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Estimating seasonal aboveground biomass of a riparian pioneer plant community: An exploratory analysis by canopy structural data

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ABSTRACT

The aboveground biomass (AGB) of vegetation is of central importance for ecosystem services by providing a measure of productivity. Models have been developed for estimating AGB via canopy structural variables in both fundamental and applied ecological studies. However, the potential of canopy structural variables for describing AGB dynamics throughout a growing season are still unclear. This study focuses on the AGB seasonal dynamics of a pioneer community, *Cynodon dactylon* (L.) Pers. (Bermuda grass), in a newly-formed riparian habitat at China's Three Gorges Reservoir. The objectives are (1) to determine the most important structural variable for estimating AGB at different growing stages during the season, and (2) to develop a model that can estimate AGB at the different growing stages and using multiple structural variables. We sampled the *C. dactylon* community six times during the growing season from May to September 2016. Six variables were engaged in the analysis, including five canopy structural variables, i.e., canopy height (H), canopy cover (CC), leaf area index (LAI), the volume related variables V_{LAI} (H × LAI) and V_{CC} (H × CC), and one seasonal growth effect variable (SV). We conducted univariate linear regression analysis to determine the most important estimator of AGB and the best subset regression analysis were used to develop the AGB estimation model. The detected most important AGB estimator changed with different growing stages throughout a season. Canopy structural characteristics of the community are key factors for determining such changes. Cover was the most important variable for AGB estimation during the early growing season and V_{LAI} was the most important variable in the mid and end of the growing season. The developed best multivariate models explained an additional 11% in AGB variance on average for the different growing stages compared with the univariate models using the most important estimators. SV was found to be useful in developing an acceptance general AGB estimation model appropriate for the entire growing season. The findings of this study are expected to provide knowledge for guiding sampling work and to assist with modeling AGB and understanding the AGB seasonal dynamics in the future.

1. Introduction

Riparian zones are an ecotone between terrestrial and aquatic ecosystems and play a central role in determining the vulnerability of natural and human systems to environmental changes (Capon et al., 2013; Nilsson et al., 1997). During the past decades, multiple ecosystem functions of vegetation coverage in a riparian zone have been recognized, such as wildlife habitats and corridors, food for aquatic and riparian biota, the stabilization of riverbanks, and the improvements in water quality (Husson et al., 2014). As the main energy source of the riparian ecosystem, the aboveground biomass (AGB) of a plant community is fundamental to other relevant resources (e.g., soil nutrients) and thus, can determine whether ecological processes are functioning appropriately (Raab et al., 2014).

In many ecosystem studies, the seasonal maximum AGB is considered the most widely used type of biomass data because it can in part indicate the productivity of an ecosystem (Raab et al., 2014; Sala and Austin, 2000; Thursby et al., 2002). Along with the increase in heterogeneity and complexity, the use of the seasonal maximum AGB alone is inadequate for describing the functional dynamics of an ecosystem

Abbreviations: AGB, aboveground biomass; CC, canopy cover; H, canopy height; LAI, leaf area index; MS, May 30–Sep. 23; SV, seasonal growth effect variable; TGR, Three Gorges Reservoir; VIF, variance inflation factor; V_{CC}, volume related variable (H × CC); V_{LAI}, volume related variable (H × LAI)

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(Fernandez-Alaez et al., 2002). It has been suggested that collecting data for AGB dynamics throughout the growing season is important for managing ecosystems (Fernandez-Alaez et al., 2002; Paillisson and Marion, 2006), modeling ecosystem processes (Hidy et al., 2012; Scurlock et al., 2002), monitoring plant-ecosystem functioning (Hooper et al., 2005), and evaluating vegetation life strategies that protect against environmental changes (Castelan-Estrada et al., 2002; Jagodzinski et al., 2016). Therefore, estimating the AGB seasonal dynamics is of primary importance for enhancing our knowledge of ecological functions and management for the restoration and protection of riparian zones.

To date, the most accurate estimations of AGB have been obtained using the destructive method (Marshall and Thenkabail, 2015; Redjadj et al., 2012). However, this method has two inherent drawbacks: (1) it is time consuming and labor intensive (Byrne et al., 2011), and most important, (2) it cannot be repeated in the same spatial location and does not allow seasonal monitoring of growth trajectories. Thus, an array of alternative non-destructive methods has been developed over the past few decades (Redjadj et al., 2012). For example, AGB can be estimated indirectly by modeling the relationships between biomass and biometrics data that are relevant to plant canopy structure (Martin et al., 2005; Pottier and Jabot, 2017). These biometrics include canopy height (Martin et al., 2005; Schmer et al., 2010), canopy cover (Flombaum and Sala, 2007; Zhang et al., 2016), leaf area index (LAI) (Liira et al., 2002; Rutten et al., 2015), and canopy volume-related indices such as the product of height and cover (Redjadj et al., 2012; Penderis and Kirkman, 2014; Pottier and Jabot, 2017).

Most of the studies of AGB estimation that utilized canopy structural variables have focused on a specific growing stage (e.g., after reaching peak biomass) during a growing season. However, to date, the potential of those variables for estimating AGB at different growing stages during the growing season have not been fully explored. This poses two questions: (1) how does the performance of an AGB estimation model change during a growing season for a specific variable? Furthermore, (2) which of the variable(s) are the most important AGB estimator(s) during the growing season for a specific type of model (e.g., linear regression model)? For the first question, researchers have reported that the performance of the models often depends on the sampling dates (i.e., growing stages) (Ferraro et al., 2012; Virkajarvi, 1999). For example, Martin et al. (2005) compared allometric equations for relating canopy height to individual biomass using data that was collected on ten sampling dates and found that the estimating parameter varied with the sampling occasions. The authors attributed this to seasonal changes in the species composition and structural characteristics of the stand (Martin et al., 2005). Using linear regression for AGB estimation via rising-plate meter measurements of canopy height, Nakagami and Itano (2014) found that the slope of the relationship between AGB and height decreased during the early season and then increased towards the end of the season. The authors further developed a novel general model by incorporating the sampling dates. To the best of our knowledge, little effort has been undertaken to date to compare the potential of different variables for AGB estimation throughout an entire growing season. The question this raises is: which variable(s) are the most important AGB estimator(s) for different growing stages during a growing season? The answer to this question will be helpful in guiding efficient sampling and modeling studies in the future.

In this study, we analyzed data collected in the riparian zone of the Three Gorges Reservoir (TGR) in China. The TGR was shaped by the Three Gorges Dam, which is one of the largest hydropower projects in the world to date (Fu et al., 2010). Since it was first impounded in 2003, the TGR has greatly altered the surrounding terrestrial environment with the largest range of annual water level fluctuations between 145 m and 175 m (after 2010), finally forming more than 300 km^2 of riparian zone (Zhang, 2008). Unlike other natural riparian ecosystems in the same climatic zone, the riparian zone that surrounds the TGR experiences low water levels in the summer but high water levels in the winter because of the artificial water level regulation. This type of dry-wet cycle causes heavy stress on the riparian ecosystem, resulting in severe habitat degradation (Su et al., 2013; Chen et al., 2015). For instance, the vegetation (predominantly herbaceous plants) that grows in the summer will be submerged and die out in the winter.

In the riparian zone of the TGR, *Cynodon dactylon* (L.) Pers. (Bermuda grass) is an endemic grass species that forms both aboveground stolons and belowground rhizomes (Dong and Kroon, 1994). Since the species has a strong ability to adapt to the dry-wet cycle disturbance of the degraded riparian habitat, it quickly became a pioneer species and the most dominant plant species in the riparian ecosystem of the TGR (Chen et al., 2015; Liu et al., 2011). Consequently, *C. dactylon* plays a crucial role in ecosystem services by providing productivity, habitat, soil conservation, and riparian reinforcement, as well as by protecting the water quality (Liu et al., 2011). Estimating the AGB seasonal dynamics of the *C. dactylon* community is thus essential for understanding riparian community succession, monitoring riparian zone restoration processes, and managing the reservoir ecosystems of the TGR (Byrne et al., 2011; Sala and Austin, 2000). Moreover, the evaluation of various canopy structural variables for their potential for estimating the seasonal AGB is also an urgent need, as stated before. Therefore, this study is focused on the *C. dactylon* community and aims: (1) to determine the most important structural variable for estimating AGB for different growing stages during a season, and (2) to develop the best model for estimating the AGB for the different growing stages using multiple structural variables. The results are expected to assist in conducting efficient seasonal AGB sampling and modeling studies in the future for different research conditions and objects.

2. Methods

2.1. Study area

The study area is located in the upper-mid section of a primary tributary (named Pengxi River) of the Yangtze River (Fig. 1). The area has a humid subtropical monsoon climate, characterized by warm winters and hot summers. The mean annual temperature is 18.6 °C and the mean annual precipitation is 1300 mm. The slope in the area is low and the main soil type is purple soil. Prior to the formation of the TGR, the area had a long history of agricultural reclamation with the major land use types of paddy fields and dry farmland. After 2003, many areas were abandoned and riparian zones formed due to the high water level fluctuations of the TGR. Since then, the riparian zone has entered a succession process. This area represents a typical riparian zone in the TGR and has been the focus of various studies related to different topics of the riparian ecosystem (Chen et al., 2012; Wang et al., 2014). Dominant plant communities in the riparian zone are *Cynodon dactylon*, *Echinochloa colonum*, *Xanthium sibirium*, and *Setaria viridis*. Among them, *C. dactylon* and *E. colonum* are largely distributed throughout the low elevations (147–165 m) and the other species are predominantly distributed throughout the higher elevations (165–175 m) (Chen et al., 2012; Wang et al., 2014) (Fig. 1). In the low elevations, *C. dactylon* occurs for the most part in a mono-species community which was the focus of our study.

2.2. Field sampling methods and data processing

2.2.1. Field sampling

Based on data from earlier vegetation investigations and the practical accessibility of the area, five sampling sites (A–E in Fig. 1c) were selected in the study area. The sampling sites did not have significant random effect on the modeling we conducted (see Appendices Table. A.1 in Supplementary material). A maximum of four quadrats (1 × 1 m) per site were sampled for the *C. dactylon* community, while the number could be reduced to two in one site based on different field conditions and workloads during sampling. During the growing season