ASSESSING THE FLOOD TOLERANCE OF WILLOWS AND COTTONWOODS PLANTED IN RIPARIAN CROPLAND OF THE LOWER MISSISSIPPI ALLUVIAL VALLEY

Thu Ya Kyaw, Courtney M. Siegert, Heidi J. Renninger, and Randall J. Rousseau

EXTENDED ABSTRACT

The Lower Mississippi Alluvial Valley (LMAV) is a vital agricultural watershed of the United States. In addition to productive farmland, the LMAV has about 3 million ha of marginal lands (Amacher and others 1997), which are usually underutilized due to seasonal flooding during the spring and summer. These riparian floodplain areas are not optimal for agricultural food production, however, they may be suitable for growing short rotation woody crops (SRWCs) for bioenergy production. Since backwater flooding is common in the marginal lands of the LMAV, the selected SRWCs need to be tolerant of flooding. Although eastern cottonwood (*Populus deltoides* W. Bartram ex Marshall) and black willow (*Salix nigra* Marshall) are well-known riparian species (Amlin and Rood 2001), their flood tolerance threshold has not yet been reported through field trials. This study leveraged the high and extended flooding that occurred in the LMAV in 2019 to examine the flood tolerance of eastern cottonwood and black willow, planted as SRWCs for bioenergy on a riparian floodplain of the Yazoo River. To determine the flood tolerance thresholds of both species, this study developed models to predict survival or mortality probability of trees by considering hydrologic and environmental parameters as predictors. From the prediction models, this study estimated how timing, seasonality, and depth of flooding threatened the survival of both species.

In June 2018, a bioenergy plantation was established at the interface between cropland and an oxbow of the Yazoo River, located in Sidon, MS in the Mississippi Delta of the LMAV. Unrooted cuttings of 300 eastern cottonwood and 300 black willows were planted in a 1.8 m by 2.7 m (6 feet × 9 feet) spacing. Before flooding that started in November 2018, the establishment survival was 60 percent and 96 percent for eastern cottonwood and black willow, respectively. Flood depth and duration were monitored every half hour by installing HOBO U20L-01 loggers in 10 groundwater wells throughout the plantation site. An additional HOBO logger was mounted about 1.6 m above the ground surface to record air temperature and more importantly, atmospheric pressure to standardize the well sensors. To obtain flood depths for each individual tree during the study period, spatial interpolation was performed by considering flood depths recorded at groundwater wells and a digital elevation model created from LiDAR point cloud data (Photo Science 2010) as input parameters. Individual tree survival was modeled using binary logistic regression

Thu Ya Kyaw, Ph.D. Candidate, Mississippi State University, Starkville, MS 39762; Courtney M. Siegert, Associate Professor, Mississippi State University, Starkville, MS 39762; Heidi J. Renninger, Associate Professor, Mississippi State University, Starkville, MS 39762; Randall J. Rousseau, Extension and Research Professor, Mississippi State University, Starkville, MS 39762.

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with the "glm" function in R (R Core Team 2021). Five predictor variables were used: (1) average monthly flood depths, (2) growing season accumulated flood depth; (3) total accumulated flood depth; (4) flood duration; and (5) accumulated air temperature during flooding. Variable selection was conducted using the "bestglm" package (McLeod and others 2020) to select five candidate models using BIC (Bayesian Information Criteria) as the selection criteria. Then, those models were re-ranked based on test data accuracy by using *k*-fold cross-validation (Moreno-Torres and others 2012). During cross-validation, data were split into training (70 percent) and testing (30 percent), and their accuracy was calculated. Finally, flood tolerance threshold values were defined for each predictor included in the models.

Post-flooding survival was 17 percent for eastern cottonwood and 41 percent for black willow. The most common predictors included in the best fit models were flood duration (included in four models) and February flood depth (included in four models) for eastern cottonwood, and March (included in four models) and April (included in all five models) flood depths for black willow (table 1). As per threshold values, black willow could tolerate higher flood depth (up to 2.73 m in March and 2.28 m in April) than eastern cottonwoods (up to 2.63 m in March and 2.20 m in April) (table 1). The best fit models did not suggest that flood duration was a predicting factor of mortality in black willow. Compared to black willow, the survival of eastern cottonwood was affected by more factors, such as flood depth, flood duration and air temperature during flooding. Generally, dissolved oxygen is inversely correlated with water temperature (Joyce and others 1985, Null and others 2017, Post and others 2018), and water temperature can be increased with warming air temperature (Kaushal and others 2010). Thus, deficiency of dissolved oxygen due to the increase in water temperature can exert a compounding stress especially when the oxygen level is limiting in the flooded rhizosphere.

The overall accuracy of the best fit model for eastern cottonwood (88 percent) was slightly higher than that of the black willow (86 percent) (table 1). In predicting individual tree mortality, the eastern cottonwood model had fewer false positive predictions (i.e., the model predicted survival, but it was a mortality) than the black willow model. On the other hand, the model of black willow was better at predicting tree survival than that of eastern cottonwood because the former had fewer false negative predictions (i.e., the model predicted mortality, but it was a survival) than the latter.

Black willow was found more tolerant than eastern cottonwood. Only elevated flood depth posed a threat to survival. The results of this study suggest that flood depth during the pre-growing season (January, February, March) and growing season months are critical for predicting the survival of both species. Initial flooding months, such as November and December, did not greatly impact the survival of either species. In this study, black willow was taller than eastern cottonwood on average. Having a height advantage may have given black willow the ability to adapt to oxygen deficiency in the soil by increasing the formation of spongy aerenchyma tissues to undertake greater oxygen transport from aerial plant parts to the roots (Pezeshki and others 1998). In summary, this study identified threshold values, and beyond which, mortality was more likely than survival. This study further confirmed that willow was more flood-tolerant than cottonwood. Information about specific flood depth, flood duration, and air temperature can be useful for modeling optimal sites for establishing eastern cottonwood and black willow in frequently flooded, marginal lands of the LMAV.

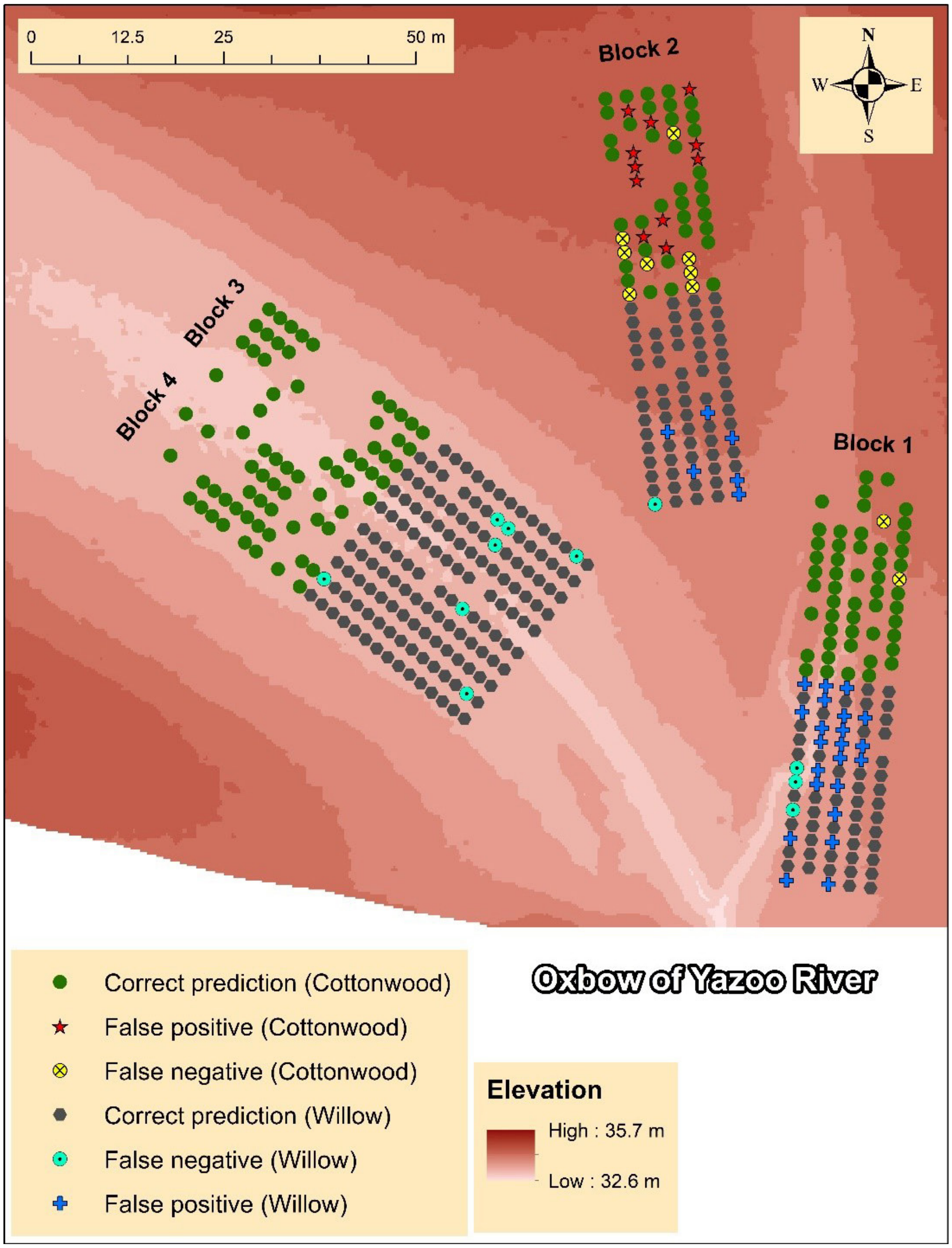

Figure 1— Map depicting the accuracy of the model with the highest test data accuracy (i.e., Model 1) for eastern cottonwood and black willow. Empty areas within the plantation plots represented mortality during the establishment period prior to flooding. False positives meant that the model predicted survival, but the individual died. False negatives meant that the model predicted a mortality, but the tree survived.

Table 1—Top five best fit models for predicting the survival or mortality probability of eastern cottonwoods (top) and black willows (bottom) based on test data accuracy

EASTERN COTTONWOOD

No.	Variables included in the model	k-fold test data accuracy (%)	All data accuracy (%)	BIC	Flood depths (m)					Flood duration (weeks)	Accumulated air temperature during flooding (°C)
					Jan	Feb	March	April	May		
1	Feb and April flood depths, and flood duration	83	88	107.4		2.10		2.20		25.47	
2	Jan and May flood depths, and flood duration	83	88	108.2	1.80				2.06	25.21	
3	Feb and May flood depths, and flood duration	81	88	106.9		2.10			2.07	25.76	
4	Feb and March flood depths, and flood duration	81	88	108.6		2.10	2.65			24.80	
5	Feb and March flood depths, and accumulated air temperature during flooding	81	88	109.3		2.10	2.65				453.57

BLACK WILLOW

No.	Variables included in the model	k-fold test data accuracy (%)	All data accuracy (%)	BIC	Flood depths (m)						Total accumulated
					Jan	Feb	March	April	May	June	
1	March, April, and June flood depths	90	86	215.5			2.73	2.28		0.52	
2	Feb, March, and April flood depths	90	86	217.5		2.19	2.73	2.28			
3	Jan, March, and April flood depths	88	86	216.6	1.96		2.73	2.28			
4	Jan, April, May, and June flood depths	88	88	219.6	1.96			2.28	2.15	0.51	
5	Jan, March, April, and total accumulated flood depths	87	86	218.9	1.96		2.73	2.28			14.73

Columns containing flood depths (m) in each month, flood duration (weeks), and accumulated air temperature during flooding (°C) represented threshold values that trees could tolerate.

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