

**THE ROLE OF SPATIAL RESOLUTION IN VEGETATION INFORMATION
EXTRACTION: A COMPARISON OF JILIN-1 AND SENTINEL-2 SATELLITE DATA
IN THE GRODNENSKAYA PUSHCHA BIOSPHERE RESERVE (BELARUS)**

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Abstract: High-resolution satellite remote sensing data provide new opportunities for analysing vegetation structure in forest ecosystems with complex spatial organization. This study examines the role of spatial resolution in vegetation information extraction using multispectral satellite imagery. The research was conducted in the potential biosphere reserve «Grodnenskaya Pushcha» in the Republic of Belarus, a protected area characterized by high forest cover and pronounced spatial heterogeneity of vegetation. Multispectral satellite images from Jilin-1 with a spatial resolution of 5 m and Sentinel-2 with spatial resolutions of 10–20 m were used for the analysis and were acquired during the peak vegetation growth period. Vegetation condition was assessed using the red-edge vegetation index NDVI705. The analysis included a comparison of spectral profiles, statistical characteristics of the NDVI705 index, and results of unsupervised clustering (K-means) obtained for identical regions of interest. The results showed that both satellite datasets exhibit similar spectral patterns in the red-edge and near-infrared regions of the spectrum, while differing in the level of spatial detail. The higher spatial resolution of Jilin-1 imagery enables the detection of internal heterogeneity of forest cover, including small forest openings, narrow riparian zones and fragmented vegetation patches. Sentinel-2 data provide a more generalized representation of landscape structure but remain effective for analysis at the regional scale. The results indicate that spatial resolution is an important factor in vegetation analysis within forest natural complexes and that the combined use of satellite data with different spatial characteristics can improve ecological monitoring in protected areas.

Keywords: NDVI705, red-edge spectral region, multispectral satellite imagery, forest ecosystems, remote sensing

Introduction

Vegetation plays a fundamental role in terrestrial ecosystems by regulating energy exchange, biogeochemical cycles and habitat diversity, particularly within protected natural areas where vegetation structure directly influences biodiversity conservation and ecosystem stability. Quantitative assessment of vegetation cover and condition is therefore an essential task in ecological monitoring and environmental management. Satellite remote sensing has become one of the most effective approaches for large-scale vegetation assessment due to its ability to provide spatially consistent observations over extensive areas.

Among the various remote sensing indicators, the Normalized Difference Vegetation Index (NDVI) and its modified forms have been widely applied for estimating vegetation cover and canopy characteristics because of their sensitivity to chlorophyll content and vegetation structure. Early studies demonstrated that NDVI-based indices provide reliable estimations of vegetation fraction across different land-cover types and therefore form the methodological basis for large-scale vegetation monitoring using satellite imagery [Jiang et al., 2006].

In forest ecosystems characterized by dense canopy cover, however, conventional broadband NDVI often suffers from saturation effects that limit its ability to detect subtle variations in vegetation condition. To address this limitation, vegetation indices based on the red-edge spectral region have been proposed. One of the most widely used indices is NDVI705, which utilizes spectral bands located near the red-edge region that are highly sensitive to chlorophyll concentration and canopy structure. Previous studies have shown that NDVI705 improves the detection of vegetation variability in dense forest canopies and provides enhanced sensitivity to physiological changes in forest ecosystems [Gitelson, Merzlyak, 1996; Sims, Gamon, 2002; Delegido et al., 2011].

The increasing availability of multispectral satellite data has significantly expanded the possibilities for vegetation monitoring. Medium-resolution imagery from the Sentinel-2 satellite mission has become a widely used data source for ecological studies due to its frequent revisit cycle and the availability of red-edge spectral bands. Sentinel-2 data have been successfully applied to vegetation mapping and ecosystem monitoring in forests, wetlands and heterogeneous landscapes [Korhonen et al., 2017; Lastovicka et al., 2020; Bhatnagar et al., 2020; Mohammadpour, Viegas D., Viegas C., 2022].

However, the effectiveness of vegetation indices derived from satellite imagery is strongly influenced by spatial resolution, particularly in landscapes characterized by complex spatial patterns. In forest-dominated ecosystems, medium-resolution pixels often integrate multiple surface components such as tree canopy, understory vegetation, forest roads and canopy gaps within a single pixel. This mixed-pixel effect may lead to smoothing of spectral information, reduced sensitivity to forest edges and riparian zones, and suppression of small-scale spatial heterogeneity within forest landscapes. Previous comparative studies using sensors with different spatial resolutions have demonstrated that higher-resolution imagery improves the detection of fragmented vegetation patches and fine-scale ecological structures [Zhu et al., 2016; Zhao et al., 2020].

In recent years, the Jilin-1 satellite constellation has provided high-resolution multispectral imagery with spatial resolutions of approximately 5 m, offering new opportunities for detailed ecological analysis. Compared with medium-resolution satellite data, the higher spatial resolution of Jilin-1 imagery may improve the detection of internal forest structure and fine-scale spatial heterogeneity. Technical documentation and regional datasets available for Belarus describe the spectral characteristics and acquisition conditions of Jilin-1 imagery and confirm its applicability for environmental studies in Eastern Europe [Jilin-1 ... Belarus (2020), 2023; Jilin-1 ... Belarus (2021–2023), 2023].

Despite these developments, systematic comparisons between Jilin-1 and Sentinel-2 imagery for vegetation monitoring in protected forest ecosystems remain limited. In particular, it remains insufficiently understood how differences in spatial resolution influence vegetation information extraction when red-edge vegetation indices are applied in structurally complex forest landscapes.

Against this background, the present study investigates how spatial resolution influences vegetation information extraction from multispectral satellite imagery in forest-dominated protected landscapes. The research is conducted in the Grodnenskaya Pushcha potential biosphere reserve [Respublikanskij zakaznik ...], a protected area of high ecological value in Belarus. By comparing NDVI705-based vegetation metrics derived from Jilin-1 and Sentinel-2 imagery acquired under different observation conditions, the study analyses differences in spectral characteristics, statistical properties of vegetation indices and spatial classification patterns. The results provide methodological insights into the use of multi-resolution satellite imagery for vegetation monitoring in protected forest ecosystems.

Materials and methods

The study was conducted within the Grodnenskaya Pushcha potential biosphere reserve located in the north-western part of the Grodno region of Belarus (Fig. 1). This protected area represents an important component of the regional ecological network and is characterized by high biodiversity and well-preserved natural landscapes. The reserve includes extensive forested territories dominated by pine, spruce, birch and mixed broadleaf stands, as well as wetlands, river valleys and small open areas. According to the functional concept of biosphere reserves, the territory is divided into core conservation zones, buffer zones and areas of regulated economic activity. Such zoning reflects different levels of environmental protection and land-use intensity and serves as a basis for biodiversity conservation, ecological monitoring and sustainable development of surrounding territories [Chervan', Dzhaio, Chen', 2024]. The spatial heterogeneity of forest ecosystems and the presence of transitional ecological zones make the Grodnenskaya Pushcha reserve a representative area for evaluating vegetation indices derived from satellite remote sensing.

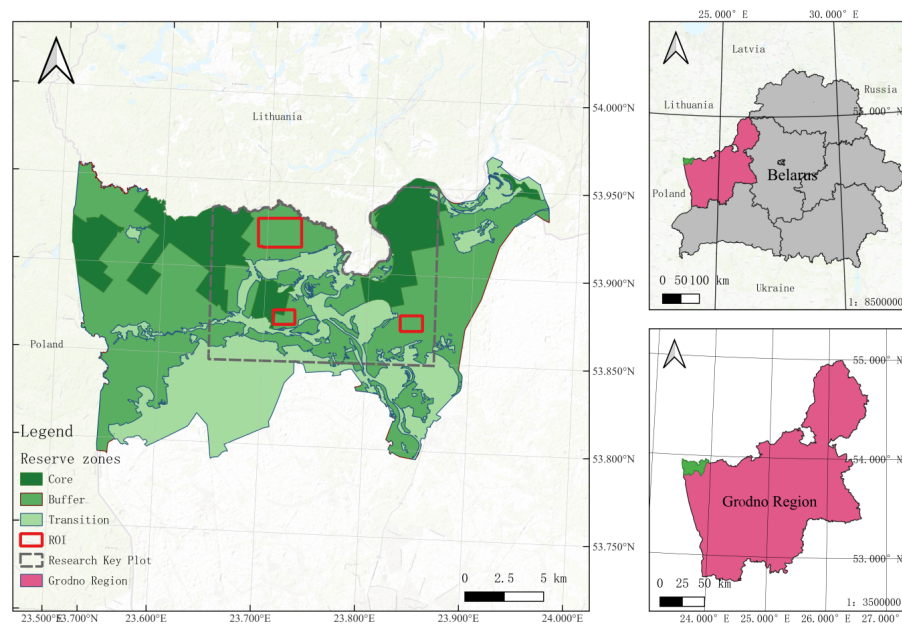


Fig. 1. Location of the study area and the selected regions of interest (ROI1–ROI3) within the Grodnenskaya Pushcha potential biosphere reserve, Republic of Belarus

The spatial distribution of the study area and the selected regions of interest are shown in Fig. 1.

Three regions of interest (ROI1–ROI3) were selected within forested parts of the study area for spectral comparison of satellite imagery. The selection was performed within the main functional zones of the biosphere reserve (core zone, buffer zone and transition zone) in order to represent different levels of ecological protection and landscape structure. Within each zone, representative forest patches were randomly selected while ensuring that the selected areas were dominated by forest vegetation and not influenced by large open areas or settlements. ROI1 and ROI2 are located within the buffer zone of the biosphere reserve and represent relatively homogeneous forest stands, while ROI3 is situated in a transition area between the core and buffer zones.

Spectral reflectance profiles derived from the selected regions of interest are presented in Fig. 2. The figure compares the spectral behaviour of Jilin-1 and Sentinel-2 imagery across comparable spectral regions using representative bands from the visible, red-edge and near-infrared parts of the spectrum. The curves represent mean spectral values extracted from the same regions of interest (ROI1–ROI3), allowing a direct comparison of spectral responses between the two satellite datasets. To ensure comparability between sensors, the spectral curves are plotted using the central wavelength of each band, while the corresponding spectral bandwidths were considered when selecting comparable spectral regions.

Multispectral satellite imagery from the Jilin-1 and Sentinel-2 platforms was used for the analysis. Sentinel-2 imagery was obtained from the European Space Agency (ESA) Copernicus Open Access Hub as Level-2A products providing bottom-of-atmosphere (BOA) surface reflectance values after atmospheric correction using the Sen2Cor processor. Jilin-1 multispectral data were accessed through the National Earth System Science Data Center of China (National Integrated Earth Observation Data Sharing Platform, <https://www.noda.ac.cn/>).

Jilin-1 multispectral imagery with a spatial resolution of 5 m was acquired over the study area on 21 July 2022 under near cloud-free conditions. Sentinel-2 multispectral imagery with spatial resolutions ranging from 10 to 20 m was obtained for 5 July 2022. In order to assess the influence of cloud cover on vegetation index performance, additional Sentinel-2 imagery from August 2020 was also analysed, representing both cloudy and cloud-free observation conditions.

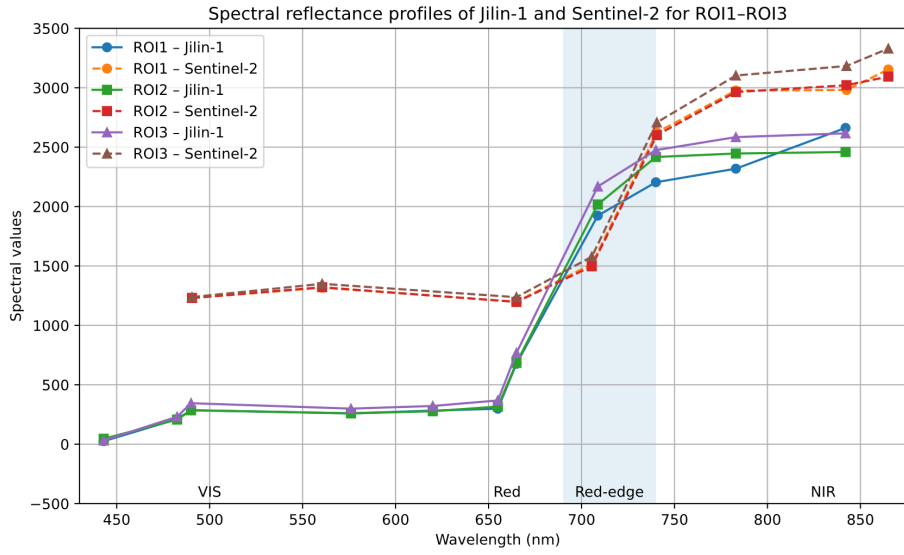


Fig. 2. Spectral reflectance profiles of Jilin-1 and Sentinel-2 imagery for three regions of interest (ROI1–ROI3). Curves are plotted using the central wavelength of each spectral band. The shaded area indicates the red-edge spectral region (690–740 nm), which is used for NDVI705 calculation. Comparable spectral regions were selected to allow cross-sensor comparison

To ensure spatial comparability between the two satellite datasets, all images were projected to a common coordinate reference system and aligned to a common spatial grid. Sentinel-2 bands with 20 m spatial resolution were resampled to the spatial grid used for the analysis using bilinear interpolation in QGIS. Image preprocessing, visualization and spatial analysis were performed using ArcGIS Pro 3.0, ENVI 5.6 and QGIS 3.42 software environments.

Vegetation condition was assessed using the red-edge Normalized Difference Vegetation Index (NDVI705), which has been shown to provide higher sensitivity to chlorophyll content and canopy structure in dense vegetation compared with the conventional broadband NDVI. The index was calculated according to the following equation:

$$NDVI_{705} = \frac{R_{750} - R_{705}}{R_{750} + R_{705}}, \quad (1)$$

where R_{750} represents reflectance values in the near-infrared red-edge band centred at approximately 750 nm, and R_{705} represents reflectance values in the red-edge band centred at approximately 705 nm.

For Jilin-1 imagery these wavelengths correspond to bands B11 and B10 respectively, while for Sentinel-2 imagery they correspond to bands B6 and B5. Although the conventional NDVI derived from Sentinel-2 bands B4 and B8 provides a spatial resolution of 10 m, the present study focuses on vegetation indices based on red-edge spectral bands. Red-edge indices such as NDVI705 reduce saturation effects in dense forest canopies and provide improved sensitivity to chlorophyll concentration. Therefore, spectrally comparable red-edge bands were selected for both satellite datasets in order to ensure consistent vegetation index calculation.

Prior to vegetation index calculation, satellite images were preprocessed to remove invalid pixels and anomalous reflectance values. NDVI705 values were constrained to the 1st–99th percentile range of the data distribution in order to reduce the influence of noise and outliers associated with atmospheric effects or residual cloud contamination.

Statistical analysis of NDVI705 values was subsequently performed to compare vegetation index distributions derived from the two satellite datasets. Mean values, standard deviations and range statistics were calculated for the analysed scenes. In addition, a two-sample t-test was applied to evaluate whether the differences in mean NDVI705 values between the two satellite datasets were statistically significant.

In addition to pixel-based statistical analysis, unsupervised classification was performed using the K-means clustering algorithm implemented in ENVI 5.6. Prior to classification, all images were spatially masked to the study area using a vector boundary (Research Key Plot) in order to exclude external background and NoData pixels from the analysis. This step ensured that only valid pixels within the study area were included in the clustering process. To ensure comparability between datasets, a consistent spectral subset was defined. For Sentinel-2 imagery, four surface reflectance bands (B2, B3, B4 and B8), representing the visible and near-infrared regions, were selected. For Jilin-1 imagery, six multispectral bands with a spatial resolution of 5 m were used to provide comparable spectral coverage. The K-means algorithm was applied with 10 clusters, a maximum of 20 iterations and a convergence threshold of 5 %. These parameters were chosen to ensure stable clustering results while maintaining a comparable level of classification detail between datasets. Due to the unsupervised nature of the K-means algorithm, the resulting clusters represent spectral groupings rather than predefined land-cover classes. The classification results were therefore used to analyse spatial clustering patterns and structural differences between Jilin-1 and Sentinel-2 imagery, with particular attention to fragmentation, spatial continuity and the representation of heterogeneous landscape elements.

The overall research workflow applied in this study is summarized in Fig. 3. The workflow includes satellite data acquisition, image preprocessing, vegetation index calculation, statistical analysis and unsupervised classification for comparative evaluation of vegetation patterns derived from the two satellite datasets.

Results and discussion

The NDVI705 values derived from Jilin-1 and Sentinel-2 imagery demonstrated generally consistent spatial patterns of vegetation distribution across the Grodnenskaya Pushcha potential biosphere reserve. In forest-dominated areas, both datasets captured similar spectral trends, indicating that the red-edge vegetation index effectively reflects the overall structure and condition of forest vegetation. At the same time, certain differences between the two datasets were observed, particularly in the visible spectral range, whereas discrepancies in the red-edge and near-infrared regions were comparatively small. This pattern suggests that the observed differences in vegetation index values may be partially associated with differences in spatial resolution and pixel composition rather than fundamental differences in spectral sensitivity between the two satellite sensors.

The similarity and divergence of spectral characteristics for representative areas are illustrated in Fig. 2, which presents spectral profiles of Jilin-1 and Sentinel-2 imagery across comparable wavelength ranges for the selected regions of interest (ROI1–ROI3). In all analysed areas, both datasets demonstrate a typical vegetation spectral response characterized by relatively low reflectance in the visible region and a pronounced increase toward the near-infrared wavelengths. However, the Jilin-1 data show slightly greater variability in reflectance values within the visible spectral bands. This variability may be associated with the higher spatial resolution of the Jilin-1 sensor (5 m), which allows the detection of fine-scale heterogeneity within forest canopies, forest edges and small landscape elements that may be averaged within the larger pixels of medium-resolution imagery.

Under near cloud-free conditions, the statistical characteristics of NDVI705 derived from the two satellite datasets were generally comparable. The calculated statistical parameters for the analysed scenes are presented in Table 1.

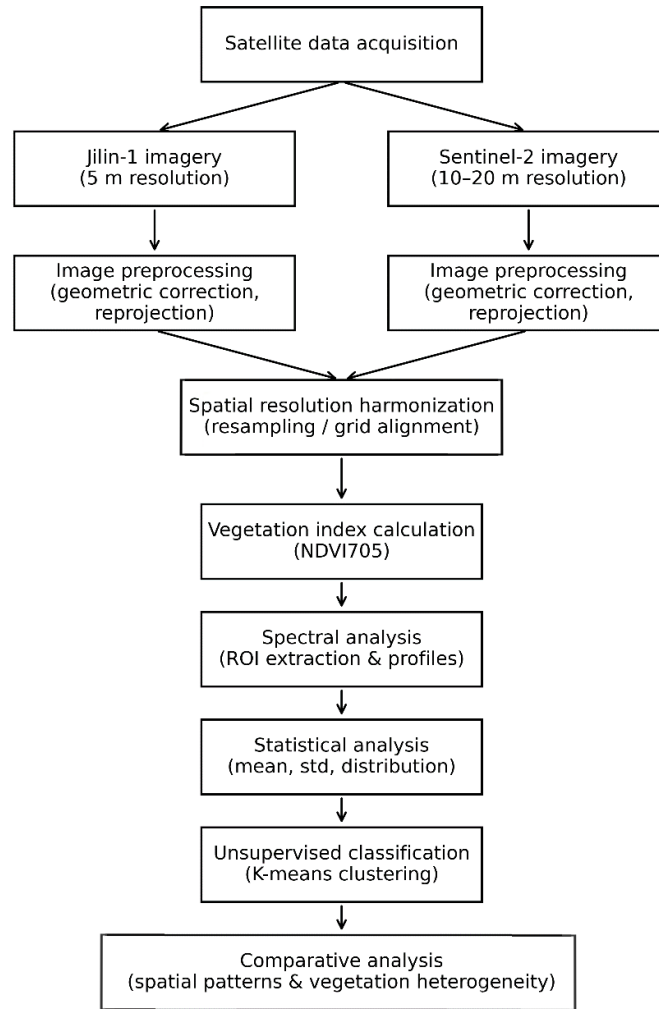


Fig. 3. Workflow of vegetation information extraction and comparative analysis between Jilin-1 and Sentinel-2 datasets

Both datasets exhibited relatively low standard deviation values, indicating stable extraction of vegetation signals across the study area. At the same time, the mean NDVI705 values derived from Jilin-1 imagery were consistently higher than those obtained from Sentinel-2. A statistical comparison using a two-sample t-test confirmed that the differences in mean NDVI705 values between the two satellite datasets were statistically significant. These differences may be related to variations in spatial resolution and the resulting pixel composition in dense forest environments.

In medium-resolution imagery such as Sentinel-2 (10–20 m), individual pixels frequently contain mixtures of several surface components, including forest canopy, understory vegetation, small canopy gaps, forest roads and other landscape elements. This mixed-pixel effect reduces the dominance of the vegetation signal within each pixel and can lead to lower average NDVI705 values. In contrast, the higher spatial resolution of Jilin-1 imagery (5 m) reduces the degree of pixel mixing and allows individual pixels to more accurately represent dense forest canopy areas. As a result, vegetation signals may be less diluted by non-vegetated components, which can lead to higher NDVI705 values in forest-dominated landscapes.

Table 1

Statistical characteristics of NDVI705 values derived from Jilin-1 and Sentinel-2 imagery under different cloud conditions

No.	Data	Mean	Std.	Max.	Min.	Range
1	Jilin-1	0.773	0.094	0.921	0.122	0.799
2	Sentinel-2	0.469	0.095	0.712	-0.023	0.735
3	Sentinel-2 (Aug.)	0.448	0.098	0.706	-0.056	0.762
4	Jilin-1 (Cloud)	0.727	0.208	1.000	-0.295	1.295
5	Sentinel-2 (Cloud)	0.717	0.216	0.998	-0.248	1.246
6	Sentinel-2 (No cloud)	0.437	0.107	0.711	-0.059	0.771

When cloud cover was present, the variability of NDVI705 values increased for both satellite datasets, as reflected by higher standard deviation values (Table 1). This increase was more noticeable for Sentinel-2 imagery, suggesting that medium-resolution pixels may be more sensitive to partial cloud contamination and atmospheric disturbances. In contrast, higher spatial resolution imagery may preserve more localized spectral information because contaminated pixels are less likely to dominate larger spatial units. This characteristic may be particularly important for ecological monitoring in temperate forest regions where completely cloud-free satellite observations are relatively limited.

Additional insight into spatial differences between the datasets was obtained using unsupervised K-means clustering (Fig. 4). Ten clusters were generated for each dataset using comparable visible and near-infrared bands to ensure a consistent level of detail. The resulting maps reveal clear differences in the spatial organization and fragmentation of clusters between the two satellite systems.

In the Sentinel-2 results, clusters tend to form relatively large and spatially homogeneous patches, reflecting a more generalized representation of the landscape. In contrast, the clustering derived from Jilin-1 imagery exhibits a more fragmented and spatially detailed pattern, with finer delineation of narrow linear features and small heterogeneous patches. These differences are consistent with the influence of spatial resolution on the representation of heterogeneous forest landscapes.

In medium-resolution imagery such as Sentinel-2 (10–20 m), individual pixels often represent mixtures of multiple surface components. This mixed-pixel effect reduces spectral contrast and leads to smoother transitions between adjacent clusters. As a result, small-scale spatial structures may be generalized or partially suppressed. In contrast, higher-resolution imagery (5 m) captures more localized variability, resulting in a more complex and internally differentiated cluster pattern.

Consequently, fine-scale spatial heterogeneity appears less pronounced in Sentinel-2 imagery compared with Jilin-1 data. This difference highlights the importance of spatial resolution in representing heterogeneous landscapes, particularly in protected forest ecosystems where small-scale variability is ecologically relevant.

In protected forest ecosystems such as the Grodnensskaya Pushcha biosphere reserve, small-scale spatial variability often reflects differences in forest age structure, species composition and local habitat conditions. High-resolution satellite imagery can therefore provide additional ecological information that may remain undetected in medium-resolution datasets. These findings are consistent with previous studies emphasizing the importance of spatial resolution for vegetation analysis in heterogeneous landscapes [Zhu et al., 2016; Zhao et al., 2020; Immitzer, Vuolo, Atzberger, 2016]. At the same time, the relatively strong performance of Sentinel-2 in representing large homogeneous landscape units confirms its suitability for regional-scale ecological assessments where fine spatial detail is not the primary requirement.

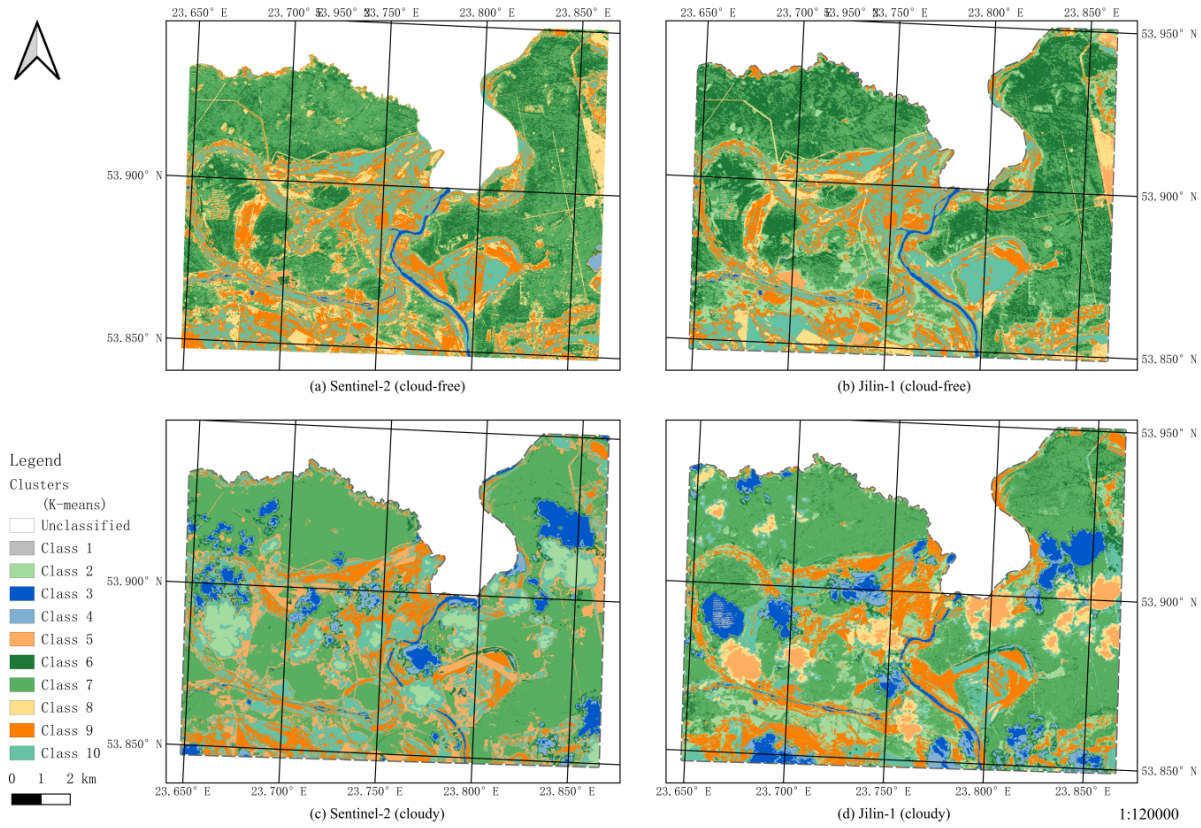


Fig. 4. Comparison of spatial clustering patterns derived from K-means classification of Jilin-1 and Sentinel-2 imagery under different cloud conditions. Ten clusters were generated for each dataset using comparable visible and near-infrared bands. Colors represent cluster labels and are used consistently across panels for visualization purposes only; they do not correspond to specific land-cover classes

The combined analysis of NDVI705 statistical characteristics and unsupervised classification results demonstrates that both Jilin-1 and Sentinel-2 imagery can support vegetation monitoring in protected forest landscapes. However, their effectiveness differs depending on the spatial scale of analysis. The higher spatial resolution of Jilin-1 imagery (5 m) enables a more detailed representation of internal forest structure and fine-scale spatial heterogeneity, including narrow riparian corridors and small forest openings that are not clearly detected in medium-resolution imagery. In contrast, Sentinel-2 imagery, with spatial resolutions of 10–20 m and a high temporal revisit frequency, remains well suited for regional-scale ecological assessments and the identification of large homogeneous landscape units. These results indicate that the selection of satellite data for vegetation analysis in heterogeneous forest ecosystems should consider both spatial resolution and the intended scale of ecological interpretation.

Conclusions

The present study evaluated the applicability of multispectral satellite imagery from the Jilin-1 and Sentinel-2 platforms for vegetation monitoring within the Grodnenskaya Pushcha potential biosphere reserve, a forest-dominated protected area characterized by complex spatial structure and high ecological value. The analysis of spectral characteristics, NDVI705 statistics and unsupervised classification results demonstrated that both satellite datasets provide consistent information on the general spatial distribution of forest vegetation.

At the same time, the results indicate that spatial resolution plays an important role in the representation of vegetation patterns in heterogeneous forest landscapes. The higher spatial resolution of Jilin-1 imagery (5 m) allows a more detailed depiction of internal forest heterogeneity, including narrow riparian zones, small forest openings and fragmented vegetation patches. Such spatial detail may provide additional ecological information relevant for analysing structural variability within protected forest ecosystems.

Sentinel-2 imagery with spatial resolutions of 10–20 m remains well suited for regional-scale vegetation monitoring and the identification of large homogeneous landscape units. Its high temporal revisit frequency and stable radiometric characteristics make it an effective data source for long-term environmental observation.

The results suggest that the combined use of satellite datasets with different spatial resolutions can improve the interpretation of vegetation patterns in structurally complex forest landscapes. High-resolution imagery contributes to the identification of fine-scale spatial heterogeneity, while medium-resolution data support broader regional assessments. This complementary use of multi-resolution satellite imagery may enhance ecological monitoring and environmental management within protected natural areas.

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**РОЛЬ ПРОСТРАНСТВЕННОГО РАЗРЕШЕНИЯ ПРИ ИЗВЛЕЧЕНИИ
ИНФОРМАЦИИ О РАСТИТЕЛЬНОСТИ: СРАВНЕНИЕ СПУТНИКОВЫХ ДАННЫХ
JILIN-1 И SENTINEL-2 В БИОСФЕРНОМ РЕЗЕРВАТЕ «ГРОДНЕНСКАЯ ПУЩА»
(БЕЛАРУСЬ)**

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Аннотация: Высокодетальные спутниковые данные дистанционного зондирования предоставляют новые возможности для анализа структуры растительности в лесных экосистемах со сложной пространственной организацией. В данной работе рассматривается роль пространственного разрешения спутниковых изображений при извлечении информации о растительности на основе мультиспектральных данных дистанционного зондирования. Исследование выполнено для территории потенциального биосферного резервата «Гродненская Пуща» в Республике Беларусь — природоохранной территории, характеризующейся высокой лесистостью и значительной пространственной неоднородностью растительного покрова. Для анализа использованы мультиспектральные спутниковые изображения Jilin-1 с пространственным разрешением 5 м и Sentinel-2 с пространственным разрешением 10–20 м, полученные в период максимального развития растительности. Состояние растительности оценивалось с использованием краснокраевого вегетационного индекса NDVI705. Анализ включал сравнение спектральных профилей, статистических характеристик индекса NDVI705 и результатов неконтролируемой кластеризации (K-means), полученных для одинаковых областей интереса. Результаты показали, что оба спутниковых набора данных демонстрируют сходные спектральные закономерности в краснокраевой и ближней инфракрасной областях спектра, однако различаются по степени пространственной детализации. Более высокое пространственное разрешение изображений Jilin-1 позволяет выявлять внутреннюю неоднородность лесного покрова, включая небольшие лесные окна, узкие прибрежные зоны и фрагментированные участки растительности, тогда как данные Sentinel-2 обеспечивают более обобщённое представление о структуре ландшафта и остаются эффективными для анализа

на региональном уровне. Полученные результаты показывают, что пространственное разрешение является важным фактором при анализе растительности в лесных природных комплексах и что совместное использование спутниковых данных с различными пространственными характеристиками может повысить эффективность экологического мониторинга на природоохранных территориях.

Ключевые слова: NDVI705, краснокраевой спектральный диапазон, мультиспектральные спутниковые данные, лесные экосистемы, дистанционное зондирование

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