non-timber forest products, the development of ecological and green rural tourism, and the revival of traditional handicrafts and high-altitude pasture cheese-making. The national park should function not as an institutional barrier or an exclusion zone for the local population, but as a powerful economic catalyst that generates value added for the area by leveraging its ecological brand³⁹.

A promising instrument for harmonizing these relationships is the implementation of Payment for Ecosystem Services (PES) mechanisms, under which communities receive financial compensation for preserving the water protection, habitat-forming, and recreational functions of mountain landscapes. This can be achieved through the partial redistribution of environmental taxes and recreational fees directly to local budgets, fostering a direct economic interest among residents to observe the protected area regulations. The institutional foundation for such interaction should be a transition toward participatory management (co-management) models through the creation of effective public-scientific advisory councils involving local self-government bodies and land users. The implementation of regional eco-labeling and local branding for craft products (in particular, traditional Carpathian cheeses) will further capitalize on the conservation status of the area and increase the profitability of local households. Ultimately, this compromise approach allows for mitigating socio-ecological conflicts, transforming local communities from potential opponents into active partners in preserving landscape diversity.

The mechanisms of socio-economic integration of NNPs, loss compensation tools, and the expected geoecological and social effects are detailed in Table 8.

Comprehensive and consistent implementation of the proposed scientific and practical measures opens up opportunities for a fundamental harmonization of the spatial-functional structure of national nature parks in the Ukrainian Carpathians. Moving away from the outdated static model of administrative zoning in favor of a dynamic landscape-ecological approach makes it possible to form a coherent and representative ecological network (ecological framework) for the area. This will ensure the necessary balance between the strict conservation of the most vulnerable high-altitude and forest geosystems and the controlled development of non-exhaustive forms of land use in peripheral zones.

³⁹ Ковальчук А. А. Механізми вирішення конфліктів між місцевими громадами та адміністраціями національних парків. *Регіональна економіка*. 2020. № 4. С. 77–85.

Table 8

Mechanisms for resolving spatial socio-economic conflicts within NNPs

Type of Conflict with Community	Restriction Introduced by Park	Compensation Mechanism or Alternative for Community
Logging / Forestry	Prohibition of sanitary and clear-cutting in new strictly protected zones	Creation of jobs in forest protection and recreation; preferential fuel wood supply for local residents (from sanitary cuttings in the economic zone)
Agropastoral (Grazing)	Livestock head limits on degraded high-altitude pastures (<i>polonynas</i>)	Support for establishing farming cooperatives; grants for developing high-altitude cheese dairies as gastrotourism sites
Recreational	Ban on off-roading (jeeping) and quad bike (ATV) use	Training and employment of local residents as tour guides; development of horseback riding and cycling tourism

The systemic transition from extensive resource use models to high-tech geospatial planning based on GIS tools and Remote Sensing (RS) data fundamentally changes the quality of conservation management. The application of modern spatial data analysis algorithms, satellite monitoring, and spatio-temporal modeling enables a transformation of NNPs operations from passive recording of violations into a system of proactive response, rapid environmental risk assessment, and adaptive landscape management.

At the same time, a key guarantee for the long-term sustainability of an optimized spatial structure is the involvement of local territorial communities in decision-making processes through participatory management tools. The practical integration of effective economic mechanisms – in particular Payments for Ecosystem Services (PES), compensation instruments, support for sustainable high-altitude pasture livestock farming, and local eco-branding–transforms the local population from potential opponents of conservation initiatives into active stakeholders in environmental preservation. Such synergy establishes a solid social foundation for the long-term conservation of the unique landscape, phytocoenotic, and biological diversity of the Carpathian region^{40, 41}.

CONCLUSIONS

A comprehensive analysis of nature management within the NNPs of the Ukrainian Carpathians demonstrates the existence of deep-seated contradictions between conservation objectives and the socio-economic interests of local

⁴⁰ Ковальчук А. А. Механізми вирішення конфліктів між місцевими громадами та адміністраціями національних парків. *Регіональна економіка*. 2020. № 4. С. 77–85.

⁴¹ Попович С. Ю. Інтеграція природно-заповідного фонду України до загальноєвропейської екологічної мережі. *Екологія та ноосферологія*. 2021. Т. 32, № 1. С. 12–23.

communities. The natural-territorial complexes of the mountain region experience intense pressure resulting from unsustainable forestry practices, the large-scale construction of small diversion hydropower plants, and the rapid commercialization of recreational activities. Unregulated mass tourism, the proliferation of motorized transport on high-altitude slopes, and overgrazing on mountain pastures trigger pastoral and recreational digression, exacerbate erosion processes, and lead to biodiversity loss.

To resolve existing resource use conflicts, a scientifically grounded reorganization of the spatial structure of NNPs is critically required, shifting from an outdated administrative zoning model toward a dynamic landscape-ecological approach. The primary step must be the expansion of the core reserve zone, with the mandatory inclusion of identified primeval forests, old-growth forests, and first-order drainage basins, alongside the formation of effective buffer zones and local ecological corridors.

Ensuring effective conservation management and systematic control over compliance with the protection regime is impossible without the digitalization of governance. The implementation of GIS technologies and Remote Sensing (RS) methods, along with the development of interactive Web-GIS geoportals, will enable a transition from passive recording of environmental violations to adaptive landscape management.

At the same time, a key condition for the long-term sustainability of the optimized NNP network is the socio-economic integration of protected areas. Involving the local population in decision-making processes through participatory management models and establishing financial incentive mechanisms will transform local communities into active partners in environmental preservation. Comprehensive implementation of these principles will ensure the conservation of the unique landscape heritage of the Carpathians and lay a reliable foundation for the sustainable development of the region.

SUMMARY

This paper investigates the spatial and ecological-economic aspects of nature management within national nature parks (NNPs) of the Ukrainian Carpathians in the context of ensuring their sustainable development. It is revealed that mountain landscape ecosystems experience intense anthropogenic pressure caused by unsustainable forestry practices, hydropower development on rivers, pastoral digression, and unmanaged recreational activities (specifically mass hiking and extreme motorized tourism). These factors induce systemic degradation of the soil-vegetation cover, disruption of the hydrological regime, and the exacerbation of spatial-resource conflicts. To optimize NNP functionality, the necessity of transitioning from traditional administrative to

landscape-ecological zoning – with a substantial expansion of core reserve zones at the expense of primeval forests and watersheds-is substantiated. It is proven that effective geoeological monitoring requires the mandatory integration of modern GIS technologies and Remote Sensing (RS) tools. Mechanisms for resolving conflicts with local communities are proposed through the introduction of participatory management, Payments for Ecosystem Services (PES), and the development of sustainable business models. Implementation of the proposed measures will harmonize conservation and economic interests, transforming the local population into active stakeholders in biodiversity preservation.

Bibliography

1. Брусак Е. І. Функціональне зонування гірських природоохоронних територій: проблеми та шляхи вирішення. *Вісник Львівського університету. Серія географічна*. 2021. Вип. 55. С. 34–45.
2. Волощук М. Д. Ерозійні процеси в Українських Карпатах та вплив рекреаційної діяльності на їх активізацію. Ужгород : Карпати, 2015. 190 с.
3. Гетьман В. І. Еколого-географічні основи територіальної організації національних природних парків України. Київ : Інститут географії НАН України, 2018. 245 с.
4. Голубець М. А. Екосистемологія. Львів : Поліграфцентр, 2000. 316 с.
5. Жук П. В., Кравців В. С. Рекреаційний потенціал Українських Карпат і перспективи його використання. *Українські Карпати: проблеми і перспективи* : матер. Міжнародн. наук.-практ. конф. Львів, 1993. С. 58.
6. Заповідні екосистеми Карпат / С. М. Стойко та ін. Львів : Світ, 1991. 248 с.
7. Заповідники і національні природні парки України. Київ : Вища школа, 1999. 232 с.
8. Кияк В. Г. Дигресія високогірних екосистем Українських Карпат під впливом пасовищного навантаження. *Екологія та ноосферологія*. 2017. Т. 28, № 1–2. С. 45–54.
9. Коваль Я. В., Антоненко І. Я. Значення гірських лісів у системі екологічної безпеки. *Гори і люди (у контексті сталого розвитку)* : матер. Міжнар. наук.-практ. конф. Ужгород : Патент, 2002. Т. II. С. 381–385.
10. Ковальчук А. А. Екологічні проблеми розвитку малої гідроенергетики в Українських Карпатах. *Гідрологія, гідрохімія і гідроекологія*. 2018. № 2(49). С. 56–65.
11. Ковальчук А. А. Механізми вирішення конфліктів між місцевими громадами та адміністраціями національних парків. *Регіональна економіка*. 2020. № 4. С. 77–85.

12. Круглов І. С. Трансформація ландшафтів Українських Карпат. *Український географічний журнал*. 2018. № 3. С. 14–22.
13. Кукурудза М. М. Менеджмент національних парків : навчальний посібник. Львів : ЛНУ ім. Івана Франка, 2003. 127 с.
14. Мельник А. В. Українські Карпати: еколого-ландшафтознавче дослідження. Львів, 1999. 288 с.
15. Мельник А. В. Функціональне зонування національних природних парків як інструмент збалансованого просторового розвитку. *Вісник Львівського університету. Серія географічна*. 2020. Вип. 54. С. 112–123.
16. Олійник В. С. Гідрологічна роль лісів Українських Карпат. Івано-Франківськ : НАІР, 2013. 232 с.
17. Олійник В. С. Паводкорегулююча роль гірських лісів Карпат. *Екологічні та соціально-економічні аспекти катастрофічних стихійних явищ у Карпатському регіоні (повені, селі, зсуви) : матер. Міжнар. наук.-практ. конф. Рахів, 1999. С. 257–260.*
18. Попович С. Ю. Інтеграція природно-заповідного фонду України до загальноєвропейської екологічної мережі. *Екологія та ноосферологія*. 2021. Т. 32, № 1. С. 12–23.
19. Про екологічну мережу України : Закон України. *Відомості Верховної Ради України*. 2004. № 45. Ст. 502.
20. Про Загальнодержавну програму формування національної екологічної мережі України на 2000–2015 роки : Закон України. *Відомості Верховної Ради України*. 2000. № 47. С. 40.
21. Про природно-заповідний фонд України : Закон України. *Відомості Верховної Ради України*. 1992. № 34. Ст. 502.
22. Проценко В. В. Використання ГІС-технологій у просторовому плануванні та моніторингу територій природно-заповідного фонду. *Екологічні науки*. 2019. № 2(25). С. 88–94.
23. Рожко І. М. Рекреаційна оцінка гірських природно-територіальних комплексів для потреб туризму (на прикладі Українських Карпат) : автореф. дис. ... канд. геогр. наук : 11.00.11. Львів, 2000. 175 с.
24. Романів А. С., Романів О. Я. Обґрунтування мережі туристичних маршрутів Національного природного парку «Синевир» на засадах ландшафтознавчих досліджень. *Фізична географія та геоморфологія*. 2004. Вип. 46. Т. 1. С. 243–250.
25. Смалійчук А. Д. Рекреаційна трансформація ландшафтів Чорногірського масиву: сучасний стан та шляхи оптимізації. *Фізична географія та геоморфологія*. 2019. Вип. 1(93). С. 78–86.
26. Смалійчук А. Д., Мельник А. В. Соціально-економічні аспекти функціонування природно-заповідних територій в умовах децентралізації. *Часопис соціально-економічної географії*. 2022. Вип. 32. С. 45–56.

27. Снігурець О. В. Вплив гідротехнічних споруд на іхтіофауну гірських річок. *Біологічні студії*. 2019. Т. 13, № 1. С. 95–104.
28. Стойко С. М. Охорона природи Українських Карпат та прилеглих територій. Київ : Наукова думка, 1980. 261 с.
29. Чернявський М. В. Проблеми збереження старовікових лісів та пралісів Українських Карпат. *Науковий вісник НЛТУ України*. 2016. Вип. 26.4. С. 120–128.

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