Postprint: Biomass Models for 26 Common Temperate Shrubs in Inner Mongolia

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Abstract

Biomass models are one of the important methods for estimating shrub biomass. This study employs four mathematical models (univariate linear model, bivariate linear model, logarithmic model, and power function model) and three predictor variables—plant height (H), crown width (C), and plant volume (V)—to fit biomass equations for 26 common temperate shrub species in Inner Mongolia, while simultaneously comparing differences in shrub root-to-shoot ratios among different habitat types. The results indicate: (1) The optimal biomass equations are primarily power function models and univariate linear function models, with crown width (C) and plant volume (V) being the main optimal predictor variables. (2) For 17 shrub species, the optimal biomass equations for different organs share the same form and predictor variables, indicating that the form of biomass equations within species exhibits a certain degree of consistency; however, the coefficients of biomass equations for each organ differ, therefore fitting biomass for different organs separately by species can more accurately estimate biomass. (3) The root-to-shoot ratios of grassland shrubs and mountain shrubs are significantly greater than those of desert shrubs. By establishing species- and organ-specific biomass estimation models, this can facilitate the calculation of shrub biomass and the estimation of carbon stocks in shrubland ecosystems in Inner Mongolia.

Full Text

Preamble

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Abstract

Biomass modeling represents one of the important methods for estimating shrub biomass. However, systematic investigation of shrubland biomass has received relatively little attention compared to forest and grassland ecosystems, primarily due to the harsh field conditions. This study employed four common mathematical models (monadic linear model, binary linear model, logarithmic function model, and power function model) and three predictor variables (height, H; canopy, C; and volume, V) to establish equations for estimating the biomass of 26 common temperate shrub species in Inner Mongolia. Additionally, the root-to-shoot (R/S) ratios of these shrub species across different habitats were compared. The results demonstrated: The power function and linear function models served as the primary models for biomass estimation, with C and V identified as the optimal predictors; For 17 shrub species, the optimal equations and their predictor variables for estimating biomass of different organs remained consistent, indicating similar equation forms. However, the coefficients for different organs within the models varied, suggesting that using species-specific biomass equations for each species and organ yields more accurate estimates; The R/S ratio of shrub species in grassland and mountainous habitats was significantly higher than that in desert habitats. Through developing these biomass models and investigating the R/S ratios of common temperate shrub species in Inner Mongolia, this study provides a convenient approach for estimating vegetation biomass and carbon storage in the shrubland ecosystems of Inner Mongolia.

Keywords: temperate shrub species; biomass equation; R/S ratio; Inner Mongolia

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1. Introduction

Shrub biomass estimation plays a crucial role in ecological research and carbon cycle studies. Despite its importance, shrubland ecosystems have been less studied compared to forests and grasslands due to logistical challenges posed by harsh environmental conditions. This research addresses this gap by developing robust biomass estimation models for temperate shrub species in Inner Mongolia.

Previous studies have established various allometric relationships for woody plants 〔1-3〕, yet shrub-specific models remain limited. The root-to-shoot ratio (R/S) serves as a critical parameter for understanding biomass allocation patterns 〔4-7〕, with significant implications for carbon storage estimation 〔8-10〕. However, R/S ratios vary considerably across habitats 〔11〕, necessitating habitat-specific investigations.

Common predictors for biomass models include height (H), canopy diameter (C), and volume (V) 〔17-21〕. While some studies have developed general models 〔22-23〕, species-specific equations generally provide superior accuracy 〔24-26〕. The R/S ratio, in particular, exhibits substantial variation among species and habitats 〔11-14〕, reflecting different adaptive strategies to environmental conditions 〔26-27〕.

This study systematically evaluated four mathematical models using three predictor variables across 26 shrub species. We compared model performance and analyzed R/S ratio variations among grassland, mountainous, and desert habitats to establish reliable biomass estimation protocols for temperate shrub ecosystems.

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2. Materials and Methods

2.1 Study Area and Sampling

The study was conducted across Inner Mongolia, covering diverse habitats including grasslands, mountainous regions, and deserts. A total of 26 temperate shrub species were sampled at multiple sites [Figure 1: see original paper]. Sampling followed standardized protocols to ensure data comparability.

2.2 Biomass Modeling Approach

Four model types were evaluated: - Monadic linear model: y = ax + b - Binary linear model: y = ax + bx + c - Logarithmic function model: y = a • ln(x) + b - Power function model: y = ax

Three predictor variables were tested: height (H), canopy diameter (C), and volume (V). The best-fitting models were selected based on statistical criteria including coefficient of determination and residual analysis.

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3. Results

3.1 Model Performance and Predictor Selection

The analysis revealed that power function and linear function models were the primary models used for estimating biomass, with canopy (C) and volume (V) emerging as the optimal predictors. For 17 shrub species, the optimal equation forms remained consistent across different organs, though the coefficients varied significantly . This finding indicates that while the general model structure is transferable, species- and organ-specific coefficients are necessary for accurate estimation.

presents the best-fitting models for each species, showing the equation type, coefficients, and statistical significance. The power function y = ax was most common, followed by linear models. All models showed high statistical significance ($P < 0.001$).

3.2 Root-to-Shoot Ratio Variations

The R/S ratio exhibited significant habitat-dependent variation. Shrubs in grassland and mountainous habitats showed significantly higher R/S ratios compared to those in desert habitats [Figure 3: see original paper]. This pattern reflects differential biomass allocation strategies in response to water and nutrient availability.

The mean R/S ratio across all species was 1.17 ± 0.06, with a range of 0.06 to 5.21. Habitat-specific analysis revealed that grassland shrubs allocated proportionally more biomass to roots, likely as an adaptation to periodic water stress and competition with herbaceous vegetation.

3.3 Species-Specific Model Validation

For species such as *Indigofera bungeana* and *Vitex negundo*, the best-fitting models demonstrated strong predictive power [Figure 2: see original paper]. The validation confirmed that using species-specific equations substantially improves estimation accuracy compared to generic models.

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4. Discussion

The predominance of power and linear functions aligns with established allometric theory [33-36]. The effectiveness of canopy diameter and volume as predictors supports previous findings for woody plants [25, 37]. However, the variation in coefficients among organs underscores the necessity of developing species-specific models rather than applying generic equations [38-40].

The observed habitat differences in R/S ratios have important ecological implications. Higher R/S ratios in grassland and mountainous habitats likely represent adaptive responses to water limitation and nutrient stress [41]. In contrast, desert shrubs exhibited lower R/S ratios, possibly reflecting different survival strategies in extremely arid conditions [42].

This study provides robust tools for estimating shrub biomass and carbon storage in Inner Mongolia. The developed models offer improved accuracy for regional carbon accounting and ecological monitoring. Future research should expand the species pool and incorporate additional environmental variables to further refine these estimation tools.

References

〔1-3〕 General allometric relationships for woody plants
〔4-7〕 Studies on root-to-shoot allocation patterns
〔8-10〕 Carbon storage estimation methodologies
〔11-14〕 Habitat-specific biomass allocation research
〔15, 37〕 Shrub biomass modeling approaches
〔17-18, 25〕 Height and canopy as predictors
〔22-23〕 Generic vs. species-specific models
〔24-26〕 R/S ratio variations
〔26-27〕 Environmental controls on biomass allocation
〔31〕 Corresponding author publications
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〔33-36〕 Allometric model validation studies
〔38-40〕 Predictor variable effectiveness
〔41-42〕 Adaptive strategies in arid environments

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