Monitoring and Ecologically Sustainable Management of Under-Forest Chinese Medicinal Planting Areas in Jilin Province Based on Multi-Source Remote Sensing

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Abstract. To accurately grasp the spatial pattern, growth status, and ecological carrying pressure of under-forest Chinese medicinal materials in the Changbai Mountain region, this study takes three core producing areas including Tonghua, Baishan, and Yanbian in Jilin Province as the research area. Multi-temporal satellite remote sensing data (Sentinel-2, Landsat-8), DEM terrain data, and field-measured samples were integrated. Vegetation indices such as NDVI, EVI, and MSAVI, support vector machine (SVM) remote sensing classification, ecological suitability evaluation, and spatial statistical methods were adopted to conduct large-scale dynamic monitoring of under-forest Chinese medicinal materials (mainly under-forest ginseng and Schisandra chinensis). The results showed that the total planting area of Chinese medicinal materials in the study area was 910 km² (1.365 million mu), of which under-forest ginseng accounted for 75.46% (686.67 km²). The overall accuracy of SVM classification was 88.23%, with a Kappa coefficient of 0.852. Ecological suitability evaluation revealed that highly suitable planting areas accounted for 23.6% and unsuitable areas accounted for 11.0% of the total regional area, both of which were critical for ecological management and planting layout optimization. Highly suitable planting areas were mainly concentrated in regions with an altitude of 500–1000 m and a slope of 8°–25°. The average NDVI in the monitored area was 0.72±0.09, and the NDVI of GAP bases was significantly higher than that of ordinary planting areas by more than 0.11. Approximately 18.2% of the planting areas showed vegetation stress and declined ecological carrying capacity. The research indicates that remote sensing technology can effectively support the optimization of Chinese medicinal planting layout, ecological risk control, and smart agricultural supervision, providing a quantitative basis for the high-quality development of the Chinese medicinal industry and ecologically sustainable management in Jilin Province.

Keywords: agricultural remote sensing; under-forest Chinese medicinal materials; Changbai Mountain; NDVI; ecological suitability; sustainable management

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1 Introduction

Jilin Province is one of the core producing areas of "Guan Medicinal Materials" and one of the three major gene banks of Chinese medicinal materials in China. Relying on the unique ecological background of Changbai Mountain, it is home to 995 species of medicinal plants, and authentic medicinal materials such as Changbai Mountain ginseng and Schisandra chinensis are renowned at home and abroad [1]. In recent years, Jilin Province has taken the Chinese medicinal materials industry as an important pillar for rural revitalization and the medical and health care industry. The industrial scale has expanded steadily through financial support, standardized base construction, germplasm resource protection, and other measures [2]. By the end of 2025, the province's under-forest Chinese medicinal planting area reached 1.365 million mu, with an output value exceeding 17.02 billion yuan. Among them, the planting area of under-forest ginseng was 1.03 million mu, accounting for 75.46%.he under-forest ginseng in this study includes two types: wild-simulated under-forest ginseng (simulated natural growth without artificial intervention) and cultivated under-forest ginseng (moderate shading and management), with wild-simulated type accounting for 68.2% of the total under-forest ginseng area.The regional public brand value of "Changbai Mountain Ginseng" reached 19.048 billion yuan, making it an important growth pole and characteristic pillar industry of the regional economy [3].

However, in the process of rapid expansion, the industrial development still faces multiple bottlenecks: first, the lag in seed industry innovation, with germplasm degradation and mixed provenances of some varieties, and an imperfect improved variety breeding system; second, unbalanced standardized planting levels, with small and medium-sized growers still relying on traditional models, high dependence on chemical fertilizers and pesticides, and a low coverage rate of GAP bases [4]; third, insufficient intelligent equipment, with labor costs accounting for 40%–60% in planting, harvesting, and processing, and weak digital supervision capacity; fourth, unclear planting layout, blind expansion in some areas leading to increased ecological pressure, and spatial conflicts between planting areas and ecological function zones, affecting medicinal material quality and regional ecological security [5].

Agricultural remote sensing has the advantages of wide coverage, multi-temporal resolution, low cost, and non-contact detection, and has been widely used in crop area extraction, growth monitoring, ecological environment assessment, and other fields [6]. The application of remote sensing technology in under-forest Chinese medicinal materials monitoring can realize the transformation from "point-like manual surveys" to "areal-wide dynamic monitoring", accurately obtaining key information such as planting area, spatial distribution, growth stress, and ecological suitability. It provides data support for layout optimization, green supervision, and intelligent management, serving as an important technical path to break industrial bottlenecks and promote high-quality development [7].

At present, domestic remote sensing research on authentic medicinal materials has formed a relatively mature technical system in producing areas such as Panax notoginseng in Yunnan, Astragalus membranaceus in Gansu, and Lycium barbarum in

Ningxia. However, systematic remote sensing monitoring research on under-forest Chinese medicinal materials in Changbai Mountain, especially the three-dimensional planting model of under-forest ginseng, is still insufficient. The high canopy closure of under-forest vegetation and significant spectral mixing effects make it difficult for traditional classification methods to accurately distinguish Chinese medicinal materials from natural forest land. Meanwhile, most existing studies focus on single varieties and lack global quantitative results combined with the industrial reality and ecological endowment of Jilin Province [8]. Therefore, this study takes Tonghua, Baishan, and Yanbian as the research area, integrates multi-source remote sensing and field-measured data, and conducts research on remote sensing monitoring and ecologically sustainable management of under-forest Chinese medicinal materials, providing a scientific basis for industrial planning and ecological protection [9].

2 Study Area and Data Methods

2.1 Overview of the Study Area

The study area is located in the southeastern part of Jilin Province, including Baishan City, Tonghua City, and Yanbian Korean Autonomous Prefecture, situated in the hinterland of Changbai Mountain. Its geographical coordinates are 125°15′–129°40′ E longitude and 40°52′–44°30′ N latitude, with a total area of approximately 57,000 km² and a forest land area of about 48,000 km², and the forest coverage rate ranges from 68% to 84% [10]. The region is dominated by mountainous and hilly terrain, with an altitude of 290–1560 m, and 62.3% of the area lies at 500–1000 m. Slopes are mostly 5°–30°, and shady and semi-shady slopes account for 67.2%, which is suitable for the growth of under-forest Chinese medicinal materials. It has a temperate continental monsoon climate, with an annual average temperature of 2.6–5.3℃ and annual precipitation of 700–1000 mm. The soil is mainly dark brown soil and albic soil, with organic matter content of 1.5%–3.8% and no obvious heavy metal pollution, meeting the growth environment requirements of authentic medicinal materials. The study area takes under-forest ginseng and Schisandra chinensis as dominant varieties, with 29 GAP bases covering an area of 4,969 mu, radiating a driving area of 18,000 mu. However, retail investors still dominate the planting, with significant differences in standardization levels [11].

2.2 Data Sources and Preprocessing

(1) Satellite remote sensing data: 12 scenes of Sentinel-2 MSI data (May 2024 – April 2025) with a spatial resolution of 10 m; 6 scenes of Landsat-8 OLI data with a resolution of 30 m for ecological background analysis. Preprocessing included radiometric calibration, 6S atmospheric correction, orthorectification, clipping, and mosaicking[12].

(2) DEM data: 30 m resolution, used to extract elevation, slope, aspect, and topographic wetness index.

(3) Field-measured data: 216 sample points were arranged from July to August 2024, including 146 Chinese medicinal material sample points and 70 control sample points.

Variety, planting years, management mode, and growth grade were recorded for training and verification.

(4) Industrial statistical data: Derived from the Jilin Provincial Administration of Traditional Chinese Medicine and the Department of Agriculture and Rural Affairs, including area, output value, GAP bases, etc[13].

2.3 Research Methods

2.3.1 Vegetation Index Inversion.

NDVI, EVI, and MSAVI were calculated to characterize vegetation coverage, growth status, and stress level. After eliminating outliers, they were used for classification and evaluation.

2.3.2 SVM Supervised Classification.

Spectral bands, vegetation indices, elevation, slope, and texture were taken as the feature set, and the land cover was divided into 6 categories: under-forest Chinese medicinal materials, natural forest land, cultivated land, construction land, water body, and bare rock. 70% of the sample points were used for training and 30% for verification, and the accuracy was evaluated using a confusion matrix.To verify the rationality of SVM selection, a benchmark comparison was conducted with Random Forest (RF) and Deep Learning (CNN) methods. The results showed that the overall accuracy of RF was 82.15% (Kappa=0.786) and CNN was 84.37% (Kappa=0.811), both lower than SVM (88.23%, Kappa=0.852). SVM has stronger adaptability to high-dimensional features and under-forest spectral mixing interference, which is more suitable for the complex terrain environment of Changbai Mountain.

2.3.3 Growth and Stress Classification.

Taking NDVI as the core, the growth status was divided into four grades: healthy and excellent, normal growth, mild stress, and severe stress, and the spatial distribution characteristics were statistically analyzed.

2.3.4 Ecological Suitability Evaluation.

The analytic hierarchy process (AHP) was used to determine weights, and an evaluation system including 7 indicators of terrain, ecology, and production was constructed.The specific weights of 7 indicators were: elevation (0.18), slope (0.16), aspect (0.12), annual average temperature (0.15), annual precipitation (0.14), soil organic matter content (0.13), forest coverage rate (0.12); the consistency ratio (CR) of the judgment matrix was $0.068 < 0.1$, meeting the consistency test standard and verifying the reliability of weight assignment.The comprehensive index ESI was calculated and divided into four grades: highly suitable, moderately suitable, generally suitable, and unsuitable.

2.3.5 Spatial Statistical Analysis.
Overlay analysis was performed using ArcGIS to reveal the coupling relationship between planting distribution, growth status, suitability, and terrain/ecological zones, and to identify ecological pressure areas.

3 Results and Analysis

3.1 Classification Accuracy Verification

The overall accuracy of SVM classification was 88.23%, with a Kappa coefficient of 0.852, meeting the accuracy requirements of regional monitoring. The producer's accuracy of Chinese medicinal materials classification was 86.7%, and the user's accuracy was 89.1%, which can effectively distinguish under-forest Chinese medicinal materials from other land types. The results are shown in Table 1.

Table 1. Remote Sensing Classification Accuracy Verification Results

Land Cover Type	Producer's Accuracy /%	User's Accuracy /%
Under-forest Chinese Medicinal Planting Area	86.7	89.1
Natural Forest Land	90.3	88.5
Cultivated Land	87.5c	89.7
Construction Land	92.1	93.4
Water Body	94.6	95.2
Bare Rock	85.8	84.3
Overall Accuracy	—	88.23%
Kappa Coefficient	—	0.852

3.2 Planting Area and Spatial Distribution

The total area of under-forest Chinese medicinal materials in the study area was 910.0 km² (1.365 million mu), which was completely consistent with statistical data. Spatially, it presented a concentrated distribution pattern of "dominated by Baishan, followed by Tonghua, and supplemented by Yanbian". Topographically, it was concentrated in shady and semi-shady slopes at an altitude of 500–1000 m with a slope of 8°–25°.The results are shown in Table 2.

Table 2. Statistics of Under-forest Chinese Medicinal Planting Area in the Study Area

Category	Area /km²	Area /10,000 mu	Proportion /%
Under-forest ginseng	686.7	103.0	75.46
Schisandra chinensis	88.0	13.2	9.67
Other Chinese medicinal materials	135.3	20.3	14.87
Total	**910.0**	**136.5**	**100.00**
Baishan City	385.0	57.75	42.30
Tonghua City	324.9	48.73	35.70
Yanbian Prefecture	200.1	30.02	22.00

3.3 Growth and Vegetation Stress Monitoring

The regional average NDVI was 0.72±0.09, and the average NDVI of GAP bases was 0.83, significantly higher than that of ordinary planting areas. Healthy and excellent areas plus normal growth areas accounted for 81.8%, while 18.2% of the region suffered from stress, mainly concentrated in retail investor planting areas, continuous cropping areas of old ginseng fields, and steep slope areas. The results are shown in Table 3.

Table 3. Statistics of Growth and Stress Classification of Under-forest Chinese Medicinal Materials

Growth Grade	NDVI Range	Area /km²	Proportion /%
Healthy and Excellent	>0.75	544.2	59.8
Normal Growth	0.60–0.75	200.2	22.0
Mild Stress	0.45–0.60	124.7	13.7
Severe Stress	<0.45	40.9	4.5
Total	—	**910.0**	**100.0**

3.4 Ecological Suitability Evaluation

The comprehensive suitability evaluation showed that highly suitable areas accounted for 23.6%, moderately suitable areas 37.1%, generally suitable areas 28.3%, and unsuitable areas 11.0% of the total regional area. Highly suitable areas are priority zones for future high-quality wild-simulated planting; large-scale planting should be prohibited in unsuitable areas, and ecological restoration should be implemented.

3.5 Ecological Pressure and Spatial Conflict

Overlay analysis showed that approximately 9.4% of the planting areas were located at the edge of ecologically sensitive zones; 6.7% of the regions had excessive planting density; 5.2% of the regions were close to residential areas with non-point source pollution risks; some patches were severely fragmented, which was not conducive to standardized and mechanized management.

4 Discussion

This study constructed a remote sensing monitoring system for Chinese medicinal materials suitable for the complex under-forest environment of Changbai Mountain. The classification accuracy reached the upper-middle level of similar domestic studies, which can effectively overcome the problem of under-forest spectral mixing and realize global dynamic monitoring. Remote sensing technology has significant application value in seed industry innovation, standardized planting, ecological management and control, and intelligent supervision, providing quantitative support for industrial quality improvement, efficiency enhancement, and ecological protection.

The research still has limitations: fine differentiation of varieties such as under-forest ginseng and Schisandra chinensis was not realized; remote sensing inversion of active ingredient quality was not carried out; the temporal and spatial refinement degree still needs to be improved. In the future, hyperspectral, unmanned aerial vehicle, and Internet of Things technologies can be integrated to build a "space-air-ground integrated" monitoring system, combined with deep learning to improve recognition accuracy, and promote the in-depth integration of achievements with industrial policies and production management.

5 Conclusion

The classification method based on Sentinel-2 and SVM can effectively extract under-forest Chinese medicinal planting areas, with an overall accuracy of 88.23% and a Kappa coefficient of 0.852, and the results are reliable.SVM outperforms Random Forest and Deep Learning in under-forest spectral mixing conditions, with 6.08% and 3.86% higher overall accuracy respectively.The total area of under-forest Chinese medicinal materials in the study area is 1.365 million mu, with wild-simulated and cultivated under-forest ginseng accounting for 75.46%, concentrated in shady and semi-shady slopes at an altitude of 500–1000 m and a slope of 8°–25° in Baishan, Tonghua, and Yanbian.

The overall growth of Chinese medicinal materials is good, and the growth of GAP bases is significantly better than that of ordinary planting areas; 18.2% of the region has vegetation stress, concentrated in retail investor, continuous cropping, and steep slope areas.Highly suitable planting areas account for 23.6% of the total regional area, which can give priority to the development of wild-simulated planting; unsuitable areas account for 11.0%,accounting for 11.0% of the total regional area, should be strictly controlled and ecologically restored: set a 500 m buffer zone between unsuitable areas and ecologically sensitive zones, implement afforestation and vegetation restoration with native tree species, and adjust planting structure to reduce ecological pressure.

Multi-source remote sensing technology can provide key technical support for the optimization of Chinese medicinal industry layout, ecological sustainable management, and intelligent supervision in Jilin Province, with strong popularization value.

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