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Spatial and Temporal Monitoring of Rangelands by the Use of Satellite-derived Indices within the Rural Territorial Community

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SUMMARY

Rangelands are important natural and semi-natural ecosystems that provide a number of vital ecosystem functions. Assessing the state of rangelands based on geoinformation products and remote sensing data serves as a key mechanism for regulating their productivity and monitoring the seasonal dynamics of the grass cover. The study involves geospatial monitoring of the state of natural meadows, pastures, and open areas with herbaceous vegetation, as well as their productivity, based on the use of the 10-day satellite products for Leaf Area Index (LAI, v1 RT6, 2014–2026), Gross Dry Matter Productivity (GDMP, v1 RT6, 2014–2026) with a spatial resolution of 300 m, and Normalized Difference Vegetation Index (NDVI, v3, 2014–present). A statistical analysis was conducted to assess the condition of rangelands and evaluate their phenology. The GDMP value varied throughout the study period from 431 kg DM/ha/day in May to 808 kg DM/ha/day in June, reaching a seasonal maximum. A decrease in the index was observed to 702 in July and 619 in August. For leaf area, the index increased from 8.2 m^2/m^2 in May to 11.7 in June, gradually decreased to 10.3 in July, and dropped significantly to 6.2 in August. The NDVI remained relatively stable throughout the season - ranging from 0.62 in May to 0.70 in June, 0.71 in July, and 0.68 in August. Therefore, the NDVI, GDMP and LAI enabled the assessment of rangeland state throughout the growing season, specifically in terms of potential biomass yield, leaf area, grass stand density.

Keywords: GDMP; LAI; NDVI; Productivity indicators.

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Introduction

Rangelands are important natural and semi-natural ecosystems that provide a forage base for live-stock and perform vital ecosystem functions, including contributing to biodiversity conservation, water regulation, and organic carbon sequestration (Teague & Kreuter, 2020; Harmon et al., 2023). Excessive pressure or the complete cessation of rangeland use can lead to a decline in biodiversity, degradation of vegetation cover, and impairment of the ecological condition of territories (Bardgett et al., 2021; Bengtsson et al., 2019). Rangelands also play an equally important role in the global carbon cycle (Eze et al., 2018; Wang et al., 2018). Due to their continuous vegetation cover and well-developed root systems, they protect soils from water and wind erosion, improve soil structure and water-holding capacity. Their functioning ensures the preservation of soil fertility and increases soil resistance to degradation processes (Xu et al., 2018; Teague & Kreuter, 2020; Harmon et al., 2023). A significant proportion of the biomass of perennial grasses is localized in the root system, which enables grasses to accumulate substantial stocks of organic carbon in the soil. Rational grazing management contributes to increasing the rate of carbon sequestration, improving nitrogen and phosphorus cycling, and reducing nutrient losses to the environment. Therefore, modern concepts of sustainable land use consider rangelands as an important natural mechanism for mitigating the effects of climate change (Xu et al., 2018; Teague & Kreuter, 2020; Harmon et al., 2023). From the perspective of land management and land use planning, rangelands are among the fundamental elements in the organization of agricultural enterprises' territories. When developing land management plans, factors such as land productivity, ecological condition, erosion risk, water regime, slope steepness, accessibility for mowing/grazing, and other natural factors are taken into account (Kokhan et al., 2020, Kokhan et al., 2024). Assessing these characteristics is a necessary prerequisite for planning measures aimed at the rational use of land, preventing degradation, and restoring the productivity of forage lands (Teague & Kreuter, 2020).

In the current context of climate change, the intensification of agricultural production, and the need to ensure sustainable land resource management, systematic monitoring of the state of rangelands has become particularly important (Bilous et al., 2022). Traditional field surveys are labor-intensive and do not provide timely information for large areas. Therefore, remote sensing methods and geoinformation products are becoming increasingly widespread, as they allow for the assessment of the spatial distribution of vegetation's biophysical characteristics, the determination of grass stand productivity, the analysis of seasonal phenological dynamics, and the right-time detection of any signs of grass stand degradation (Harmon et al., 2023; Pergola et al., 2024). Assessing the state of rangelands based on geoinformation products and remote sensing data serves as a key mechanism for regulating their productivity and monitoring the seasonal dynamics of the grass cover (Rapiya et al., 2024). For example, GDMP (Gross Dry Matter Productivity, kg DM/ha/day) estimates the total potential biomass yield produced by plants, excluding losses associated with plant respiration. NDVI (Normalized Difference Vegetation Index) measures the greenness and photosynthetic activity of vegetation based on the difference between near-infrared and red reflectance, while LAI (Leaf Area Index, m^2/m^2) determines the total one-sided leaf area per unit of ground surface area, representing vegetation canopy density. Given the relevance of this issue, the study involves geospatial monitoring of the state of natural meadows, pastures, and open areas with herbaceous vegetation, as well as their productivity, based on the use of geoinformation products and the NDVI vegetation index.

Methods

The study was conducted using the model territory of the Stepanetska hromada in Cherkasy district as a case study. The QGIS software was used, and the following geoinformation products were applied: the NASADEM Merged DEM Global 1-arc-second V001 digital elevation model, ESRI 10m Annual Land Cover maps (2017–2025), and the 10-day satellite products for Leaf Area Index (LAI, v1 RT6, 2014–2026), Gross Dry Matter Productivity (GDMP, v1 RT6, 2014–2026) with a spatial resolution of 300 m (Copernicus Land Monitoring Service), and Normalized Difference Vegetation Index (NDVI, v3, 2014–present). The data were obtained from the Google Earth Engine and Copernicus Browser platforms. All source materials were transformed to the WGS 84 / UTM Zone 36N (EPSG:32636) coordinate system, standardized by spatial resolution, and cropped to the boundaries of the study areas.

Based on the land cover map, polygons of the Rangeland class (meadows/pastures/open areas with herbaceous vegetation) were identified, for which monthly values were calculated for May–August 2025. For NDVI, the arithmetic means of three 10-day images were determined; for LAI and GDMP, the sums of 10-day values for the month were calculated. The digital values were converted into physical values. Using zonal statistics, the average values of the indicators were determined within the Rangeland polygons, followed by the export of data to IBM SPSS Statistics v 27. In addition to the attribute table of Rangeland polygons, slope steepness values calculated using NASADEM, as well as data on agricultural soil groups and the degree of soil erosion, were included.

Results

The territory of the Stepanetska hromada is characterized by a significant diversity in soil cover. In terms of area, chernozems predominate: deep chernozems with low organic matter content (46%), deep leached chernozems with low organic matter content (17%), and podzolized chernozems (11%). Slopes not exceeding 3 degrees are predominant in the territory. However, in the southeastern and southern parts of the territory, there are slopes ranging from 5–7 to 7–12 degrees and exceeding 12 degrees. This has significantly influenced the development of the agricultural sector. It is in this part of the community that the majority of natural meadows, pastures, and open grassy areas are concentrated. A total of 61 agricultural soil groups have been identified within the community. They are grouped into five categories based on the degree of water erosion: unwashed, slightly washed, moderately washed, heavily washed, and severely washed. The median slope value for all the slopes on which the studied land plots are located was determined to be 6.8 degrees (standard deviation was 1.95). Unwashed soils are characterized by a median slope of 5.1 degrees, slightly washed soils by 6.0, moderately washed by 6.9, heavily washed by 7.7, and severely washed - by 8.0 degrees.

A statistical analysis was conducted to assess the condition of rangelands and evaluate their phenology based on GDMP, LAI, and NDVI data. Spearman's correlation coefficient *rs* was used - a nonparametric statistical measure applied to determine the strength and direction of the relationship between two variables represented by geoinformation products. It assesses the monotonic relationship between variables, i.e., whether the values of one variable increase in tandem with the increase of the other. NDVI is widely used to assess the condition of rangelands, particularly for monitoring plant growth and the start of phenological phases, and - in conjunction with GDMP - to determine the productivity of agrophytocenoses and the accumulation of total dry matter produced by plants as a result of growth. GDMP is determined directly from NDVI data, so dense, healthy vegetation with a high NDVI absorbs more light; therefore, it is used to model photosynthetic intensity and calculate biomass accumulation over a specific period.

Based on the analysis of the relationship between variables, ideal linear monotonically increasing relationships were established between the parameters in 2025 at a significance level of 0.01 - NDVI_May/GDMP_May had a correlation coefficient (*rs*) of 0.97; in July, GDMP showed a strong positive correlation with LAI and NDVI: GDMP_July/LAI_June (*rs* = 0.87), GDMP_July/LAI_August (*rs* = 0.97), and GDMP_July/NDVI_June (*rs* = 0.90). The relationship between LAI and GDMP was not strictly linear. Typically, it follows an asymptotic or exponential curve. An increase in the number and area of leaves significantly improved light absorption and GDMP growth. However, this relationship reaches a saturation point where the leaves absorb the maximum amount of light, and further increases in LAI result in only a slight increase in GDMP. Statistical analysis was performed on data from all four periods of grass growth and development across all available spatial units within the community's territory. The GDMP value varied throughout the study period from 431 kg DM/ha/day in May to 808 kg DM/ha/day in June, reaching a seasonal maximum. A decrease in the index was observed to 702 in July and 619 in August. For leaf area, the index increased from 8.2 m^2/m^2 in May to 11.7 in June, gradually decreased to 10.3 in July, and dropped significantly to 6.2 in August. In contrast to the previously mentioned productivity indicators, the NDVI remained relatively stable throughout the season - ranging from 0.62 in May to 0.70 in June, 0.71 in July, and 0.68 in August (Figures 1-3).

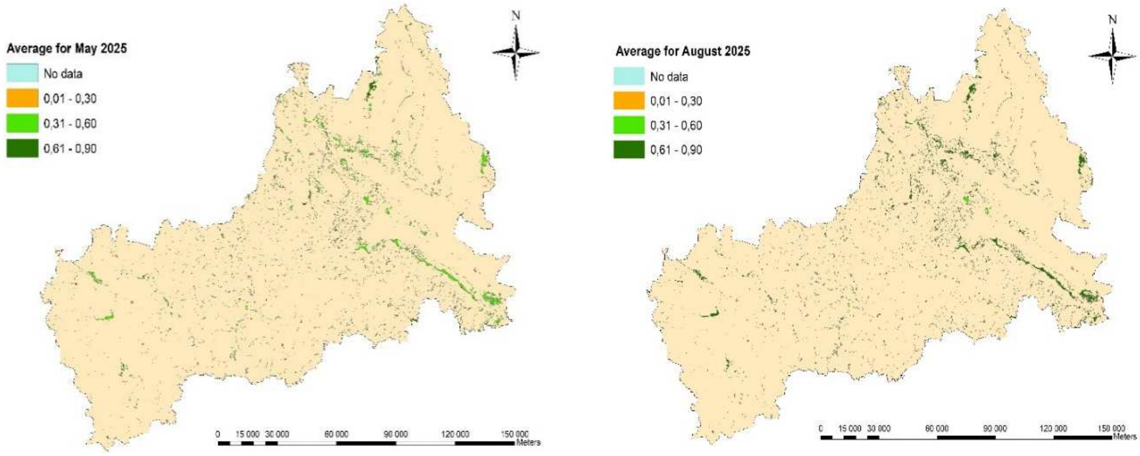

***Figure 1**. Spatial Distribution of NDVI for the "Rangelands" in May and August, 2025*

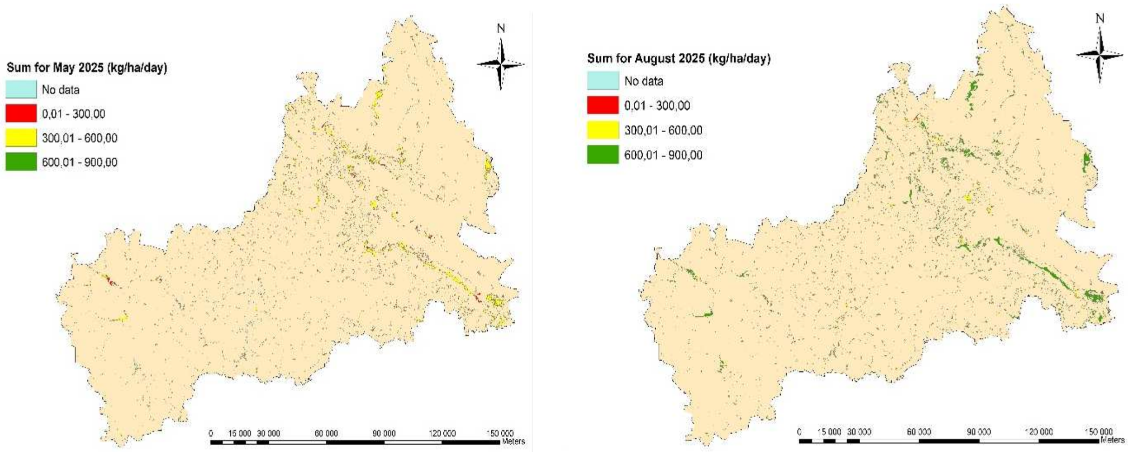

***Figure 2**. Spatial Distribution of Gross Dry Matter Productivity for the "Rangelands"*

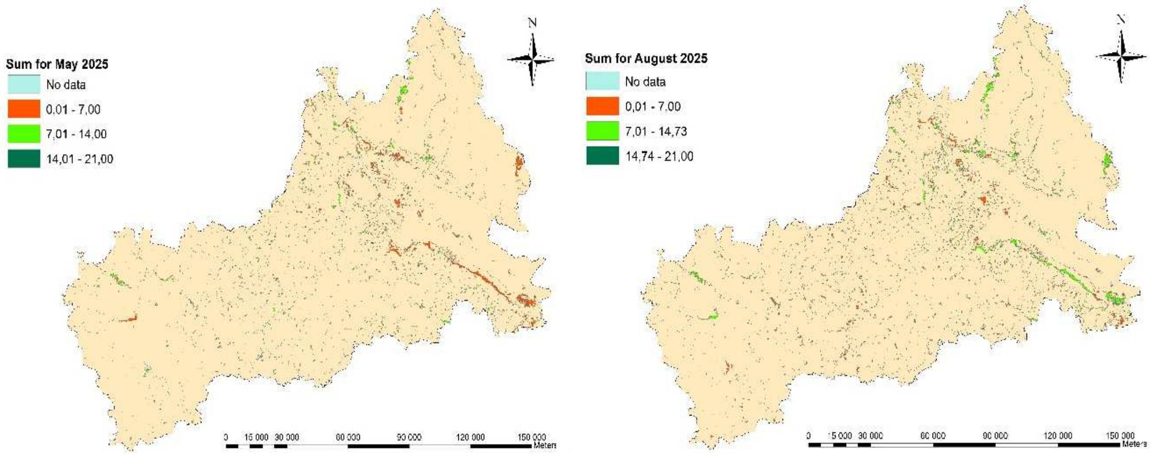

***Figure 3**. Spatial Distribution of LAI for the "Rangelands"*

Conclusions

The study showed that the NDVI vegetation index and geoinformation products such as GDMP and LAI enable the assessment of rangeland state throughout the growing season, specifically in terms of potential biomass yield (on a 10-day, monthly, seasonally), leaf area, grass stand density, and photosynthetic activity, which facilitates the analysis of seasonal phenological dynamics and the timely detection of signs of grass stand degradation.

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