Ecological Engineering 103 (2017) 275–287

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng

Research paper

Hydrology and soil magnetic susceptibility as predictors of planted tree survival in a restored floodplain forest

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ARTICLE INFO

Article history:
Received 16 September 2016
Received in revised form 10 March 2017
Accepted 1 April 2017
Available online 14 April 2017

Keywords:
Bottomland forest
Flooding
Restoration
Seedling
Tree growth
Wetland mitigation

ABSTRACT

Flooding in floodplain forests is an important abiotic constraint on tree recruitment, as well as on planted tree survival and growth in restorations. Nevertheless, trees are often planted in floodplain restorations without regard to a site's hydrologic context, resulting in poor survival. There is a need for improved tools for identifying critical abiotic factors that control tree growth and mortality at reforestation sites. We planted 400 bareroot tree seedlings of four commonly planted species in plots along five 100-m transects along a hydrologic gradient in a recently restored wetland to determine the effect of hydrology on planted tree survival. We evaluated the effect of exposure to flooding on survival and growth for two growing seasons. We also evaluated the use of soil magnetic susceptibility (MS) as a proxy for soil drainage and predictor of tree survival and growth. Soil MS is easily measured and mainly reflects the concentrations of ferrimagnetic minerals, which can dissolve with iron reduction in poorly drained soils. In the first year, the overall survival rate of the planted seedlings was 61%. By the end of the study period, survival had declined to 25%. Of the four species planted, *Quercus bicolor* survived best, followed by *Quercus palustris* and *Carya illinoensis*. No *Juglans nigra* seedlings survived to the end of the study. Duration of inundation and species identity were important predictors of growth and survival; as duration of inundation increased, height growth and probability of survival for each species decreased. Soil MS was not strongly correlated with either flood duration or elevation and was not an effective predictor of tree survival at this site, but might be a useful tool to guide planting in areas with a more pronounced hydrologic gradient. This research can help provide higher precision tree planting in accordance with species' natural distribution across soil moisture gradients, ultimately leading to greater planting success in restorations.

1. Introduction

Inundation in floodplain forests is an important constraint on tree establishment (Middleton, 2000; Battaglia et al., 2002), as well as on planted tree survival and growth in restorations (Pennington and Walters 2006; Kabrick et al., 2012). Flooding decreases oxygen availability and light at the soil surface (Teskey and Hinckley, 1977; Baskin and Baskin, 1998), which can lead to poor seedling survival. Floodplain forests are often the focus of tree planting and restoration efforts, especially in the southern United States (Clewell and Lea, 1990; Sharitz, 1992; Noss et al., 1995; Stanturf et al., 2001). However, current approaches to floodplain restoration often ignore site-specific hydrologic variability, resulting in unexpected mortality of planted species and failure to achieve restoration goals (King et al., 2006; Pennington and Walters, 2006). Since individual tree survival, along with overall species composition and diversity, is determined primarily by hydrology in floodplain forests (Toner and Keddy, 1997; Turner et al., 2004), in-depth knowledge of the hydrologic regime at a restoration site is essential for reforestation success. In addition to soil inundation, other site conditions influencing tree establishment and survival include light availability and herbivory (Menges and Waller, 1983; Lin et al., 2004; Turner et al., 2004). Understanding these factors, particularly flooding, and their effects on tree survival and growth in a site-specific context will aid restoration managers in their reforestation efforts.

Qualitative flood tolerance rankings have been used to describe species' ability to survive a certain depth of flooding over a number of days (Bell and Johnson, 1974; Teskey and Hinckley, 1977; Hook, 1984). Flood tolerance differs among species because of their diverse adaptations for enduring inundation (Kozlowski, 1982a,b, 1984; Keddy and Ellis, 1985), such as developing adventitious roots to facilitate oxygen diffusion (Teskey and Hinckley, 1977). How-

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http://dx.doi.org/10.1016/j.ecoleng.2017.04.011
0925-8574/

ever, a complete evaluation of flood tolerance for all tree species is not available (Lin et al., 2004). Furthermore, these ratings do not take into consideration other environmental factors that could influence tree species' establishment and survival (Battaglia et al., 2004). Thus, qualitative ratings of flood tolerance have limited practical utility for restoration planning, and there is a need for improved quantitative tools for predicting tree growth and mortality in the context of a particular reforestation site.

Currently, there are very few simple tools to measure hydrologic conditions in restored wetlands. Piezometers and unlined observation wells are used to measure hydrology, but they can be expensive and time-consuming (Faulkner et al., 1989; Thompson et al., 2012). In contrast, soil magnetic susceptibility (MS), a proxy for soil drainage at sites with similar soil parent materials (Grimley and Vepraskas, 2000; Grimley et al., 2004), is easy to measure at a reasonable cost, is quantitative, and may be a useful tool for restoration managers when planning tree plantings. Under anaerobic soil conditions concentrations of ferrimagnetic minerals, typically magnetite and maghemite, are dissolved (Grimley and Arruda 2007; Lu et al., 2012). The concentrations of these magnetic minerals control soil MS. Although other soil forming factors, such as parent materials, can affect soil MS (de Jong et al., 2000; Blundell et al., 2009), MS has been shown to reliably reflect drainage conditions at sites where other local factors are relatively similar. Under such conditions, soil MS can be useful as a guide for matching individual tree species' requirements to site-specific soil moisture regimes. Measurements of soil MS have primarily been used in geoarchaeology and soil science, but have not been used extensively in restoration practice. Previous research on the use of soil MS in wetlands suggests that soil MS could be applicable in ecological restoration (Grimley et al., 2008; Wang et al., 2008; Simms and Lobred, 2011). For example, soil MS has been used successfully to delineate wetland boundaries by distinguishing between upland and wetland soils (Grimley et al., 2004; Simms and Lobred, 2011). In a study surveying the distribution of naturally occurring trees in forested areas of east-central Illinois, higher soil MS was associated with well drained soils, which are suitable to upland species, whereas lower soil MS was prevalent in poorly drained or waterlogged soils and associated with flood-tolerant species (Grimley et al., 2008; Wang et al., 2008). The present study is the first to compare soil MS to current hydrologic data and planted tree survival and growth in a restoration context as a test of concept for future reforestation efforts.

We addressed two objectives. The first objective was to determine how the growth and survival of planted tree seedlings of four species varied with local hydrologic conditions in a recently reforested floodplain. Although we expected that different tree species would vary in their response to a soil saturation gradient, in general, we expected that planted tree growth would be least and mortality would be greatest in areas with prolonged flooding. The second objective was to determine whether soil MS could be used as a proxy for soil drainage to guide the planting of tree seedlings. Given that soil parent material and surface textures are relatively similar across the study site, we expected that soil MS would be a suitable proxy for current soil drainage and thus, a good predictor of planted tree survival.

2. Materials and methods

2.1. Study area

The project site is within the 50.9-ha Sugar Camp Creek wetland mitigation bank in Franklin County, Illinois (Fig. 1). This study was conducted in the southwestern corner of the mitigation bank, which was restored by the Illinois Department of Transportation (IDOT) beginning in 2013. To re-establish wetland hydrology, IDOT filled all on-site ditches, blocked outlets to Sugar Camp Creek, lowered pre-existing levees along the creek, constructed low berms along the perimeter of the site, removed culverts within the site, excavated portions of the site, and installed four fixed-threshold spillways (Illinois Department of Transportation, 2009). The soils mapped in the study area are hydric, frequently flooded Bonnie silt loam and non-hydric Belknap silt loam (Preloger, 2003; Pociask and Shofner, 2007). Prior to modification for agricultural activity, the extent of the hydric soil at the Sugar Camp Creek site indicated that most of the site was a wetland area in the past (Pociask and Shofner, 2007). There are also remnant floodplain forest patches to the east of the site.

2.2. Tree planting and monitoring

In late May 2014, we planted 400 bareroot tree seedlings (20–74 cm in height), which were obtained from the Mason State Tree Nursey in Topeka, IL, along five 100-m transects (Fig. 1). Soil conditions along transects spanned a gradient from very wet to wet-mesic, and soil was undisturbed by IDOT's site preparation activities. Along each transect, we established one 2-m x 2-m plot every 20 m in which we planted 16 individuals total, four of each of the following species: swamp white oak (*Quercus bicolor* Willd.), pin oak (*Quercus palustris* Muenchh.), pecan (*Carya illinoensis* [Wangenh.] K. Koch), and black walnut (*Juglans nigra* L.). These species are among the most commonly planted tree species in floodplain restorations in central U.S. (Kabrick et al., 2012). Each seedling was marked with an aluminum tag with identifying information. Baseline height and stem diameter at 18-cm height were measured for each seedling at the time of planting. In September 2014, height and stem diameter of surviving seedlings were re-measured and any signs of herbivory were noted. Sampling procedures were repeated in May and August of 2015.

Variables that could either limit or enhance the survival and growth of seedlings were measured within the plots. Illinois State Geological Survey (ISGS) has been monitoring ground and surface water elevations at the Sugar Camp Creek site since 2005, which provided a detailed and precise record of hydrologic variation. The ground elevation at each plot was determined by superimposing the point layer for the plots (determined by GPS) on a LiDAR-based digital elevation model (Illinois State Geological Survey, 2015) and using the 'Extract' tool in ArcGIS v. 10.1. Surface-water data were collected at hourly sampling intervals using a pressure transducer data logger. The elevation for the surface-water data logger was measured using survey grade GPS to assign a reference elevation so that surface water elevation at each plot could be calculated. Total flood duration and consecutive flood duration at each plot were determined by tallying the consecutive hours that water levels exceeded the ground elevation of each plot based on water levels from the hydrograph. Both the total cumulative duration and the maximum continuous duration of inundation at each plot were tallied from June 2014 until August 2015. Light penetration through the plant canopy was measured using a LI-COR LI-250A Light Meter at 1 m above the ground and at the soil or water surface, depending on whether the plot was inundated at the time of collection. These readings were then relativized to light measurements collected under full sunlight, under no canopy vegetation.

2.3. Soil magnetic susceptibility and grain size determinations

Soil magnetic susceptibility was measured in the field in May 2015 on the soil surface with a portable Bartington MS2 meter and MSD loop (Bartington Instruments, Oxford, UK). MS was measured in the center of each plot on soil surfaces that were gently smoothed with work boots and cleared of any loose plant litter. This method-