Remote Sensing Identification and Distribution Characteristics of Dominant Tree Species in the Habitat of the Sichuan Snub-Nosed Monkey in Shennongjia (Postprint)

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Abstract

To address the challenge of obtaining large-scale distribution data of tree species in basic habitat research for the Shennongjia Sichuan snub-nosed monkey, this study attempts to hierarchically identify tree species using multi-source multi-temporal remote sensing data combined with expert knowledge. First, winter Landsat 8 OLI data were employed to hierarchically extract the spatial distribution ranges of evergreen and deciduous forests based on phenological characteristics; subsequently, hierarchical identification of evergreen species (Abies fargesii, Pinus armandii, Picea wilsonii, Quercus spinosa) and deciduous species (Betula albosinensis, Larix kaempferi, Fagus engleriana, Toxicodendron vernicifluum, Quercus aliena var. acuteserrata, Populus wilsonii) was accomplished according to the spectral characteristics of field tree samples from summer WorldView-2 high-resolution remote sensing imagery; classification results were then refined using field vegetation quadrats, expert knowledge, and elevation data; finally, spatial analysis of topographic and regional distribution characteristics of dominant tree species was conducted using GIS. Experimental accuracy indicates that in evergreen forests, Abies fargesii, Pinus armandii, Quercus spinosa, and pest-affected Pinus armandii achieved relatively high overall accuracy, while in deciduous forests, Betula albosinensis and Toxicodendron vernicifluum demonstrated relatively higher identification accuracy; certain species such as Populus wilsonii and Quercus aliena var. acuteserrata exhibited lower identification accuracy; overall, evergreen species accuracy was superior to that of deciduous species. From the integrated perspective of phytogeography, remote sensing, and GIS, this study effectively integrates multi-source, multi-temporal remote sensing data with species phenological characteristics and expert knowledge, proposing a tree species identification method that (1) provides an approach for

identifying dominant arbor species in complex mountainous environments with general applicability; (2) achieves integrated utilization of species phenological characteristics and remote sensing data features, effectively reducing data acquisition costs; and (3) avoids misclassification resulting from over-reliance on spectral features through result refinement with ground quadrats and expert knowledge. This will provide more precise data support for the protection and restoration of Shennongjia Sichuan snub-nosed monkey habitats.

Full Text

Remote Sensing Identification and Distribution Characteristics of Dominant Tree Species in the Habitat of Rhinopithecus roxellana in Shennongjia

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Abstract: Due to the difficulty in obtaining large-scale distribution data of tree species in the habitat of Rhinopithecus roxellana in Shennongjia, this study attempted to integrate multi-source, multi-temporal remote sensing data with expert knowledge to identify species at different hierarchical levels. First, winter Landsat 8/OLI data were used to extract the spatial extent of evergreen and deciduous forests based on phenological characteristics. Subsequently, summer WorldView-2 high-resolution imagery was employed to hierarchically identify dominant tree species, including evergreen species (*Abies fargesii*, *Pinus armandii*, *Picea wilsonii*) and deciduous species (*Betula albo-sinensis*, *Larix kaempferi*, *Fagus engleriana*, *Quercus aliena*, *Populus wilsonii*, *Toxicodendron vernicifluum*). Finally, elevation data combined with field vegetation quadrats and expert knowledge were used to refine the classification results. Spatial analysis of the terrain and geographic distribution characteristics of the main dominant species was then conducted.

Experimental accuracy indicated that evergreen species such as *Abies fargesii* and *Pinus armandii* achieved higher classification accuracy, while pest-affected *Pinus armandii* showed relatively lower accuracy. In deciduous forests, species like *Populus wilsonii* and *Quercus aliena* demonstrated relatively higher accuracy, whereas some species such as *Quercus spinosa* exhibited poor accuracy. Overall, evergreen species achieved better accuracy than deciduous species. By integrating perspectives from plant geography, remote sensing, and GIS, this study combined multi-source, multi-temporal remote sensing data, species phenological characteristics, and expert knowledge to propose a novel tree species identification method. This approach offers several advantages: (1) it provides an effective pathway for identifying dominant tree species in complex mountainous environments and demonstrates versatility across various geographic settings; (2) it fully leverages the integration of species phenological features and remote sensing data characteristics to reduce data costs; and (3) it incorporates ground sampling and expert knowledge to ensure classification accuracy, thereby avoiding excessive reliance on spectral characteristics and reducing misclassification errors. This method will provide more accurate vegetation data for the protection and restoration of Rhinopithecus roxellana habitat in Shennongjia.

Keywords: multi-source and multi-temporal remote sensing data; high-resolution WorldView-2 imagery; tree species identification; vegetation; expert knowledge

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1. Study Area

The Rhinopithecus roxellana population in Shennongjia is distributed at elevations between 1,800–3,100 m [7]. The habitat vegetation includes temperate coniferous and deciduous broad-leaved forests between 1,800–2,600 m, with *Pinus armandii* and *Quercus aliena* as the main species. Between 2,600–3,100 m, cold-temperate evergreen coniferous forests dominate, with *Abies fargesii* and understory bamboo (*Fargesia* spp.) or evergreen rhododendron being predominant [7].

2. Datasets

The experimental data included: (1) Landsat 8/OLI imagery (2014) with 30 m multispectral resolution and 15 m panchromatic resolution, covering approximately 470 km^2; and (2) WorldView-2 imagery (2013) with eight multispectral bands.

2. Field Survey

Field surveys comprised tree species location mapping and vegetation quadrat investigations. Multiple surveys were conducted in April and July 2014 across Rhinopithecus roxellana habitats including Dalong and Qiaodonggou in Shennongjia. Vegetation quadrats were established using random sampling methods distributed across the habitat gradient. Tree species locations were randomly collected, with individual tree positions delineated on remote sensing imagery through visual interpretation. Based on the importance of dominant species in the golden monkey habitat, ease of field collection, and image interpretation difficulty, the following tree species were targeted: *Abies fargesii*, *Pinus armandii*, *Picea wilsonii*, *Betula albo-sinensis*, *Larix kaempferi*, *Fagus engleriana*, *Toxicodendron vernicifluum*, *Quercus spinosa*, *Quercus aliena*, and *Populus wilsonii*, along with shrub types and alpine meadows including rhododendron (*Rhododendron* spp.) and bamboo (*Fargesia* spp.). Their spatial distribution is shown in [Figure 1: see original paper].

1. Remote Sensing Data Preprocessing

Preprocessing included: (1) radiometric correction of OLI imagery; (2) fusion of multispectral and panchromatic bands to produce 5 m resolution multispectral data; and (3) topographic orthorectification of OLI imagery using DEM data.

2. Hierarchical Classification Using Multi-source Multi-temporal Data

The classification workflow proceeded as follows: (1) supervised classification of fused Landsat 8/OLI data delineated evergreen and deciduous forest extents; (2) these extents were converted to vector boundaries to clip summer WorldView-2 imagery, obtaining separate evergreen and deciduous forest subsets for subsequent hierarchical species identification; (3) based on field-delineated samples, pixel-based supervised classification identified evergreen and deciduous tree species separately; and (4) elevation data and botanical literature [8-9] were used to refine classification results and conduct spatial analysis of dominant species' terrain and geographic distribution characteristics.

1. Sample Analysis

The J-M (Jeffries-Matusita) Transformed Divergence parameter was used to measure training sample separability, with values ranging from [0,2], where 0 indicates complete confusion between classes and 2 indicates complete separation. Initial calculations of spectral separability for all tree species revealed severe confusion among most species except evergreen *Abies fargesii*. However, separability improved significantly when species were stratified into evergreen and deciduous groups. Due to space limitations, detailed tables are not presented. This demonstrates that hierarchical extraction by first classifying evergreen/deciduous forests reduces inter-species confusion, as seen between *Pinus armandii* and *Picea wilsonii*, or between *Picea wilsonii* and *Quercus spinosa*.

2. Stratified Extraction Process

Winter imagery shows distinct interpretation characteristics for evergreen versus deciduous vegetation. Leveraging this phenological trait, we proposed using winter data to separate evergreen from deciduous forests, then employing summer data for hierarchical species extraction. This approach effectively reduces species confusion. [Figure 2: see original paper] shows a Landsat 8/OLI 6-5-4 band combination (RGB).

Supervised classification in software categorized the imagery into deciduous forest, evergreen forest, and other land cover types, achieving 94.21% accuracy based on test samples. Post-classification processing combined with surrounding object analysis determined shadow area attributes. Considering that *Pinus armandii* and *Abies fargesii* are the main constructive species in the golden monkey habitat, classification was refined to improve accuracy of dominant species. Post-classification data were converted to vectors to obtain evergreen and deciduous forest boundaries, which were used to clip WorldView-2 multispectral imagery. Based on ground sample data, pixel-based supervised classification extracted evergreen and deciduous tree species separately. Classification accuracy was calculated using field quadrats: evergreen species *Abies fargesii* and *Quercus spinosa* achieved high overall accuracy (82.36% and 86.59% respectively), with user accuracies of 94.21% and 73.91%. Deciduous species *Betula albo-sinensis* and *Toxicodendron vernicifluum* showed relatively high identification accuracy.

Mixed forests were merged into evergreen forests in the analysis. Using these vector boundaries, the corresponding ranges were clipped for further processing.

3. Species Identification

Field surveys revealed distinct spectral characteristics for some species. [Figure 3: see original paper] shows the stratified evergreen and deciduous forest results, while [Figure 4: see original paper] illustrates species distributions. However, some types showed low accuracy: *Quercus aliena* achieved only 66.67% user accuracy and 67.57% producer accuracy, while pest-affected *Pinus armandii* reached 51.37% and 22.5% respectively. Species with large classification errors were merged into other evergreen or deciduous categories.

5. Expert Knowledge Correction

From a remote sensing perspective, tree canopy spectral features are the primary basis for species classification. From a geographic perspective, however, species distribution is driven by environmental characteristics and follows certain patterns. Therefore, we combined classification results with expert knowledge from *Hubei Flora* [8-9] to analyze elevation distributions of each species in ArcGIS. Statistical analysis of field quadrats yielded the elevation range for each species. Misclassification caused some species to occur outside their expected elevation ranges. For example, *Pinus armandii*' s statistical distribution from field data was 1,000-3,100 m, but expert knowledge refined this to 1,000-2,600 m. Classification results outside the refined elevation range were adjusted to other deciduous or evergreen categories. The final classification results and distribution of some dominant species are shown in [Figure 1000: see original paper].

presents the classification accuracy (%), showing user and producer accuracies for each class: *Abies fargesii* (94.21%, 73.91%), *Pinus armandii* (82.88%, 31.02%), pest-affected *Pinus armandii* (86.59%, 82.36%), *Picea wilsonii* (66.67%, 95.61%), *Quercus spinosa* (74.55%, 62.27%), *Rhododendron* spp. (70.18%, 59.41%), *Betula albo-sinensis* (67.57%, 68.71%), *Toxicodendron vernicifluum* (22.55%, 51.37%), *Fagus engleriana* (58.35%, 93.05%), *Quercus aliena* (96.95%, 65.21%), *Populus wilsonii* (45.08%, 63.47%), *Larix kaempferi* (54.19%, 97.03%), other evergreen/mixed forests (85.51%), and other deciduous forests.

[Figure 5: see original paper] shows the preliminary tree species identification results, while [Figure 6: see original paper] displays elevation distribution characteristics.

2. Distribution Characteristics of Dominant Species

1. Terrain Distribution Characteristics

Spatial analysis was performed on the classification results shown in [Figure 7: see original paper] combined with elevation data. Statistical analysis revealed that *Abies fargesii* primarily occurs at 2,250-3,100 m, with peak distribution at 2,600 m, and shows greater distribution on shady slopes than sunny slopes, indicating strong shade tolerance. *Pinus armandii* mainly distributes at 1,850-2,800 m, with maximum occurrence at 2,450 m, predominantly on sunny slopes, reflecting its light-demanding characteristics. Other evergreen and mixed forests show complex distribution patterns due to Shennongjia' s rugged terrain, particularly the steep slopes from Guanyindong toward the airport area, where most were classified as mixed forest—consistent with actual conditions. *Betula albo-sinensis* primarily occurs at 2,000-2,800 m, with peak distribution at 2,300 m, showing relatively balanced distribution across shady and sunny slopes.

2. Regional Distribution Characteristics

Combining tree species distribution maps with field quadrat data and forestry surveys reveals the vertical vegetation types in the main activity areas of Shennongjia' s golden monkeys. In the Qianjiaping area: 1,900-2,100 m is deciduous broad-leaved forest; 2,100-2,400 m is evergreen coniferous forest dominated by *Betula albo-sinensis* and *Fagus engleriana*; 2,400-2,600 m is mixed evergreen-deciduous broad-leaved forest. In the airport direction area: 1,500-1,900 m is deciduous broad-leaved forest; 1,900-2,300 m is mixed coniferous-broadleaved forest; 2,300-3,100 m is evergreen coniferous forest dominated by *Abies fargesii* and rhododendron. *Abies fargesii* is widely distributed above 2,100 m. In the Luoquantao area, the vertical vegetation shows: below 1,900 m is deciduous broad-leaved forest; above 1,900 m is evergreen coniferous forest. *Pinus armandii* and *Betula albo-sinensis* are widely distributed, particularly on shady slopes with steep gradients. Due to the steep terrain in Luoquantao, field samples could not be obtained, but classification results indicate *Pinus armandii*, *Picea wilsonii*, and other coniferous species are the main distributions.

4. Discussion and Conclusions

This experiment utilized high-resolution remote sensing imagery to obtain spatial distributions of dominant tree species in Rhinopithecus roxellana habitat in Shennongjia. Analysis of terrain distribution characteristics provides crucial data for vegetation composition assessment and habitat diagnosis and prediction. The experiment also identified spatial distribution and damage area of pest-affected *Pinus armandii*, offering effective guidance data for analyzing impacts on golden monkey food composition, winter food supplementation, pest monitoring, and management.

Regarding remote sensing data selection, this study explored the effectiveness of WorldView-2 high-resolution imagery for tree species identification. Previous international studies using WorldView-2 data primarily focused on urban areas in Europe, America, and tropical Africa where species composition is relatively simple. Tree species identification in complex mountainous environments remains underexplored. While some studies [10] used multi-temporal satellite data to reflect phenological characteristics of 11 common tree genera in Berlin, these targeted urban vegetation. Additionally, vegetation development exhibits convergence and divergence, and spectral characteristics show strong regional specificity. A systematic method for guiding rational application of multi-temporal data in different geographic environments is still lacking. Most studies rely solely on spectral or derived features.

Compared with previous research, this study offers three advantages: (1) It completes tree species identification in complex mountainous environments, demonstrating the feasibility of multi-source, multi-temporal remote sensing for identifying main dominant species and showing versatility across geographic settings; (2) It fully exploits the integration of remote sensing characteristics and species phenology, reducing data costs; and (3) It incorporates ground quadrats and expert knowledge, using elevation-based expert knowledge to refine classification results, thereby avoiding misclassification from excessive spectral dependence.

Overall accuracy was higher for evergreen than deciduous species. Spectral information effectively identified species like *Pinus armandii* and *Quercus spinosa*. However, some species like *Quercus aliena* could not be reliably identified using spectral information alone because tree distribution is closely related to terrain [11] and soil factors. Although elevation was considered, it was not incorporated as prior knowledge into the intelligent classification model. Future work will integrate geospatial knowledge with remote sensing data models and analyze inter-species spatial relationships.

This study employed conventional pixel-based supervised classification for initial exploration of species identification feasibility. While more complex object-oriented methods or models incorporating texture and spatial relationships were not selected, subsequent work will adopt object-based classification integrating spatial relationships and expert knowledge, potentially using Markov Random Field models.

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Note: Figure translations are in progress. See original paper for figures.