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GIS analysis of the boundaries of the Carpathian National Nature Park: Comparison of global and local geodata sources and their importance for environmental monitoring

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Abstract. The relevance of the study lies in the need to ensure high accuracy in determining the boundaries of the Carpathian National Nature Park (CNNP), which is important for the reliability of environmental monitoring using geographic information systems (GIS) and field studies. The conservation of natural ecosystems and effective management of the Carpathian National Nature Park territory are impossible without the integration and analysis of spatial data in geographic information systems, which ensure sound planning of nature conservation measures and control of the state of the environment. The aim of the article was to analyse geospatial datasets (boundary polygons) of the CNNP available in open sources and official materials, compare their accuracy and suitability for analysing environmental indicators, conduct spot field verification, and develop the authors' version of the park's refined boundaries. The study analysed the possibilities of using open geospatial data, in particular satellite images, digital terrain models, and thematic layers of the Global Forest Watch platform in QGIS and ArcGIS environments. A comparison of different sources revealed significant errors in publicly available datasets, leading to distortions in statistical estimates of forest area, land use changes, and the identification of areas of anthropogenic impact. Based on geospatial analysis, field surveys, and comparison of official materials, the authors propose their own version of the refined boundaries of the CNNP. The paper provides an example of how inaccuracies in the boundaries of global monitoring systems, in particular on the Global Forest Watch platform, can significantly alter estimates of deforestation or forest degradation areas. This highlights the need for constant verification and updating of geospatial data for protected areas. The results of the study prove that the combination of

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open data, field research and modern GIS technologies is an effective tool for improving the accuracy of environmental data analysis. The proposed approach can be used as a model for improving the spatial boundaries of other protected areas in Ukraine, promoting sustainable nature use and transparent ecosystem management

Keywords: open data; geospatial layer; satellite imagery; QGI; ArcGIS

INTRODUCTION

Accurate spatial and temporal characterisation of the boundaries of nature conservation areas determines the quality of environmental monitoring, planning of conservation measures and reporting on international environmental obligations. For the Carpathian National Nature Park, located in a complex mountain system with high landscape and biotic diversity, errors in contours can cause systematic deviations in ecosystem area calculations, anthropogenic impact assessments, and site selection for observations (Urbano *et al.*, 2024). In the context of multi-source mapping (global databases, national registers, local geodata), it is necessary to verify the geospatial consistency and methods of integrating such data in order to obtain a single reliable boundary model suitable for management and scientific tasks.

The Carpathian National Nature Park (CNNP) is one of the most important nature conservation sites in Ukraine, located within the Chornohora, Gorgany, and the Pokuttya-Bukovyna Carpathians. Administratively, the park covers the Yaremche, Vorokhta, and Polyanytsya territorial communities of Ivano-Frankivsk region. Its official area is 50,495 hectares, and it encompasses unique mountain ecosystems, including subalpine meadows, beech and fir forests, high-altitude bogs, and rare geological formations (Carpathian National Nature Park, n.d.). It is home to a significant number of endemic, relict and red-listed species of flora and fauna, making the park critically important for biodiversity conservation. Due to the complex terrain, high ecological value and limited area, the accuracy of geospatial data is critical for environmental analysis, nature conservation planning and international reporting.

In scientific works, the issues of boundary compliance, geodata quality and methods of their comparison for protected areas are considered from different perspectives. V. Brusak & V. Shtuglynets (2021) demonstrated the potential of GIS mapping for the systematic inventory of the nature reserve fund (NRF) of the Ukrainian Carpathians: QGIS was used to compile maps of the location of NRF objects by landscape complexes and to assess the representativeness of landscape types; the authors recommended optimising the network of parks for a balanced representation of mountain landscape types. A. Novikov (2021) developed GIS maps of the geomorphological and phytogeographical zoning of the Ukrainian Carpathians in the form of operational geographical units, which increases the consistency of local taxa with modern digital sets and ensures routine use in biogeography. L.V. Shtohryn & D.V. Kasiynchuk (2024), based on morphometric analysis and multivariate statistics, showed the dominance of orographic and climatic factors in the formation of landslide processes in the Carpathian region; the consistency of the model parameters reinforces the requirement for high spatial accuracy of the initial boundaries during territorial hazard assessments. The authors R.L. Kravchynskyi *et al*. (2025) systematised the abiotic components of the environment and described field research and monitoring methods, emphasising the need for validated boundaries as a framework for thematic studies.

The study by J. Randall *et al.* (2022) shows that the integration of field research and interactive visualisations in GIS for invasive species management: mapping spatio-temporal patterns of distribution, creating web applications for navigation and queries, and visualising data from the field helps to align management tactics with landscape changes and prioritise areas of intervention. This approach reinforces the argument for the need for accurate and consistent park boundaries as a basis for spatial analysis and management planning. At the global source level, the Protected Planet/WDPA initiative provides monthly updates and standardisation of data on protected areas; at the same time, the WDPA User Guide outlines limitations in data interpretation and cases of point representation of objects, which affects local analyses. D. Tezel *et al*. (2021) demonstrated the use of 3D GIS and high-resolution datasets to accurately determine the boundaries of protected areas and align them with property boundaries, which is relevant for parks with complex internal land structures. The aim of the study was to compare global and local geodata sources regarding the boundaries of the Carpathian National Nature Park, to quantitatively assess their spatial consistency and errors, and to propose a methodology for constructing a verified GIS model of boundaries suitable for environmental monitoring of the park.

MATERIALS AND METHODS

The study was conducted at the Department of Ecology of Ivan Franko National University of Lviv during the summer of 2025. The following geospatial data sources were used in the study: The World Database on Protected Areas (WDPA) (n.d.) via Living Atlas in Pro – two polygons with an area of 612 km^2 and 500 km^2; OpenStreetMap (OSM) (n.d.) – the primary polygon, with an area of 529 km^2, exported from the platform, partially overlapped the territory of the Carpathian Biosphere Reserve and extended into the Zakarpattia region. This configuration of boundaries did not correspond to the administrative location of the CNNP, which is entirely within the Ivano-Frankivsk region. The author edited the polygon in accordance with the official boundaries of the region and the actual spatial coverage of the park. As a result, the area of the edited layer was 512 km^2, which more accurately reflects the actual territory of the CNNP. Official data from the Carpathian National Nature Park administration (2024) (unpublished materials from the park administration obtained by the authors upon request) was used – a polygon with an area of 499 km^2, which became the basis for further editing. All boundary changes were made exclusively on the basis of this original layer. It should be noted that all polygons with the boundaries of the CNNP analysed in this study were probably created as part of various projects, in particular OpenStreetMap (n.d.), The World Database on Protected Areas (n.d.), as well as an internal polygon used by the park administration for its own mapping, and none of them are officially approved.

This creates additional challenges for researchers using open sources for environmental analysis, as they may use CNNP boundaries from different sources, leading to significantly different characteristics and conclusions about a given territory. It should be noted that different datasets in open environmental information databases have differences in coding systems and cartographic projections, which often leads to incorrect calculations of the actual area of the territory. In most cases, such data only allow working with relative indicators expressed as percentages, rather than absolute values of areas.

To assess the accuracy of the boundaries, the following was carried out: visual analysis of Sentinel-2 satellite images (resolution 10 m) (European Space Agency, n.d.); comparison of boundaries with ecological trails, topographical landmarks and field observations; field verification of the inclusion of important natural features, such as the arboretum, the banks of the Prut River – the Hoverla Research and Conservation Scientific Department, and the peaks of the Chornohora Range. To ensure maximum accuracy of spatial analysis, all layers, including the base layer, were reprojected into the ETRS89 / UTM Zone 35N coordinate system, which is optimal for the park's location – for accurate area calculation. For analysis of the territory on Global Forest Watch (GFW), all polygons were reprojected into the WGS 1984 / EPSG 4326 coordinate system. Data from the Global Forest Watch platform (n.d.) was used to assess the importance of the accuracy of polygons reflecting the boundaries of the CNNP, as well as to demonstrate the practical impact of geometric deviations on environmental indicators.

Assessment of boundary consistency: "Deviation from intersection area (%)" indicator. The "Deviation from intersection area (%)" indicator was used to quantitatively assess the spatial consistency of different sources of park boundaries. Its purpose is to measure the relative size of the uncovered part of the compared polygon relative to the official (baseline) boundary in order to ensure the comparability of results between sets of different areas. A value of 0% means complete coincidence, while higher values indicate increasing discrepancies. In the ArcGIS Pro software environment, the Intersect function was used to create intersection layers for each of the polygons with the base polygon, and the attribute table data was used to determine the difference in the areas of the intersecting polygons, as well as the percentage of overlap with the base polygon. For further analysis of territories by environmental indicators, it was important to understand how much the area intersecting with the base polygon differs from the area of the polygon itself. This indicator was calculated using the formula:

$$\text{Deviation of area from intersection} = |\text{Area of polygon} - \text{Area of intersection}| / \text{Area of baseline polygon} \times 100. \qquad (1)$$

Correlation analysis was performed in Microsoft Power BI (Desktop) on a sample of six polygons (Author, WDPA 612, WDPA 500, OSM 529, OSM 512, CNNP 499). Bubble scatter plots were constructed for pairs of variables: geometric/areal metrics and corresponding ecological indicators were plotted on the axes; the size of the markers is proportional to the polygon area, and the colour codes the data source. Data preparation included bringing percentage indicators to the baseline polygon (Authors') to ensure comparability between sources.

RESULTS AND DISCUSSION

The analysis revealed significant discrepancies between the geospatial data sources used to delineate the boundaries of the Carpathian National Nature Park. Although some layers show a high degree of spatial coincidence with the reference contour, even minor deviations in area and geometry can lead to significant distortions in the calculation of environmental indicators, such as forest loss, fire impact and forest cover growth. A visual comparison of the boundaries of all the geospatial layers considered is shown in Figure 1, which illustrates the nature and scale of spatial discrepancies.

The territory of the CNNP according to The World Database on Protected Areas (n.d.): WDPA 612 – its difference from the base area is 21.3%, the degree of territorial overlap is 86%, and the deviation of its area from the intersection is already 35%. This means that if the WDPA 612 polygon is used to analyse the territory of the CNNP, 35% of its area will not correspond to the actual territory of the CNNP. Thus, it should be emphasised that this geospatial layer cannot be used even for superficial generalised studies or schematic representations of the CNNP. On the other hand, the WDPA 500 polygon has a slight deviation in area – only -0.97%, but 5.8% of its territory is not within the boundaries of the CNNP, and the degree of spatial coincidence with the reference polygon is only 93.23%. The visualisation of these layers is shown in Figure 2.

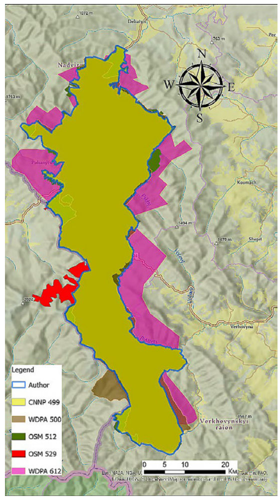

Figure 1. Spatial overlay of the boundaries of the authors' layer of the CNNP with the layers of the WDPA, OSM, and the official CNNP layer
Source: developed by the authors based on The World Database on Protected Areas (n.d.), OpenStreetMap (n.d.)

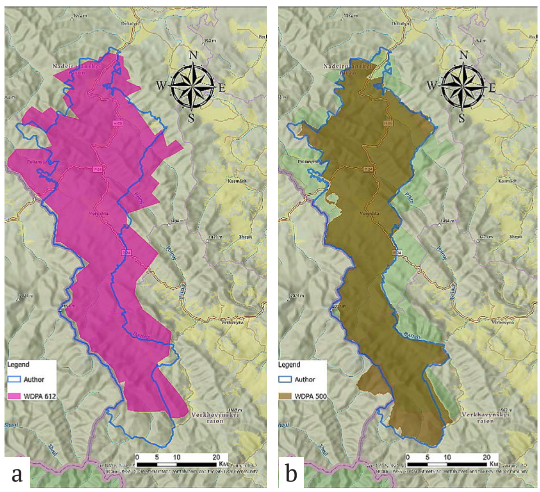

Figure 2. Spatial overlay of the Carpathian NNP boundaries with the authors' layer
Note: a – with the WDPA 612 layer; b – with the WDPA 500 layer
Source: developed by the authors based on The World Database on Protected Areas (n.d.)

CNNP according to OpenStreetMap (n.d.) (Fig. 3): OSM 529 (obtained by direct export to QGIS via the Quick OSM plugin) – the area of the polygon is 529.37 km^2, which is 4.84% larger than the reference area. The degree of territorial overlap with the authors' polygon is 98.60%, i.e. only 1.4% of its territory is not included in the CNNP. At the same time, the deviation of the area from the intersection is 6.24%, which indicates a moderate discrepancy in geometric coverage. It should be noted that this geospatial layer contains a gross error and includes only part of the Carpathian Biosphere Reserve (CBR) (n.d.), namely the Nature Conservation Bureau (n.d.), so it cannot be used as representative of the CNNP. OSM 512 has an area of 512.25 km^2, which is 1.45% less than the reference area. The degree of spatial overlap is 98.57%, meaning that 1.43% of the territory does not correspond to the boundaries of the CNNP. The deviation of the area from the intersection is 2.88%, which is minimal and indicates high accuracy. This polygon is the closest to the authors' among the OSM layers and can be recommended for use in environmental monitoring, but with caution regarding the edge areas.

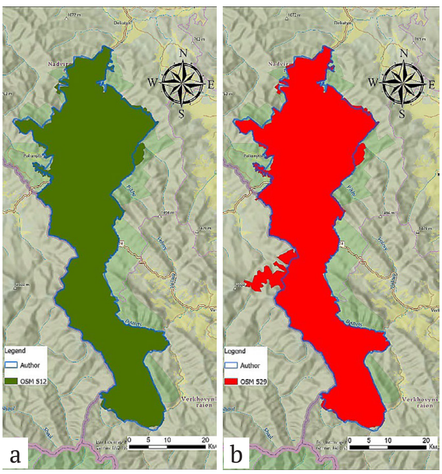

Figure 3. Spatial overlay of the Carpathian NNP boundaries with the authors' layer
Note: a – with OSM layer 512; b – with OSM layer 529
Source: developed by the authors based on OpenStreetMap (n.d.)

The territory of the Carpathian National Nature Park (n.d.) according to the geospatial layer of the CNNP 499: the most accurate, but does not include some ecologically important areas, the area of the polygon is 499.87 km^2, which is 1.01% less than the authors' polygon. The degree of territorial overlap is 98.92%, i.e. only 1.08% of its area does not correspond to the actual boundaries of the CNNP. The deviation of the area from the intersection is 0.08%, which is minimal and indicates high accuracy of geometric coverage. This polygon is the closest to the authors' among all the layers considered, both in terms of area and spatial coincidence (Fig. 4). It can be considered as a basis for use in environmental monitoring, spatial analysis and planning of nature conservation measures. As a result of the authors' reconstruction of the boundaries, an updated polygon with a GIS area of 50,495 ha was created, which fully corresponds to the official data. The reconstruction was carried out exclusively on the basis of the CNNP 499 polygon, to which the territories of the Hoverla Research and Conservation Scientific Department arboretum, the riparian zone of the Prut River, and the peaks of the Chornohora Range were added, which were not included in the original polygon but are actually part of the park's territory according to its functional use and nature conservation documentation.

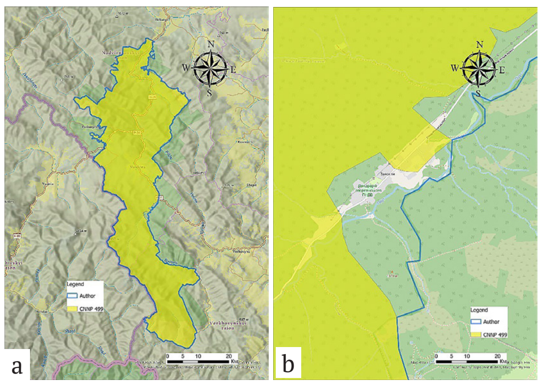

Figure 4. Spatial overlay of the Carpathian NNP boundaries with the authors' layer
Note: a – with the CNNP layer; b – preservation of the details of the authors' restoration on the territory of the arboretum
Source: developed by the authors

Table 1 shows the results of the analysis of polygon areas and their deviations, and Figure 5 shows a visualisation of correlations for various indicators. For comparative calculations and further GIS analysis, the authors' version of the boundaries with an area of 504.95 km² was taken as the basis. As can be seen from Table 1, an important indicator is not only the difference in polygon areas, but also the degree of overlap, i.e. what part of the reference polygon coincides with the base polygon. In the ArcGIS Pro software environment, using the Intersect function, layers of intersection of each of the polygons with the base were created, and through the attribute table data, the difference in the areas of the polygons with the intersection was determined, as well as the percentage of overlap with the base polygon. For further analysis of the territories according to environmental indicators, it was important to understand how much the area intersecting with the base polygon differs from the area of the polygon itself (formula 1) – these data are given in the column Deviation from the intersection area (%) in Table 1.

Table 1. Comparison of CNNP polygons:
Contour overlap and geometric deviations from the authors' layer

Name of polygon	Polygon area (km²)	Intersection area (km²)	Percentage of overlap (%)	Difference between area and intersection (km²)	Deviation of area from intersection (%)	Deviation from area (%)
Authors' 504	504.95	504.95	100.00	0.00	0.00	0.00
WDPA 612	612.57	435.24	86.19	177.33	35.10	21.31
OSM 529	529.37	497.87	98.60	31.50	6.24	4.84
OSM 512	512.25	497.72	98.57	14.53	2.88	1.45
WDPA 500	500.04	470.75	93.23	29.29	5.80	-0.97
CNNP 499	499.87	499.48	98.92	0.39	0.08	-1.01

Source: developed by the authors

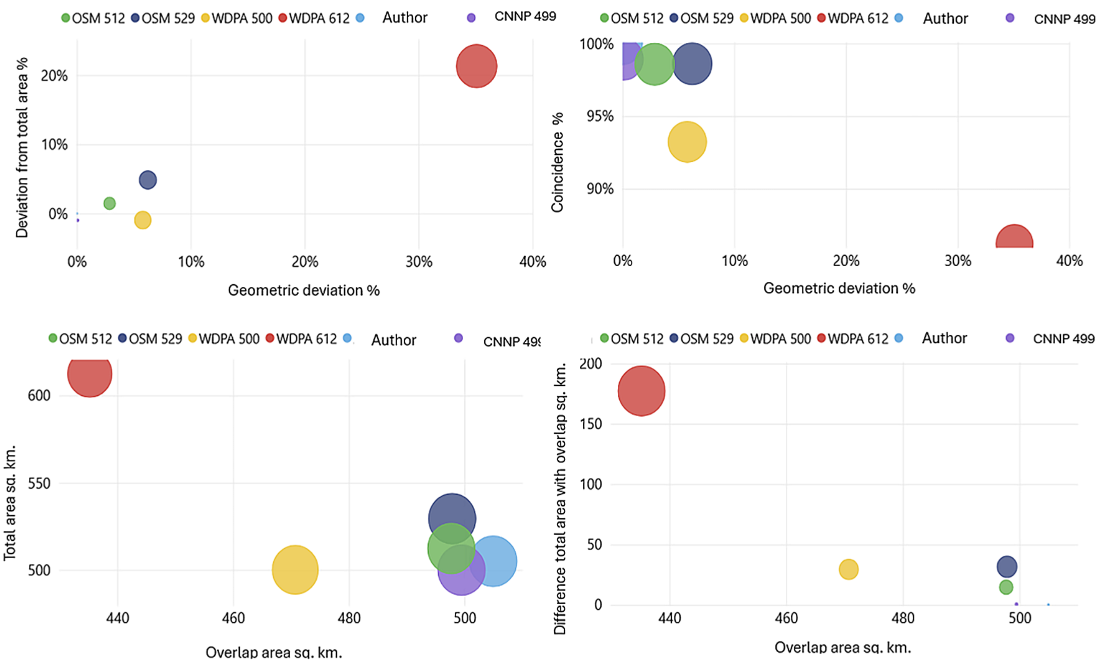

Figure 5. Correlation analysis of spatial characteristics of nature conservation areas boundaries: Relationships between geometric deviation, planar discrepancies and degree of territorial overlap
Source: developed by the authors

Global Forest Watch (n.d.) was selected as a model example of the use of geospatial databases with environmental indicators. It is an open web application for monitoring the state of forests in near real time, used by researchers around the world. The initiative is implemented by the World Resources Institute (n.d.) in partnership with Google, USAID, the University of Maryland, Esri, Vizzuality, and other scientific, non-governmental, and private organisations. The platform uses satellite data, including from NASA MODIS sensors, as well as image processing algorithms to detect tree cover loss, fires, land use changes and other processes. For experimental confirmation of this study, all six polygons representing the boundaries of the CNNP according to various sources (WDPA, OSM, authors', etc.) were uploaded to GFW. Based on these geospatial layers, analytical data on forest cover, forest loss, forest growth and forest fires were obtained, which are summarised in Table 2, and Figure 6 shows a visualisation of the correlation of the layers according to selected indicators. This made it possible to quantitatively assess how even minor deviations in the polygon area can lead to significant distortions in environmental indicators, which is critically important for reliable environmental monitoring.

Table 2. Boundary consistency and deviations in environmental metrics: Forest loss, fires, and forest gain

Name	Forest loss 2001-2024 (ha)	Deviation in forest loss (%)	Forest loss from fires 2001-2024 (ha)	Deviation in forest loss from fires (%)	Forest gain 2000-2020 (ha)	Deviation in forest gain (%)
Authors' 504	1,430	0.00	11	0	212	0.00
WDPA 612	3,880	171.33	28	154.55	320	50.94
OSM 529	1,600	11.89	16	45.46	222	4.72
OSM 512	1,500	4.90	14	27.27	217	2.36
WDPA 500	1,580	10.49	12	9.09	237	11.79
CNNP 499	1,400	-2.10	11	0	208	-1.89

Source: developed by the authors

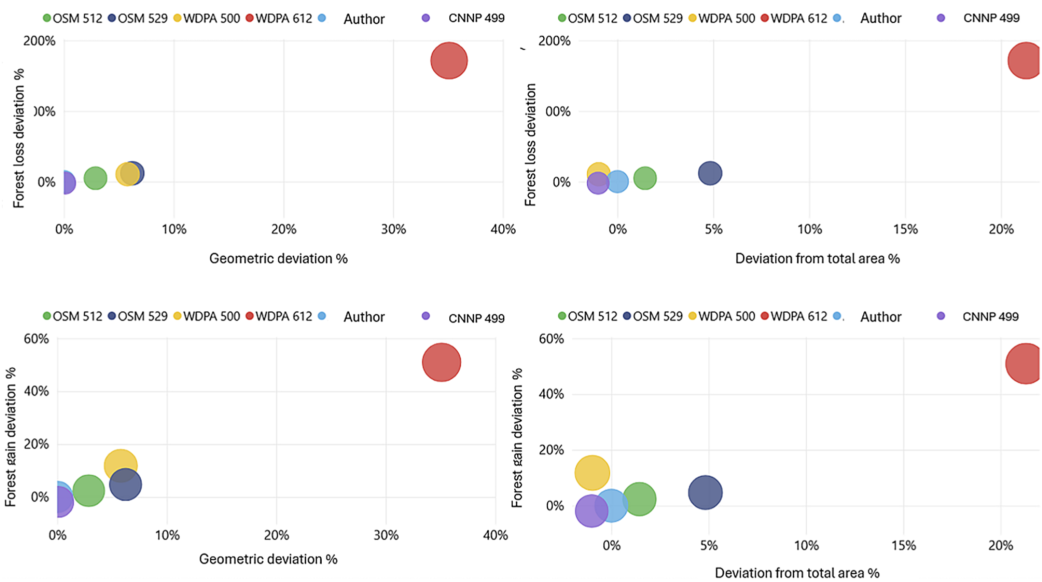

Figure 6. Correlation analysis of the impact of geometric and planar deviations of nature conservation areas on environmental indicators: Forest loss and growth
Source: developed by the authors

To compare environmental indicators for forest loss and gain in the CNNP territory, the WDPA 500 and CNNP 499 geospatial layers were used, with almost identical minimum deviations from the authors' geospatial layer at -0.97% and 1.01%, respectively. However, when the deviation is considered in terms of forest loss, a completely different picture emerges: for WDPA 500, it is 10.49%, and for CNNP 499, it is -2.10%, i.e. a difference in the range of 12.5%; for forest loss from fires, it is 9.09% and 0% respectively, and for forest growth, it is 11.79% and -1.89% respectively. These examples prove that even a small difference in the area and geometry of the polygon (1% in area and 5.8% in geometry for this example) can lead to significant distortions in the calculation of environmental indicators.

Despite minor geometric differences between the OSM 529 and OSM 512 layers compared to the authors' polygon (area deviation is 4.84% and 1.45% respectively, and spatial coincidence is over 98.5%), the analysis of environmental indicators shows significant discrepancies: forest cover losses for OSM 529 exceed the reference value by 11.89%, and for OSM 512 – by 4.90%; forest losses from fires increase by 45.46% and 27.27%, respectively; forest growth also shows deviations – 4.72% for OSM 529 and 2.36% for OSM 512. These results confirm that even minimal discrepancies in area and boundary configuration can lead to significant distortions in the calculation of environmental indicators, especially when assessing forest loss, the impact of fires and forest cover dynamics. Taking the most critical example from WDPA 612, its 21% difference in area and 35% difference in geometry already distorts the indicators for forest loss by 171.33%, forest loss from fires by 154.55% and forest growth by 50.94%. Figure 7 shows an example of a report from Global Forest Watch.

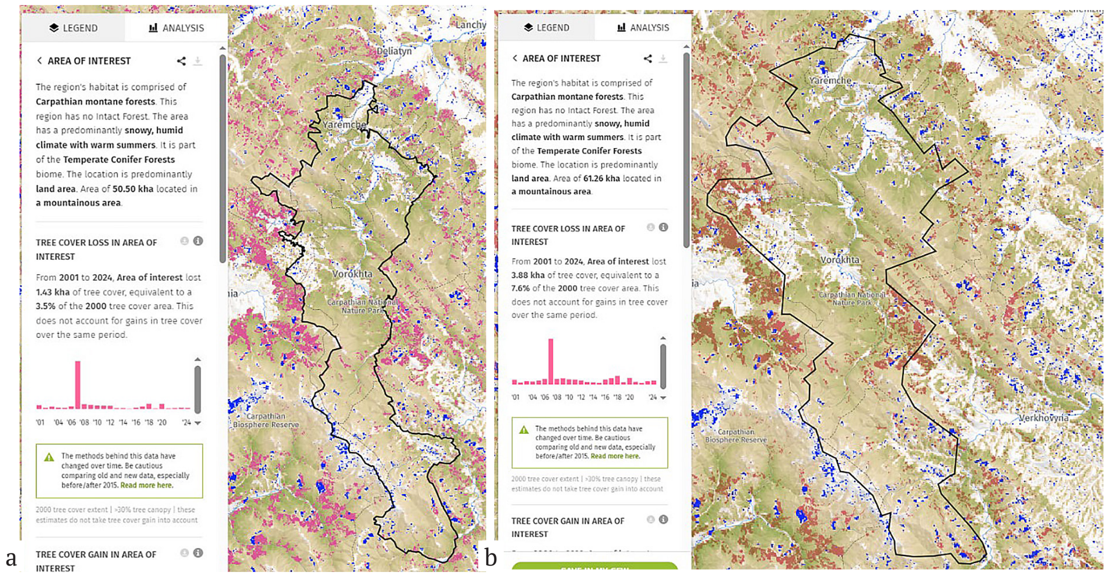

Figure 7. Example of a Global Forest Watch analytical report
Note: a – for the Authors' geospatial layer; b – for the WDPA 612 geospatial layer
Source: developed by the authors based on Global Forest Watch (n.d.)

The results confirm the critical sensitivity of environmental assessments to the accuracy and consistency of the boundaries of nature conservation areas. Even with high spatial overlap (≈98-99%), small differences in area and geometry (1-5%) lead to significant discrepancies in forest loss, growth and fire indicators. This indicates the need to apply unified data collection and processing methods to improve the accuracy of assessments. In addition, such discrepancies can influence management decisions and the development of forest protection strategies. Below is a comparative analysis with the works of other authors who have researched related topics.

Researchers V. Brusak & V. Shtuglynets (2021) demonstrated that the representativeness of mountain landscape types in the Carpathian NRF largely depends on the quality of the source geodata: the generalisation of contours and the inconsistency of projections lead to systematic biases in the representation of landscape complexes. This is consistent with the findings of this study: polygons with similar areas but different contours (e.g., OSM 512 vs. the authors' layer) show noticeable deviations in ecological metrics (forest loss +4.90%). The difference lies in the focus: V. Brusak & V. Shtuglynets assess landscape representativeness, while this study quantitatively shows how contour errors are transferred to applied ecological indicators through the "Deviation from intersection area (%)" indicator. The study by X. Kang *et al*. (2024) demonstrated that a systematic framework for defining the boundaries of protected areas increases spatial accuracy and territorial integrity, which directly affects the reliability of ecosystem status assessments and the zoning of management priorities. This is consistent with the present approach to metric verification of boundaries and demonstrates the importance of integrated analysis to reduce errors in ecological indicators.

A. Novikov (2021) proposed GIS-oriented zoning (geomorphological and phytogeographical) as a set of operational units consistent with modern digital data. His approach emphasises the need to "align" thematic taxa with reference spatial frameworks. These results confirm this thesis with practical examples: differences in boundary configurations (even for almost identical areas) significantly affect aggregated ecological assessments (e.g., WDPA 500 vs. CNNP 499: deviation in forest loss 10.49% vs. -2.10%). The difference in approaches is that this study focuses on metric verification of boundary consistency between sources before linking them to taxa and indicators. L.V. Shtohryn & D.V. Kasiynchuk (2024) showed the dominance of orographic and climatic factors in the formation of landslide processes, which requires high spatial accuracy of base layers for territorial hazard assessments. The results of this study are consistent: for mountain parks, where boundaries often follow natural boundaries (watersheds, ridges), each "shift" of the boundary line can change both the hazard area and its statistical generalisation. The article adds quantitative granularity to this sensitivity through coincidence metrics and "Deviation from intersection area (%)", demonstrating that geometric boundary errors translate into errors in the assessment of environmental risks and processes. Research by H. Gao *et al*. (2022) shows that spatial modelling of conservation networks and boundary accuracy directly affect the effectiveness of management and prioritisation of areas. This confirms the importance of polygon alignment and metric control for valid spatial conclusions.

Researchers R.L. Kravchynskyi *et al*. (2025) emphasise the standardisation of field methods and systematic monitoring of abiotic components of CNNP, which requires a validated spatial framework. This study provides such a framework: the authors' polygon (50,495 ha) is reduced to the official area, taking into account omitted functionally important areas (the Hoverla Research and Conservation Scientific Department arboretum, the Prut riparian zone, and the peaks of the Chornohora Range). The similarity lies in the requirement for geometry validation. J. Randall *et al.* (2022) demonstrated the effectiveness of integrating field surveys, web GIS, and visualisation tools for invasive species management. The conclusions of this study complement their results: the correctness of boundaries is a prerequisite for valid observation routes, prioritisation of areas and interpretation of spatio-temporal patterns. The examples given in the article (OSM discrepancies 529 due to the inclusion of part of the CBR and the corresponding overestimation of forest loss and fires) illustrate that even a "high-quality" workflow becomes unreliable without verified contours.

The World Database on Protected Areas (n.d.) explicitly points to limitations in data interpretation, particularly cases where objects are represented by points and heterogeneity in the origin of geometries. This is fully consistent with the identification of critical discrepancies: WDPA 612 shows an area deviation of 35% and an overestimation of environmental indicators (forest loss +171.33%; fires +154.55%). Studies by P. Potapov *et al*. (2022) and A. Tyukavina *et al*. (2022) demonstrated a methodology for global detection of tree cover loss based on satellite data and post-processing algorithms. The results of this study are conceptually consistent: aggregated estimates on the GFW platform are sensitive to the choice of input polygon. This study demonstrates that contours with almost equal areas but different geometric consistency (e.g., WDPA 500 and CNNP 499) yield different loss results (+10.49% vs. -2.10%) and gains (+11.79% vs. -1.89%). This is a practical difference: while P. Potapov *et al*. and A. Tyukavina *et al*. focus on change detection algorithms, this study shows how the geometry of administrative nature conservation boundaries scales the error when aggregating these changes.

In their study, L. Kleinewillinghöfer *et al*. (2022) proposed an unbiased assessment of areas using Copernicus High Resolution Layers and reference data; the approach is consistent with the principle of "agreed area → valid indicators" and can be used as a baseline area validation for the final CNNP boundary model before aggregating losses/gains. Researchers M. Jurišić *et al*. (2023) and O. Chaskovskyy *et al*. (2025) showed that ecological sensitivity zoning schemes and visitor forecasts in national parks depend on the accuracy of the spatial framework; it has been established that small contour discrepancies between sources (OSM vs. authors' layer) can shift management priorities (observation routes, load zoning). Researchers M.S. Parvez & X. Feng (2024) proposed a general method of spatial delimitation combining optimisation and user control; This approach supports the logic of a "quality gate": before linking taxa/boundary indicators, they should be algorithmically reconciled between sources and undergo a metric audit (coincidence, "Deviation from intersection area (%)"). M. Deputat *et al*. (2025) demonstrated, using the Carpathian region as an example, that the interpretation of climate-sensitive indicators (NDSI, snow cover) in the mountains depends on correct zonal binding; the results obtained complement this conclusion with practice: different contours scale the total estimates of changes even for almost equal areas.

Scientists V. Ruschak & I. Chepurnyi (2025) and M. Karabiniuk *et al*. (2025) emphasise that to ensure the accuracy of remote assessments, it is necessary to have a coordinated polygon, since proper coordination of boundaries is a key condition for the stability of results. This confirms the importance of accurately defining the boundaries of protected areas, such as the Carpathian National Nature Park, to ensure the reliability of environmental data and effective monitoring of the state of the environment. The study by X. He & H. Wei (2023) highlights the importance of accurately defining the boundaries of protected areas for biodiversity conservation and effective natural resource management, which is relevant to this study. The authors point to the need to integrate geospatial data through GIS and satellite imagery to improve monitoring accuracy, identify errors in publicly available datasets, and refine park boundaries, which is critical for assessing forest area and land use changes. The results of the study confirm the effectiveness of combining open data, field research, and modern GIS technologies to improve the management of protected areas, which is important for sustainable nature management.

A body of previous research confirms the basic requirement: validated and agreed boundaries are a prerequisite for correct spatial conclusions in mountain parks. The contribution of this study is to operationalise this requirement through the metric "Deviation from intersection area (%)", a systematic audit of multi-source polygons (WDPA, OSM, local CNNP data) and a demonstration of practical implications for monitoring forest loss, fires and growth. The differences between sources (especially WDPA 612) are not "cosmetic": they cause significant distortions in environmental indicators and can lead to misguided management decisions. The proposed approach provides a reproducible, quantitatively sound route to a single verified model of CNNP boundaries and can be replicated for other mountain NRF in Ukraine.

CONCLUSIONS

Accurate delineation of protected areas is critical to ensuring reliable environmental monitoring, especially in complex mountainous terrain such as that found in the Carpathian National Nature Park. Microclimatic zoning, high biodiversity with endemic and rare species, and intense anthropogenic pressure – in particular recreational use and forestry – necessitate maximum accuracy of geospatial data. The use of inaccurate polygons from global databases such as WDPA can lead to erroneous scientific conclusions, incorrect monitoring planning, and errors in international reporting. Even minor deviations in area (1-5%) can cause significant errors in calculations of indicators such as forest cover loss, forest fire area and forest growth, which in turn affects the quality of environmental assessments and the effectiveness of nature conservation planning.

The authors' research demonstrates the need for local verification of the boundaries of nature conservation areas and proposes an updated CNNP polygon as a reliable tool for further environmental assessments. The authors' polygon (504.95 km^2) with a full intersection (100%) was taken as a reference. The CNNP polygon 499 showed a minimal deviation in area (0.08%) and, accordingly, insignificant deviations in environmental indicators (forest loss -2.10%; growth -1.89%), which confirms the correctness of the locally verified boundaries. On the other hand, geometrically divergent polygons lead to significant shifts in metrics. For OSM 512, with an area difference of 2.88% from the intersection, an increase in forest loss of +4.90% and fire loss of +27.27% is recorded. For OSM 529, with an area difference of 6.24%, forest loss is +11.89% and fire loss is +45.46%. WDPA 612 is particularly indicative: an area difference of 35.10% and overestimated indicators (forest loss +171.33%; fires +154.55%; increase +50.94%), which makes the use of such a contour unacceptable even for overview tasks. At the same time, WDPA 500 (area difference 5.80%) shows moderate but significant deviations (forest loss +10.49%; growth +11.79%), which can change management priorities and interpretations. There was a justified need for local verification of boundaries and the use of the updated CNNP polygon as a reference framework for environmental assessments, spatial planning and reporting. It is recommended to use Sentinel 2 (Copernicus) satellite products for land cover and NDVI change analysis, MODIS and Landsat for long-term series, Global Forest Watch for forest loss assessment, and OpenStreetMap together with local geodata for infrastructure mapping. In total, even 1-5% geometric error can scale indicator errors to >10%, confirming that validated and agreed boundaries are a prerequisite for correct conclusions and effective nature conservation management. Prospects for further research lie in the development of integrated methods for continuous local verification of CNNP boundaries using multi-temporal satellite data, automated GIS algorithms, and field observations to improve the accuracy of environmental monitoring and the soundness of management decisions.

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ГІС-аналіз меж Карпатського НПП: порівняння глобальних і локальних джерел геоданих і важливість для екологічного моніторингу

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Анотація. Актуальність дослідження полягає у необхідності забезпечення високої точності визначення меж Карпатського національного природного парку (КНПП), що є важливим для достовірності екологічного моніторингу із застосуванням геоінформаційних систем (ГІС) та польових досліджень. Збереження природних екосистем і ефективне управління територією Карпатського національного природного парку неможливі без інтеграції та аналізу просторових даних у геоінформаційних системах, що забезпечують обґрунтоване планування природоохоронних заходів і контроль стану довкілля. Метою статті був аналіз геопросторових наборів даних (полігонів меж) КНПП, доступних у відкритих джерелах та офіційних матеріалах, порівняння їхньої точності та придатності для аналізу екологічних показників, проведення точкової польової верифікації та розробка авторського варіанта уточнених меж парку. У дослідженні проаналізовано можливості використання відкритих геопросторових даних, зокрема супутникових знімків, цифрових моделей рельєфу, а також тематичних шарів платформи Global Forest Watch у середовищах QGIS та ArcGIS. Порівняння різних джерел показало наявність значних помилок у публічно доступних наборах даних, що призводить до викривлень у статистичних оцінках площі лісів, змін землекористування та визначення зон антропогенного впливу. На основі геопросторового аналізу, польових обстежень і співставлення офіційних матеріалів запропоновано авторський варіант уточнених меж КНПП. У роботі наведено приклад того, як неточності меж у глобальних системах моніторингу, зокрема на платформі Global Forest Watch, можуть суттєво змінювати оцінку площ вирубок або деградації лісів. Це підкреслює необхідність постійної перевірки та оновлення геопросторових даних для природоохоронних територій. Результати дослідження доводять, що поєднання відкритих даних, польових досліджень і сучасних ГІС-технологій є ефективним інструментом для підвищення точності аналізу екологічних даних. Запропонований підхід може бути використаний як модель для вдосконалення просторових меж інших природоохоронних територій України, сприяючи сталому природокористуванню та прозорому управлінню екосистемами

Ключові слова: відкриті дані; геопросторовий шар; супутникові знімки; QGIS; ArcGIS