Assessing the Transferability of Forest Volume Estimation Models between Hokkaido and Kyoto Using Remote Sensing Data

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1. Introduction

Understanding the biomass and volume of forested areas is crucial for evaluating the richness and health of forest ecosystems. Forest volume serves as a key parameter in assessing the status of these ecosystems, providing insights into biodiversity, carbon sequestration, and overall ecological balance (Haq et al., 2024). Accurate estimation of forest volume is essential for effective forest management, conservation strategies, and climate change mitigation efforts. Continuous monitoring and management practices are essential to address the challenges posed by deforestation, forest degradation, and the subsequent impact on global carbon cycles (Gibbs et al., 2007). Integrating ecological data with socio-economic factors is crucial for developing sustainable forest management strategies that contribute to biodiversity conservation and benefit local communities and economies. However, despite advancements of recent remotely sensed methods for forest resource modeling, challenges remain in effectively transferring models across regions (McRoberts and Tomppo, 2007). One significant issue is the lack of emphasis on incorporating forest management practices into the modeling process.

Our research aims to investigate the transferability of forest volume estimation models across different regions in Japan, focusing on Hokkaido and Kyoto. By combining multiple remote sensing data sources, including LiDAR, SAR, and optical imagery, we seek to identify the key variables influencing model accuracy and transferability. Our goal is to provide a comprehensive understanding of the factors affecting model transferability and offer recommendations for improving forest volume estimation in diverse ecological contexts.

2. MATERIALS AND METHODS

The study focuses on two distinct regions in Japan: the Toyohira River Basin in Hokkaido and the Oono District in Kyoto (Figure 1). These two regions provide a diverse set of environmental conditions for studying forest volume estimation and model transferability, providing insights into the influence of geographical, climatic, and management factors influence forest structure.

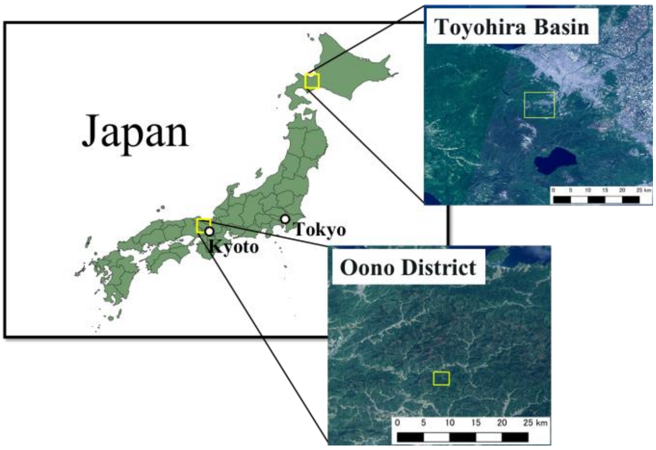


Figure 1: Geographical locations of the two study sites.

2.1 Remotely Sensed Data and Other Processing Variables:

Both optical and synthetic aperture radar (SAR) data were utilized. The optical satellite data was obtained from Sentinel-2, using the Global Mosaic service to generate cloud-free products of the study regions. For Hokkaido, the periods for mosaic data used were from April 1 to June 30, 2021 (spring) and from July 1 to October 15, 2021 (autumn). For Kyoto, the periods were from March 1 to June 30, 2023 (spring) and from July 1 to October 31, 2023 (autumn). Thus, two seasonal datasets were created for each region to capture the phenological variations. From the mosaic data, two indices were derived: the Red-Edge Normalized Difference Vegetation Index (ReNDVI) and the Normalized Difference Moisture Index (NDMI). The SAR data, which can reflect scattering components correlating to the stems and boles of trees through volume scattering, was sourced from the L-band PALSAR-2. In addition to the original backscattering information, two specific indices were created from the SAR data: the Enhanced Cross-Polarization Ratio (EXPR) and the Radar Vegetation Index (RVI). EXPR is an experimental index developed that includes all polarizations.

$$EXPR = \frac{(\gamma_{HV}^0 + \gamma_{VH}^0)/2}{(\gamma_{HH}^0 + \gamma_{VV}^0)/2} \quad (1)$$

$$RVI = \frac{8\gamma_{HV}^0}{\gamma_{HH}^0 + \gamma_{VV}^0 + 2\gamma_{HV}^0} \quad (2)$$

Aerial LiDAR (Light Detection and Ranging) data used in this study were sourced from the Basic Survey Results and Public Survey Results managed by the Geospatial Information Authority of Japan (GSI), under the Ministry of Land, Infrastructure, Transport and Tourism (MLIT). The point cloud dataset is utilized to further develop Canopy Height Model (CHM) representing tree heights and used as a variable in modeling. Climatological Normal Mesh data is also used in the modeling: Annual Precipitation (mm), Annual Mean Temperature (°C), Daily Mean Annual Radiation (MJ/m^2). OpenStreetMap (OSM) road network data is used as the proximity factors: Primary and track categories of roads were extracted from the OSM dataset and distances from these features were calculated for the Kyoto and Hokkaido regions.

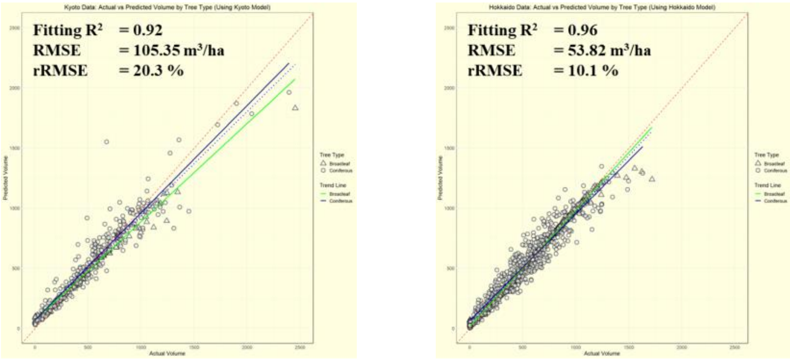
2.2 Random Forest Modeling:

The Random Forest algorithm was applied to estimate stem volume based on the prepared variables. The samples were split into a 70% training set and a 30% testing set. A 10-fold cross-validation method was implemented for each of the created models. A total of five models were developed: $Model_{Kyoto}$ and $Model_{Hokkaido}$, which aim to estimate the stem volume for their respective regions: $Model_{K\text{-}H}$ and $Model_{H\text{-}K}$, where $Model_{K\text{-}H}$ uses the Kyoto data (Oono region) to estimate the Hokkaido (Toyohira Basin) region, and $Model_{H\text{-}K}$ does the reverse.

These models were further analyzed to identify the characteristics of regional differences, assess the generalizability of the modeling, and provide further perspectives.

3. Results and Discussion

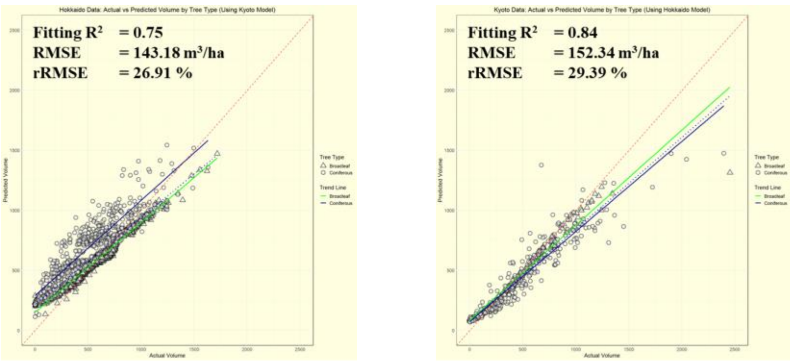
Figure 2 shows the scatter plot of the modeling results (y-axis) compared to the reference stem volume (x-axis) for both the Kyoto and Hokkaido regions. The scatter plots contain two types of forest data: coniferous (represented by circles) and broadleaf (represented by triangles). The green and blue solid lines represent the trend lines for broadleaf and coniferous forests, respectively. The red dashed line in the center indicates the 1:1 line, and the blue dashed line represents the overall trend line for all forests combined. The Kyoto data shows a broader range of reference volumes, which might explain the higher RMSE compared to the Hokkaido data. However, the Hokkaido model displays a better overall fit, as indicated by the higher R^2 and lower RMSE values.



(a) (b)

Figure 2: Scatterplot of the Random Forest Modeling results for its evaluation. (a) Kyoto model and, (b) Hokkaido model.

The transferability of the Kyoto and Hokkaido models to predict stem volume in the opposite region is considered. Figures 3 show the scatter plots for this evaluation: Figures 3 (a) $Model_{K\text{-}H}$, and Figures 3 (b) $Model_{H\text{-}K}$. When the developed model is transferred to another region, the predictive accuracy drops when the models are applied to new regions compared to their native regions. These results indicate that, although the models demonstrate some generalizability, their accuracy diminishes in new regions. Both models tend to overestimate stem volume at lower values, with the Kyoto model predicting Hokkaido data showing a significant overestimation across a broad range of volumes, especially in coniferous trees. This discrepancy may suggest that differences in forest growth characteristics and social conditions between the regions are impacting the model performance.



(a) (b)

Figure 2: Scatter plot of the Random Forest Modeling results with the consideration of model transferability: (a) $Model_{K\text{-}H}$ and, (b) $Model_{H\text{-}K}$.

4. Conclusion and Recommendation

The observed differences in model performance across regions underscore the significance of region-specific factors, including local growth conditions and forest management practices. This highlights the necessity for tailored models that account for regional variability to improve accuracy in forest volume estimation. The notable errors observed in coniferous forest types suggest the influence of local management practices on tree growth. In Hokkaido, where conservation forests limit activities like thinning, growth conditions differ from more actively managed forests in Kyoto. Thinning practices, known to impact conifer growth rates in Japan, should be incorporated into modeling efforts for accuracy. Further research will focus on identifying information that minimizes regional discrepancies in forest conditions.

References

Gibbs, H.K., Brown, S., Niles, J.O., & Foley, J.A. (2007). Monitoring and estimating tropical forest carbon stocks: making REDD a reality. *Environmental Research Letters*, Volume 2, 045023.

Haq, S.M., Waheed, M., Darwish, M., Siddiqui, M.H., Goursi, U.H., Kumar, M., Song, L., & Bussmann, R.W. (2024). Biodiversity and carbon stocks of the understory vegetation as indicators for forest health in the Zabarwan Mountain Range, Indian Western Himalaya. *Ecological Indicators*, Volume 159, 111685.

McRoberts, R.E., & Tomppo, E.O. (2007). Remote sensing support for national forest inventories. Remote Sensing of Environment, Volume 110, 412-419.