MODELING STEM PROFILE OF *TRIADICA SEBIFERA* IN SOUTHERN FORESTLANDS OF MISSISSIPPI

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Abstract—Chinese tallow (*Triadica sebifera*) is one of the most aggressive invasive species in the southern forestlands of United States. To explore the stem taper of tallow, outside-and-inside bark stem profile equations were fitted using Max and Burkhart (1976), Cao (2009) modified Max and Burkhart, and Clark, Souter, and Schlaegel (1991) segmented polynomial models. Sample trees were collected from oak-gum-cypress (*Quercus/Liquidambar styraciflua/Taxodium distichum*) and longleaf/slash pine (*Pinus taeda/ Pinus echinata*) forests in southern Mississippi using destructive sampling method. Results showed that: 1) Clark, Souter, and Schlaegel (1991) segmented polynomial model was the best fitted model for both DOB and DIB stem profile of tallow in these two forestlands; 2) the stem of tallow was generally sturdy in oak-gum-cypress forest while it was slender in longleaf/slash pine forest; however, no significant difference was found. Those models provide a tool for managers to project future growth stocking of tallow accurately and make management decision.

INTRODUCTION

The Chinese tallow tree (Triadica sebifera (L.)) in the spurge family (Euphorbiaceae) is a monoecious, deciduous tree, native to central and southern China (Zhang and others 1994). Since its introduction as an ornamental and potential oil producing species in the 1770s, it has become an invasive species in the southern forestlands of the United States (Bruce, 1993). Previous study recorded that approximately 185,000 acres of southern forests had been invaded by tallow tree (Tan, 2012) especially in the coastal prairies and plains (Gan and others 2009). Fast growth and spread are critical factors for colonization and establishment of Chinese tallow in the affected regions.*trst*

Stem growth described by profile functions is an important indicator of tree growth. Taper equations are the mathematical function of the diameter change with respect to height on the basis of species, age, and stand condition (Husch and others 1982; Brooks and others 2008). Numerous taper functions have been developed for different tree species with various forms from simple ones (Kozak and others 1969, Ormerod 1973, Hilt 1980, Zakrzewski and others 2006) to complex (Max and Burkhart 1976, Cao and others 2009 Clark and others 1991, Jiang and others 2005). Methol (2001) classified taper equations into four categories: single functions, within-tree variable form, between-tree variable form, and segmented polynomial models; moreover, Jiang and others (2005) summarized them into three classifications including simple taper functions, variable form taper functions, and segmented polynomial taper functions.

Simple taper functions mainly define tree profiles with a single continuous equation for the whole bole (Bruce and others 1968, Hilt 1980, Gordon and others 1995). However, these simple taper equations were unable to precisely describe the whole bole profile, although they could reflect the general stem form (Jiang and others 2005). Max and Burkhart (1976) developed a segmented polynomial regression method to build a profile equation for loblolly pine (*Pinus taeda*). Clark and others (1991) found it as a better performer in predicting diameter. Likewise, Sharma and Burkhart (2003) described it as the combination of three sub-models at two join points. However, the application of Max and Burkhart model is limited to a small range of diameters and heights because of the complexity (Matney and Parker 1992, Parker 1997). Cao (2009) modified the Max and Burkhart loblolly pine model by calibrating DBH and upper stem diameter. Then Clark and others (1991) developed a form-class segmented profile model which provided volume estimation more accurately than the segmented Max and Burkhart model. Souter (2003) employed a segmented profile function in southern tree species to predict diameter at a specified height. Overall, segmented polynomial models composed of a

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series of sub-models representing various sections of the stem are better than simple and variable form taper functions and are widely used (Ounekham, 2009).

To compare the stem taper of tallow in different forestlands in southern Mississippi, a group of profile models were constructed using Max and Burkhart (1976), Cao (2009) modified Max and Burkhart, and Clark, Souter, and Schlaegel (1991) segmented polynomial models.

METHODS

Data Collection

In total, 33 sample trees were collected in this study and 11 of them were from the oak/gum/cypress bottomland forest in southern Mississippi (Old River Wildlife Management Area in Poplarville city, Pearl River County, MS); 16 were sampled from the Grand Bay National Estuarine Research Reserve (NERR) (Jackson County, MS) and an additional 6 trees were obtained from the Mississippi Sandhill Crane National Wildlife Refuge (NWR) (Jackson County, MS) in the Gulf Coast Complex. The Grand Bay and Sandhill are primarily longleaf/slash pine forests.

Destructive sampling was used to obtain the diameter along different height of the stem. Before felling sample trees in the field, total height and diameter at breast height (DBH) was measured. Trees were then cut (to a stump height of approximately 10 cm) and the stem was divided into 1 m sections. Disks with 3-5 cm thickness were then extracted from the midpoint of each section. The diameter (inside bark and outside bark) was obtained at the upper end of each section. Diameter at selected height positions (0.8 m and 5.3 m) was also recorded.

Analysis

Three segmented polynomial approaches of Max and Burkhart (1976) (Equation 1), Cao (2009) (Equation 2), and Clark, Souter, and Schlaegel (1991) (Equation 3) were selected to fit the stem profile of tallow and they all fitted using TProfile (Matney 1992).

$$\frac{d}{D} = \left\{\left(b_1\left(\frac{h}{H}-1\right)+b_2\left(\frac{h^2}{H^2}-1\right)+b_3\left(\alpha_1-\frac{h}{H}\right)^2 I_1 + b_4\left(\alpha_2-\frac{h}{H}\right)^2 I_2\right)\right\}^{0.5} \tag{1}$$

Where: H indicates the total height (m) whereas D represents DBH (cm); d is diameter at height h (cm) and h is height above the ground to the measurement point (m). The indicate condition of this model is: $h = H$, $d = 0$, *and* $h = 1.37$, $d = D$. $I_1 = 1$ if $\frac{h}{H} \le a_1$, and $I_1 = 0$, otherwise; $I_2 = 1$ if $\frac{h}{H} \le a_2$, and $I_2 = 0$, otherwise. b_1, b_2, b_3, b_4, a_1, a_2 are all parameters to be estimated.

$$y^*\left(1-\frac{h}{H}\right) = b_1^* \times \left(1-\frac{h}{H}\right) + b_2(1-\frac{h}{H})^2 + b_3 \times I_1(1-\frac{h}{H}-a_1)^2 + b_4 \times I_2(1-\frac{h}{H}-a_2)^2 \tag{2}$$

$$b_1^* = \frac{y\left(1-\frac{1.37}{H}\right) - \hat{y}\left(1-\frac{1.37}{H}\right) + b_1 \times (1-\frac{1.37}{H})}{(1-\frac{1.37}{H})}$$

Where: $y^* = d^{*2}/D^2$ and d^* is calibrated diameter; the parameter b_1 is modified to parameter b_1^*. The other variables had the same meaning with Max and Burkhart model.

$$d = \{I_S\left\{D^2\left(1+\frac{\left(b_2+\frac{b_3}{D^3}\right)\left(\left(1-\frac{h}{H}\right)^{b_1}-\left(1-\frac{1.37}{H}\right)^{b_1}\right)}{\left(1-\left(1-\frac{1.3}{H}\right)^{b_1}\right)}\right)\right\} + I_B\left\{D^2-\frac{(D^2-F^2)\left(\left(1-\frac{1.37}{H}\right)^{b_4}-\left(1-\frac{h}{H}\right)^{b_4}\right)}{\left(\left(1-\frac{1.37}{H}\right)^{b_4}-\left(1-\frac{5.3}{H}\right)^{b_4}\right)}\right\}^{0.5} + I_T\{F^2\left(b_6\left(\frac{h-5.3}{H-5.3}-1\right)^2 + I_M\left(\frac{1-b_6}{b_5{}^2}\right)\left(b_5-\frac{h-5.3}{H-5.3}\right)^2\right)\}\} \tag{3}$$

Where: F is the diameter at 5.3 m, b_1,b_2,b_3 is the regression coefficient for butt section, b_4 is the coefficient for lower stem, and b_5, b_6 are the coefficients for height above 5.3 m. Hence, the four indicator variables in Equation (3) are defined as following:

$$I_S = \begin{cases} 1 & h < 1.37 \\ 0 & otherwise \end{cases}$$

$$I_B = \begin{cases} 1 & 1.37 < h < 5.3 \\ 0 & otherwise \end{cases}$$

$$I_T = \begin{cases} 1 & h > 5.3 \\ 0 & otherwis \end{cases}$$

$$I_M = \begin{cases} 1 & h < (5.3 + b_5(H-5.3 \\ 0 & otherwise \end{cases}$$

Final best fitted taper model selection was evaluated by root mean squared error (RMSE) (Equation 4) and a fit index (FI) (Equation 5) (Schlaegel 1981).

$$RMSE = \sqrt{\bar{e}^2 + SD^2} \tag{4}$$

$$FI = 1 - [\frac{\sum_{i=1}^{n}(Y_i-\hat{Y}_i)^2}{\sum_{i=1}^{n}(Y_i-\bar{Y})^2} \tag{5}$$

Where: SD is standard deviation of the predicted errors, e_i is the prediction error or difference between observations (Y_i) and the predictions $(\hat{Y}_i)$; $\bar{Y}$ is the mean of Y_i.

RESULTS

Both DOB and DIB profile models were fitted and for the inside-bark taper fitting process, DIB replaced DOB with the other variables being the same as with the DOB fitting process. Fitted profile models were presented in fig. 1. In addition, RMSE and FI showed that all three models performed well for DOB profile of tallow in oak/gum/cypress forest at Poplarville although Clark and others (1991) (RMSE = 0.052, FI = 0.974) was better than the Max and Burkhart taper model (RMSE = 0.060, FI = 0.964) and Cao (2009) modified Max and Burkhart model (RMSE = 0.060, FI = 0.964). However, no significant difference was found. Likewise, for DOB of tallow in longleaf/slash pine forest at Grand Bay and Sandhill, still no distinct difference was found among three profile models though Clark and others (1991) performed better (RMSE = 0.069, FI = 0.947) than Max and Burkhart (RMSE = 0.088, FI = 0.912) and the Cao (2009) modification model (RMSE = 0.090, FI = 0.910) according to RMSE and FI. Regarding the DIB profile models of tallow at Poplarville, there was also no evidence of difference among the three fitted models: Max and Burkhart (RMSE = 0.057, FI = 0.962), Cao (2009) modification model (RMSE = 0.061, FI = 0.956), and Clark and others (1991) (RMSE = 0.057, FI = 0.968). Nevertheless, Clark and others (1991) (RMSE = 0.078, FI = 0.930) performed better than the other two models which exhibited the same performance (RMSE = 0.088, FI = 0.880) for DIB profile model of tallow at longleaf/slash pine forest.

DISCUSSION AND CONCLUSIONS

Clark and others (1991) had better performance for both DOB and DIB profiles of tallow in oak/gum/cypress forest at Poplarville, but there was no significant difference among the three fitted profile equations. Similarly, Clark and others (1991) was also the best fitted model for tallow in longleaf/slash pine at Grand Bay and Sandhill as compared with the Max and Burkhart (1976) and the Cao (2009) modified Max and Burkhart models. Studies (Larson 1965, Garber and Maguire 2003, Bluhm and others 2007) have reported that stem profile varied with stand conditions. However, in this study there is no obvious difference for both DOB and DIB profile of tallow in the two different coastal forests. The importance of profile equations in improving the estimation of volume/biomass for managing and valuing

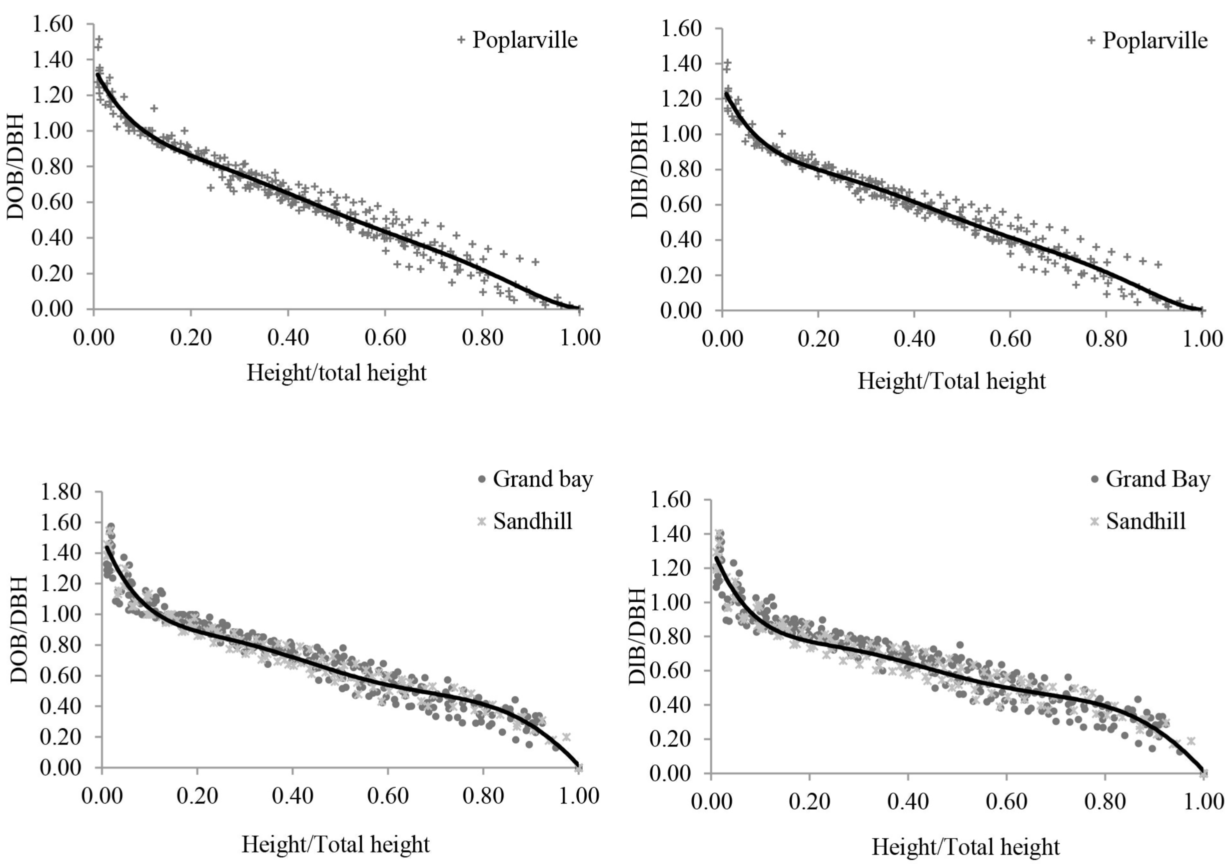

Figure 1—Plots of observed stem profile (DOB and DIB) at Poplarville, Grand Bay, and Sandhill.

forests and the difficulty of selecting an appropriate model that works well for multiple species and diverse site conditions makes the equations an exploited research topic (Clutter and others 1983, McClure and others 1986, Muhairwe 1999).

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