

Postprint: Aboveground Biomass Model Development and Allocation Patterns of *Loropetalum chinense* Communities Across Different Restoration Stages in Guilin Karst Hills

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Abstract

To accurately estimate the aboveground biomass of standing trees in *Loropetalum chinense* communities at different restoration stages in Guilin karst mountains, bivariate models using diameter at breast height (basal diameter) and plant height as independent variables and univariate models using diameter at breast height (basal diameter) as the independent variable were established. The optimal models for different restoration stages were selected using the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) combined with R^2 , and the accuracy of the established models was evaluated using the Standard Error of Estimate (SEE), Mean Systematic Error (MSE), and Total Relative Error (TRE). The constructed biomass models were then used to analyze the allocation patterns of community aboveground biomass and *Loropetalum chinense* aboveground biomass at different restoration stages. The results showed that: (1) Using five models for regression analysis, the estimation performance for stem and aboveground biomass in *Loropetalum chinense* communities at different restoration stages was excellent, followed by leaf and branch biomass. Model : $W = a + b(D^2H)$ was selected to establish the optimal model for aboveground biomass in the tree-shrub stage, while Model : $W = a \times D^b \times H^c$ was selected for the shrub stage and small-tree forest stage; (2) Using the established standing tree biomass growth models for *Loropetalum chinense* communities at different restoration stages to estimate vegetation biomass, the ranking of stem biomass and aboveground biomass among different restoration stages was: small-tree forest stage > tree-shrub stage > shrub stage. The ranking of leaf biomass and branch biomass was: tree-shrub stage > small-tree forest stage > shrub stage; (3) For *Loropetalum chinense*, the edificator species in the community,

the ranking of its aboveground biomass was: tree-shrub stage > small-tree forest stage > shrub stage, while the proportion of *Loropetalum chinense* biomass in the total community biomass at different restoration stages of *Loropetalum chinense* communities continued to decline. The research results indicate that with the natural restoration succession of *Loropetalum chinense* communities in Guilin karst mountains, the energy foundation and nutrient sources for ecosystem functioning develop as the community progresses toward more advanced successional stages, and the edificator status of *Loropetalum chinense* may be gradually replaced, relegating it to the sub-tree layer.

Full Text

Model Construction and Above-Ground Biomass Allocation Across Successional Stages of *Loropetalum chinense* Communities in Karst Hills of Guilin

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Abstract

To accurately estimate above-ground biomass of standing trees across different restoration stages of *Loropetalum chinense* communities in Guilin karst hills, we developed binary models using diameter at breast height (or basal diameter) and plant height as independent variables, and univariate models using only diameter at breast height (or basal diameter). The optimal models for each restoration stage were selected based on the Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), and coefficient of determination (R^2). Model accuracy was evaluated using the standard error of estimate (SEE), mean systematic error (MSE), and total relative error (TRE). The constructed biomass models were then applied to analyze the allocation patterns of both community-level and *L. chinense* above-ground biomass across restoration stages. Results showed: (1) Regression analysis using five model forms demonstrated excellent predictive performance for trunk and total above-ground biomass, with slightly lower accuracy for leaf and branch biomass. Model IV ($W = a + b(D^2H)$) was selected as the optimal model for the shrub-to-tree stage, while Model III ($W = a \times D^b \times H^c$) proved optimal for both the shrub stage and small-tree forest stage. (2) Biomass estimation using these stage-specific models revealed that trunk and total above-ground biomass increased progressively across restoration

stages, following the order: small-tree forest stage > shrub-to-tree stage > shrub stage. In contrast, leaf and branch biomass peaked at the shrub-to-tree stage, following the order: shrub-to-tree stage > small-tree forest stage > shrub stage. (3) As the dominant species, *L. chinense* above-ground biomass also peaked at the shrub-to-tree stage, but its proportional contribution to total community biomass declined continuously across restoration stages. These findings indicate that as natural succession progresses in Guilin karst *L. chinense* communities, the energy base and nutrient sources for ecosystem functioning advance toward more stable states, while the dominant status of *L. chinense* may gradually be replaced by other species, relegating it to the sub-canopy layer.

Keywords: *Loropetalum chinense* community; above-ground biomass; estimation models; different restoration stages

Introduction

Biomass is a crucial metric for quantifying the status and function of individuals and populations within communities, representing an important parameter for forest productivity and ecosystem functioning. It also holds significant implications for understanding carbon cycling mechanisms and carbon storage in ecosystems (Odum & Barrett 1971; Li et al. 2013; Zeng 2014; Wang et al. 2014). Forest biomass measurement methods primarily include direct harvesting and indirect estimation. While direct measurement offers higher precision, it is time-consuming, labor-intensive, and highly destructive to ecosystems (Liu 2009; Yang et al. 2016). Indirect methods mainly utilize biomass models to construct regression equations for estimation, with diameter at breast height (or basal diameter) and plant height being the most commonly employed independent variables (Wang et al. 2012; Cui et al. 2017).

The karst hills of Guilin, located in northeastern Guangxi, represent one of the region's concentrated karst distributions. Rocky desertification is particularly pronounced in this area, making vegetation restoration the primary task for ecological management (Li et al. 2008). While numerous studies have investigated community structure (Li et al. 2017), litter dynamics (Chen et al. 2017), spatial patterns (Mei et al. 2017), and soil characteristics (Mónika Knáb et al. 2012; Chen & Zhou 2017) in karst regions, *Loropetalum chinense* communities—widely distributed as a typical natural forest type in Guilin karst hills—have received limited attention despite forming distinct restoration stages (Ma et al. 2012; Ma et al. 2013). Although Wang et al. (2017) examined biomass allocation patterns in *L. chinense*, comprehensive ecological studies across different restoration stages remain scarce, with existing research focusing only on species diversity (Ma et al. 2013), niche dynamics (Ma et al. 2012), and litter decomposition (Qin et al. 2017). This study addresses this knowledge gap by constructing stage-specific biomass models and analyzing above-ground biomass allocation patterns across restoration stages of *L. chinense* communities in Guilin karst

hills. Our objectives are to elucidate the changing characteristics of biomass allocation during natural succession and provide a scientific basis for understanding community structure dynamics and guiding vegetation restoration in this region.

1. Study Area

The study area is located in Xi Village, Ertang Township, southern Guilin, Guangxi Zhuang Autonomous Region (110°15' E, 25°12' N), in northeastern Guangxi. The region features typical karst geomorphology at elevations of 150–280 m. It experiences a mid-subtropical humid monsoon climate with long summers and short winters, an average annual temperature of 18.9 °C, a frost-free period of 300 days, mean annual precipitation of 1949.5 mm, and annual evaporation of 1490–1905 mm.

2. Methods

2.1 Sample Plot Establishment

During July–August 2016, we established sample plots in *Loropetalum chinense* communities at different restoration stages using typical sampling methods and conventional community survey techniques. Sites were selected with consistent site conditions across karst hills in Guilin. Three replicate plots were established for each of three restoration stages: shrub stage, shrub-to-tree stage, and small-tree forest stage. Plot characteristics are detailed in . For the shrub-to-tree and small-tree forest stages, each plot measured 20 m × 20 m and was subdivided into four 10 m × 10 m subplots. For the shrub stage, each plot measured 10 m × 10 m and was subdivided into four 5 m × 5 m subplots. In each plot, we recorded woody plant species, diameter at breast height (or basal diameter), tree height, crown width, stem density, and canopy closure. Environmental factors including elevation, aspect, slope position, slope gradient, and rock exposure rate were also documented.

2.2 Biomass Measurement and Sample Collection

Following the methods of Wang et al. (2015), we measured biomass using standard tree sampling for the arborous layer. For the shrub layer, we established four 2 m × 2 m quadrats at each plot corner, recording species, height, and diameter of all stems. Fresh weights of branches, leaves, and trunks were measured separately. Plant organ samples were oven-dried at 105 °C for 2 hours to deactivate enzymes, then at 75 °C to constant weight to determine total dry mass for each component.

2.3 Biomass Model Development and Estimation

Biomass estimation methods include the conversion factor continuous function method, IPCC method, and weighted biomass regression modeling. Research by Li et al. (2012) demonstrated that weighted biomass regression modeling provides the most stable results. Therefore, this study employed weighted biomass regression models. Luo et al. (1999) and Zeng et al. (2010) compared linear and nonlinear biomass models, concluding that nonlinear models are superior. Integrating models developed by Cai et al. (2014), Li et al. (2017), and Wei et al. (2017), we used allometric relationships to establish nonlinear biomass models, including binary models based on diameter and height, and univariate models based on diameter alone. The model structures were:

- **Model I:** $W = a \times (D^2H)^b$
- **Model II:** $W = a \times D^b$
- **Model III:** $W = a \times D^b \times H^c$
- **Model IV:** $W = a + b \times (D^2H)$
- **Model V:** $W = a + b \times D$

where W is above-ground biomass (g), D is diameter at breast height or basal diameter (cm), H is height (cm), and a , b , and c are model parameters. Optimal equations were selected based on minimum AIC and BIC values, with parameters estimated accordingly. Model performance was evaluated using four metrics: coefficient of determination (R^2), standard error of estimate (SEE), mean systematic error (MSE), and total relative error (TRE). All data processing was conducted using SPSS 20.0 statistical software.

3. Results

3.1 Above-Ground Biomass Models for Different Restoration Stages

Using measured biomass data for leaves, branches, trunks, and total above-ground components across restoration stages, we fitted five model forms using weighted regression. Model evaluation metrics are presented in . Optimal models were selected based on minimum AIC and BIC values combined with maximum R^2 . For the shrub stage, Model III ($W = a \times D^b \times H^c$) provided the best fit for all components (leaves, branches, trunk, and total above-ground biomass). For the shrub-to-tree stage, Model IV ($W = a + b(D^2H)$) was optimal for trunk biomass, while Model III yielded the highest R^2 for leaves, branches, and total biomass. However, because the differences in AIC and BIC between Models III and IV were minimal, Model IV was selected as the best overall model for the shrub-to-tree stage. For the small-tree forest stage, Model I ($W = a \times (D^2H)^b$) was optimal for total above-ground biomass based on AIC and BIC criteria, though Model III produced higher R^2 values for all components. Given the small differences in AIC and BIC but substantial difference in R^2 for branch biomass, Model III was selected as the optimal model for the small-tree forest

stage. Model validation comparing observed versus predicted values showed total relative error (TRE) generally below 10% and mean systematic error (MSE) below 30%, indicating good model precision.

3.2 Above-Ground Biomass Allocation and Characteristics Across Restoration Stages

Substituting growth parameters into the component biomass models revealed that community above-ground biomass across restoration stages ranged from 55.73 to 244.25 t/hm² (see). With natural succession, leaf and branch biomass accumulation initially increased then decreased, peaking at the shrub-to-tree stage (23.558 t/hm² and 38.161 t/hm², respectively) and reaching minima at the shrub stage (10.081 t/hm² and 9.005 t/hm²). In contrast, trunk and total above-ground biomass increased progressively, reaching maxima at the small-tree forest stage (203.275 t/hm² and 244.248 t/hm²) and minima at the shrub stage (63.7 t/hm² and 85.93 t/hm²). Arborous layer biomass peaked at the small-tree forest stage for all components (leaves: 14.902 t/hm², branches: 19.317 t/hm², trunk: 156.759 t/hm², total: 188.521 t/hm²), while shrub layer biomass peaked at the shrub-to-tree stage (leaves: 15.452 t/hm², branches: 26.419 t/hm², trunk: 111.347 t/hm², total: 233.153 t/hm²).

3.3 Biomass Allocation and Characteristics of *Loropetalum chinense* Across Restoration Stages

Analysis of *L. chinense* above-ground biomass revealed values ranging from 30.24 to 168.08 t/hm² across restoration stages (see). All components (leaves, branches, trunk, and total above-ground biomass) showed an initial increase followed by a decrease, peaking at the shrub-to-tree stage (17.0 t/hm², 26.96 t/hm², 124.11 t/hm², and 168.08 t/hm², respectively) and reaching minima at the shrub stage (8.42 t/hm², 7.52 t/hm², 53.09 t/hm², and 71.65 t/hm²). The proportional contribution of *L. chinense* biomass to total community biomass declined continuously across restoration stages, with the highest proportions at the shrub stage (83.51–83.38%) and lowest at the small-tree forest stage (42.53–44.52%). At the shrub-to-tree stage, *L. chinense* biomass was dominated by the arborous layer (>98.5%). Transition to the small-tree forest stage saw a marked decline in arborous layer biomass (~40% reduction), while shrub layer biomass remained relatively stable (~55%).

4. Discussion and Conclusion

Biomass model construction based on easily measurable variables provides an accurate method for biomass assessment. This study's stratified sampling approach, based on comprehensive surveys of *Loropetalum chinense* communities across restoration stages in Guilin karst hills, provided reliable data for model development. To identify the most accurate models, we compared five model

forms for above-ground biomass estimation. Two critical aspects determine optimal biomass models: model applicability and the degree of fit between observed and predicted values (Li et al. 2014). Previous research indicates that R^2 and SEE are the most commonly used metrics reflecting model fit, while TRE and MSE are important indicators of prediction accuracy, with values approaching zero representing optimal performance (Zeng & Tang 2011; Chen et al. 2016). In this study, R^2 values for component models across restoration stages ranged from 0.487 to 0.968, with leaf and branch models showing lower coefficients while total above-ground biomass models demonstrated the best fit—consistent with findings by Zhu et al. (2016) and Li et al. (2015). This reflects that leaves and branches are more strongly influenced by biotic and abiotic factors (e.g., light, water) (Bond et al. 2002), introducing greater variability. Model IV ($W = a + b(D^2H)$) was selected for the shrub-to-tree stage, while Model III ($W = a \times D^b \times H^c$) proved optimal for shrub and small-tree forest stages.

Comparative studies indicate that karst hills constitute low-biomass forest ecosystems, with biomass accumulation primarily limited by harsh site conditions that restrict tree growth rates and ecological longevity (Zhu et al. 1995). Our biomass estimates using the developed models showed total above-ground biomass increasing across restoration stages (small-tree forest > shrub-to-tree > shrub), indicating that the nutritional and energy foundations of the ecosystem are stabilizing with succession—consistent with Ma et al. (2009). The dominant contribution of trunk biomass across all stages highlights its importance for biomass accumulation in Guilin karst *L. chinense* communities, corroborating Su (2017). While shrub layers dominated the shrub-to-tree stage, arborous layers dominated the small-tree forest stage. However, field surveys revealed high species richness and stand density in the shrub layer at the small-tree forest stage, suggesting that karst hills can support high shrub density and diversity but not high shrub biomass due to environmental constraints.

Karst hills exhibit unique community structures related to their specialized habitats, which create variable and anomalous vertical distributions of branch and leaf biomass (Zhu et al. 1995). As the dominant species, *L. chinense* above-ground biomass peaked at the shrub-to-tree stage but its proportional contribution to community biomass declined in the small-tree forest stage. This suggests that *L. chinense* dominates only in early and mid-successional stages, with its dominance weakening in later stages. As site conditions improve with succession, *L. chinense* may be gradually replaced by better-adapted species and relegated to sub-canopy positions.

In summary, the above-ground biomass models developed for *L. chinense* communities are specific to the karst region of the Lijiang River basin, providing a convenient tool for researchers estimating biomass across restoration stages. These models offer a theoretical foundation for long-term monitoring of community structure and energy flow in this region. However, because forest biomass is closely related to numerous biological and environmental factors—including regional hydrothermal conditions, soil properties, forest type, stand age, species

composition, and live stem density (Huang et al. 2008; Wang et al. 2008)—the parameter selection for biomass models may vary. Therefore, further validation of these models is warranted.

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