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Environmental Impact on forest ecosystems using remote sensing data: case study of Novhorod-Siverske Polissia (Ukraine)

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SUMMARY

The aim of the study is to present the research results on long-term anthropogenic and military operation impacts on forest ecosystems of Novgorod-Siverske Polissia to improve management of border areas and understand further natural resource management. To achieve this goal, natural and anthropogenic forest covers were considered and analyzed, as well as existing objects of the nature reserve fund located on the territory of Novgorod-Siverske Polissia. Analysis of time series of remote data for mapping long-term trends and periodic components of the studied area showed that one of the most informative for detecting long-term changes are the average values for the entire analysis period and the average increments of leaf area index for a certain observation period. Changes in the leaf area index are considered on the example of the studied border area. Using the original multispectral satellite images, maps of the spatial distribution of the rate of leaf area index changes, integrated over 6 years due to both indirect and direct anthropogenic impact, complicated by hostilities, were constructed.

Keywords: Disturbed forest ecosystems; Multispectral space imageries; Leaf area index.

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Introduction

A distinctive feature of the Novhorod-Siverske Polissia region is its strategic location at the junction of the borders of Ukraine, Russia, and Belarus. Within the Chernihiv Oblast, the state border with Russia stretches for more than 200 km. The border areas are characterized by significant diversity in social, ethnic, and economic conditions, as well as in the distribution, structure, and development of natural ecosystems.

This study focuses on natural complexes that are simultaneously affected by climate change and the exploitation of natural resources, as well as by increasing anthropogenic impacts and the consequences of military operations during the recent years of armed conflict. The combination of these factors has highlighted the need for a more comprehensive understanding of the ecological potential of forest ecosystems, their sustainable use, and the spatial and temporal dynamics of natural complexes. Such knowledge is crucial for facilitating the restoration of affected landscapes and ensuring effective long-term land management within modern territorial communities.

Method and Theory

In the early days of the full-scale invasion, enemy troops moved along the existing infrastructure of the Novhorod-Siverske Polissia region. The movement of heavy equipment, the construction of fortifications, and combat operations are damaging the soil cover (Ovsianyi, 2023; Uruskyi et al., 2024). This leads to vegetation degradation and exacerbates wind and water erosion. Fallen rockets and unexploded ordnance remain in the forests.

The nature reserve sites in the study region are characterized by a large number of small-scale areas (more than half of the sites cover an area of up to 100 hectares). Among these sites, the Mezyn and Desna-Starogut National Nature Parks are particularly noteworthy (Figure 1).

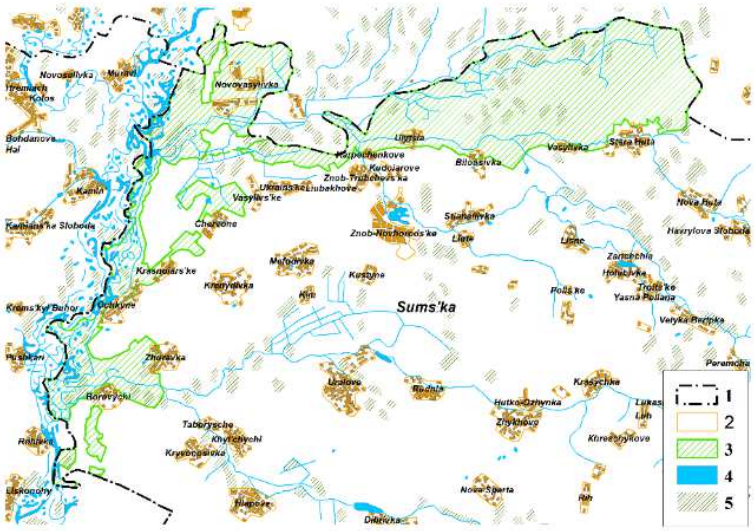

***Figure 1**. Research Area of the Novhorod-Siverske Polissia (1 - State border, 2 – towns, 3 - territories of the national nature parks, 4 – water bodies, 5 – swamps)*

The condition of forest ecosystems was assessed based on changes in the leaf area index (LAI), a key quantitative indicator of dense vegetation (Dudar, et al., 2026). The open-access, free Sentinel-3/OLCI LAI version 1.1 product (https://land.copernicus.eu/en/products/vegetation/leaf-area-index-300m-v1.0), developed as part of the European Copernicus Programme and available at a resolution of 300 m for the entire globe every 10 days starting in 2020, was selected as the primary source of satellite data (see specifications at https://sentiwiki.copernicus.eu/web/s3-olci-instrument), and,

accordingly, the derived information product LAI (https://land.copernicus.eu/en/products/vegetation/leaf-area-index-300m-v1.0).

An important biophysical parameter of vegetation, the leaf area index (LAI), is a dimensionless variable and the ratio of leaf area to a unit of ground surface area. This ratio can be linked to gas exchange and vegetation processes such as photosynthesis (Duchemin et al., 2006), evaporation and transpiration (Tran et al., 2023, Jongschaap, 2006, Cleugh et al., 2007), precipitation interception (Dietz et al., 2006), and carbon flux (Soegaard, 1999; Leuning et al., 2005; Chen et al., 2007). LAI can serve as an indicator of forest stress; thus, it can be used to study the relationships between environmental stress factors and insect damage to forests (Johnson et al., 2024)).

Results

Let's take a look at the Desnyansko-Starogutsky National Nature Park, located in the far northeast of the Novhorod-Siverske Polissia region along the border with Belarus, where the Starogutsky Forests have been preserved, featuring ancient trees, swamps, meadows, and rare species of plants and animals. As a result of fighting and heavy shelling, not only cities but also protected areas are being destroyed. Numerous areas of forest have been damaged—trees have been uprooted, broken, or blown up by mines, and many living pine and birch trees have been destroyed. Numerous unexploded mines and shells remain within the park's territory. Maps of LAI distribution within the study area were obtained annually during the peak of the growing season—June—from 2020 to 2025 (Figure 2).

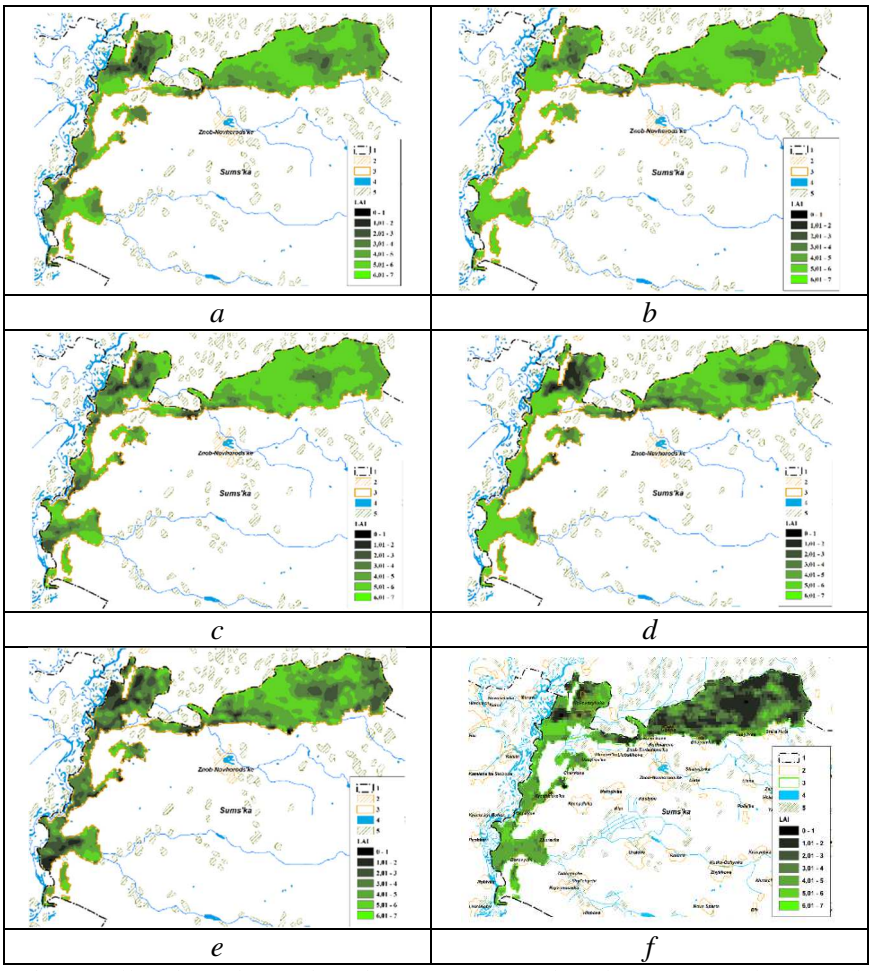

***Figure 2**. Satellite-based LAI distribution maps within the Desnyansko-Starohutskyi National Nature Park*
(1 – State border, 2 – territory of the national nature park, 3 – towns, 4 – water bodies, 5 – swamps): a – 2020, b – 2021, c – 2022, d – 2023, e – 2024, f – 2025

In Figure 3 the spatial distribution of LAI change rate within the study area integrated over 6 years is shown.

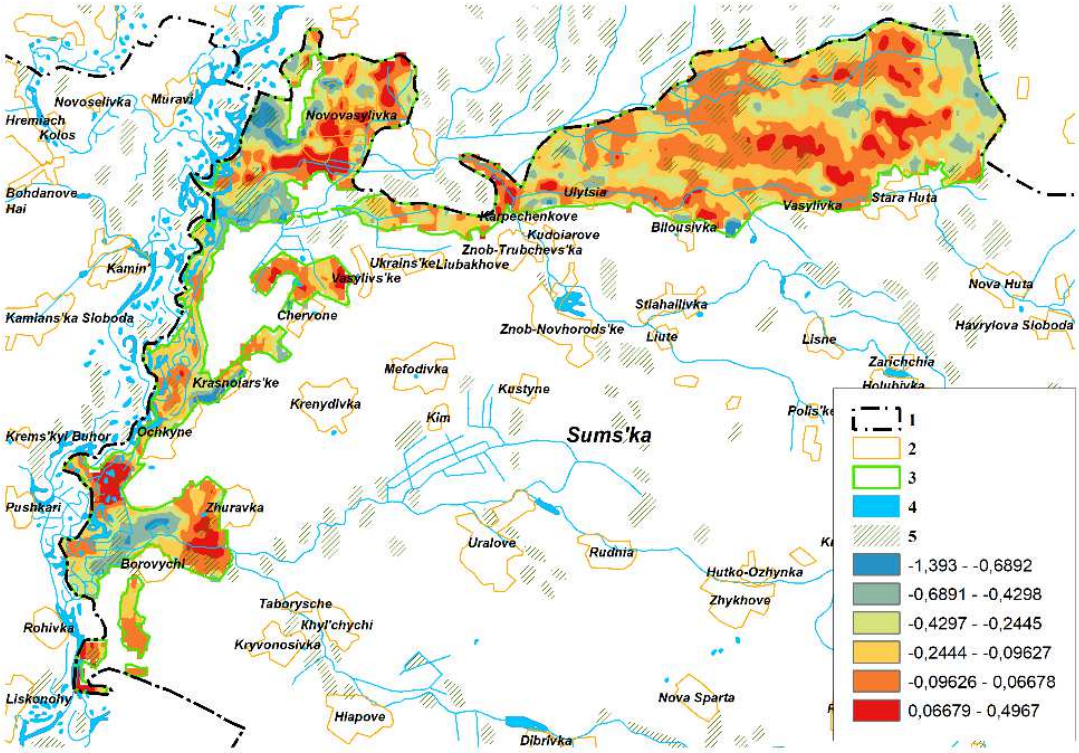

***Figure** 3. Satellite-based LAI change rate distribution map within the Desnyansko-Starohutskyi National Nature Park*
(1 – State border, 2 – territory of the national nature park, 3 – towns, 4 – water bodies, 5 – swamps)

Conclusions

The results of this study highlight the value of remote sensing–based mapping of the Leaf Area Index (LAI) as an effective indicator for assessing the condition and vulnerability of forest ecosystems. Using the Novhorod-Siverske Polissia region as a case study, the research demonstrates that time-series analysis of satellite remote sensing data provides a reliable and efficient approach for monitoring land surface dynamics in remote and difficult-to-access areas. This methodology enables the identification of both long-term trends and periodic variations in vegetation characteristics. Among the most informative indicators of long-term ecosystem change were the mean LAI values over the entire observation period and the average rate of LAI change during specific monitoring intervals.

Based on multispectral satellite imagery, spatial distribution maps of LAI—the principal quantitative indicator of vegetation structure and productivity—were generated, and long-term temporal datasets were developed.

The estimated linear trend of LAI dynamics demonstrated satisfactory accuracy, with a root mean square error (RMSE) of 0.527 across the study area. The annual rate of LAI change ranged from –1.74 to 1.68 year^{-1}, with a mean value of –0.165 year^{-1}, indicating an overall decline in vegetation condition throughout the region.

The analysis of the Desniansko-Starohutskyi National Nature Park further confirmed these trends. By 2024, the area characterized by very low LAI values had expanded to 45.98 ha, representing a 3.4-fold increase compared with 2020. Conversely, the extent of areas with high LAI values declined by

nearly 1.8 times over the same period. These findings indicate a substantial deterioration of vegetation health by 2024, which can be attributed not only to natural environmental factors but also to the indirect effects of military activities that have adversely affected forest ecosystems within the study area.

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