Geomorphology 204 (2014) 277–286

Contents lists available at ScienceDirect

Geomorphology

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

Coupling legacy geomorphic surface facies to riparian vegetation: Assessing red cedar invasion along the Missouri River downstream of Gavins Point dam, South Dakota

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ARTICLE INFO

Article history:
Received 3 May 2013
Received in revised form 15 August 2013
Accepted 16 August 2013
Available online 27 August 2013

Keywords:
Invasion
Geomorphic surface
Flow regulation
Hydro-eco-geomorphology

ABSTRACT

Floods increase fluvial complexity by eroding established surfaces and creating new alluvial surfaces. As dams regulate channel flow, fluvial complexity often decreases and the hydro-eco-geomorphology of the riparian habitat changes. Along the Missouri River, flow regulation resulted in channel incision of 1–3 m within the study area and disconnected the pre-dam floodplain from the channel. Evidence of fluvial complexity along the pre-dam Missouri River floodplain can be observed through the diverse depositional environments represented by areas of varying soil texture. This study evaluates the role of flow regulation and depositional environment along the Missouri River in the riparian invasion of red cedar downstream of Gavins Point dam, the final dam on the Missouri River. We determine whether invasion began before or after flow regulation, determine patterns of invasion using Bayesian *t*-tests, and construct a Bayesian multivariate linear model of invaded surfaces. We surveyed 59 plots from 14 riparian cottonwood stands for tree age, plot composition, plot stem density, and soil texture. Red cedars existed along the floodplain prior to regulation, but at a much lower density than today. We found 2 out of 565 red cedars established prior to regulation. Our interpretation of depositional environments shows that the coarser, sandy soils reflect higher energy depositional pre-dam surfaces that were geomorphically active islands and point bars prior to flow regulation and channel incision. The finer, clayey soils represent lower energy depositional pre-dam surfaces, such as swales or oxbow depressions. When determining patterns of invasion for use in a predictive statistical model, we found that red cedar primarily establishes on the higher energy depositional pre-dam surfaces. In addition, as cottonwood age and density decrease, red cedar density tends to increase. Our findings indicate that flow regulation caused hydrogeomorphic changes within the study area that permitted red cedar invasion of the riparian habitat and that the type of depositional environment partially determines where along the riparian landscape red cedar invades.

1. Introduction

Hydrogeomorphic processes interact with riparian ecosystem processes, creating dynamic and complex environments that provide an array of ecosystem services (Schumm, 1973; Naiman and Decamps, 1997). Altering river hydrogeomorphology often alters the riparian ecosystem, most visibly through species invasion. In particular, river flooding of riparian habitats typically increases channel and floodplain complexity by eroding established surfaces and creating new alluvial surfaces (Schumm, 1973). Once floodwater dissipates, the exposed alluvial surfaces become available for riparian vegetation establishment (Bendix and Hupp, 2000). As flood characteristics change, so do the alluvial surface characteristics; and as a result, the riparian ecosystem form and function often change. In riparian areas that no longer experience flooding, once-active fluvial surfaces become legacy geomorphic surfaces that record historic fluvial events and channel characteristics.

The cottonwood (*Populus* spp.) decline across much of North America is an example of riparian ecosystem response to changes in flood characteristics (Rood and Mahoney, 1990; Rood et al., 2003). Riparian cottonwood trees prefer bare sediment for establishment and require moist soils in the late spring for germination with a water table that recedes at approximately the same rate that the seedling roots elongate (Segelquist et al., 1993; Mahoney and Rood, 1998). Thus, floods must clear germination surfaces and sufficiently wet the alluvial sediments for successful cottonwood germination and establishment. As flow regulation and climate change diminish hydrogeomorphic processes that favor native riparian plant communities like the cottonwood community, riparian ecosystems become susceptible to species invasion (Friedman et al., 1998; Shafroth et al., 2002; Braatne et al., 2008).

Given the interdependence of hydrogeomorphology and riparian ecosystem processes (Francis, 2006), a combination of geomorphic and ecosystem parameters may help predict areas susceptible to invasion by exploring drivers and patterns of invasion (Tickner et al., 2001). The goals of this study are to determine the likely drivers and patterns of invasion by eastern red cedar (*Juniperus virginiana*) of native cottonwood forests downstream of Gavins Point dam along the Missouri

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0169-555X/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.geomorph.2013.08.012

River (Fig. 1). We develop a Bayesian multivariate regression model that incorporates geomorphic and ecological parameters to show fluvial surfaces susceptible to invasion. Land managers and other researchers that need to make predictions for this river reach and other alluvial riparian corridors can use our model or model-building process, respectively. We chose this reach because of its ecological and geomorphic similarities to other rivers throughout the Great Plains region and because riparian cottonwood ecosystems are threatened along rivers throughout North America due to dam-related hydrologic changes (Rood and Mahoney, 1990).

The Missouri River within the study area is believed to have been a geomorphically dynamic system prior to dam building along the river's main stem. Dams impact rivers and riparian zones by (i) reducing the magnitudes of large flows that normally create new riparian surfaces or move sediment onto existing riparian surfaces, (ii) reducing the concentration of sediment transported in flows downstream of the reservoir, and depending upon reservoir operation methods, and (iii) changing the normally seasonal timing of maximum and minimum flow stages (Magilligan and Nislow, 2005). Changes in any of these three fluvial characteristics may increase invasion risk of riparian habitats.

The Missouri River has six large dams along its main stem, managed primarily for flood control, navigation, irrigation, recreation, and in the past two decades, for fish and wildlife. Historically, cottonwood forests lined the Missouri River (Dixon et al., 2012), with the approximate age of cottonwood stands corresponding to the approximate age of geomorphic surfaces (Everitt, 1968). New cottonwood establishment surfaces continually formed along the river as lateral channel migration produced features such as point bars and mid-channel bars (Williams and Wolman, 1984; Greco et al., 2007). The Missouri River dams reduced flooding and sediment load downstream of each dam structure (Jacobson et al., 2009), rendering many point bars geomorphically inactive and decreasing sand bar formation (Williams and Wolman, 1984; Dixon et al., 2012). Erosional and depositional surfaces created and maintained by the pre-dam floods are now legacy geomorphic surfaces that experience limited flooding and are highly stabilized by vegetation, are farmed, or are in pasture. In addition, approximately one-third of banks are stabilized with revetment (Elliott and Jacobson, 2006). The decreased sediment load has caused channel bed lowering downstream of each dam as the river system establishes a new quasiequilibrium (Williams and Wolman, 1984; Jacobson et al., 2010). As the riverbed lowers, the water table drops and soil moisture decreases in the abandoned riparian zone (Jacobson et al., 2011).

In recent decades, eastern red cedar has been establishing in the understory of cottonwood forests along reaches of the Missouri River (Dixon et al., 2010) and other rivers in the Great Plains (Johnson, 1998). Eastern red cedar is native to the uplands of the Great Plains and surrounding region; however, it is not native to the riparian areas. Fire suppression or shelterbelt plantings may have contributed to eastern red cedar invasion of lowland prairies and increased eastern red cedar density in the uplands. An increase in eastern red cedar occurrence in habitats neighboring the riparian areas may be a contributing factor in the eastern red cedar invasion of the riparian cottonwood forests.

Knowledge of the ecological influence of eastern red cedar establishment along Great Plains streams is limited. However, one study along

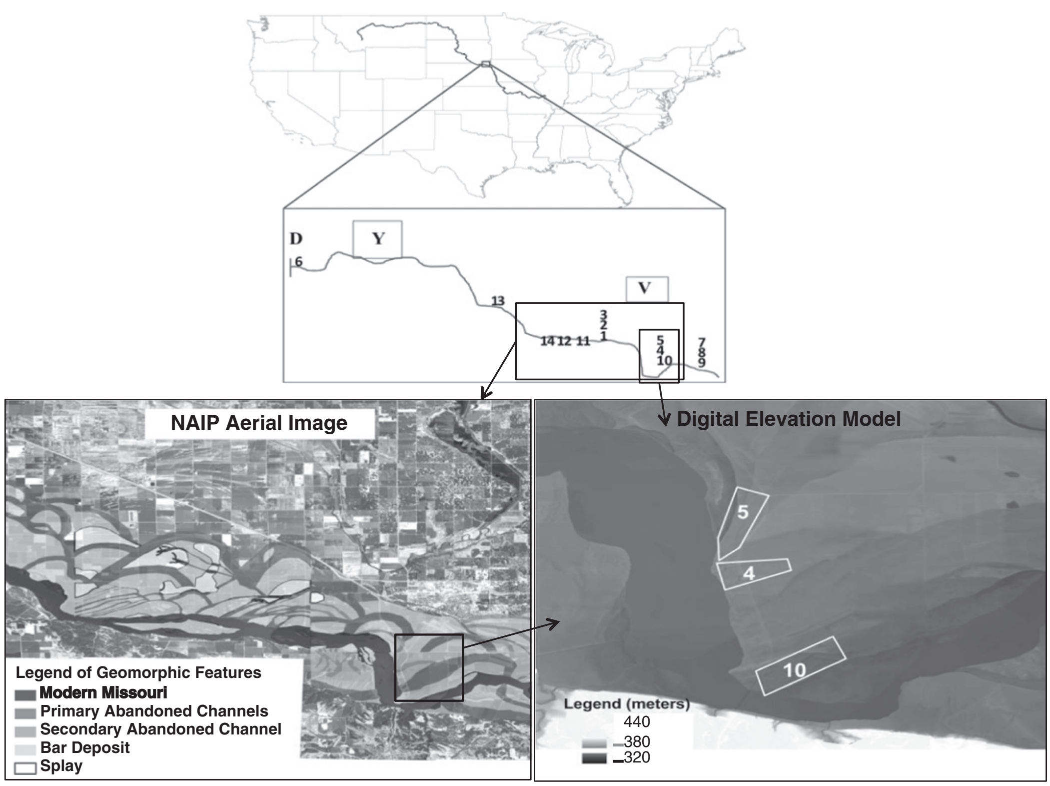

Fig. 1. Map of the Missouri River and study area. Vertical line at the upstream end of the study reach with the label D denotes the location of Gavins Point dam. Boxes are the two urban areas, Y for Yankton and V for Vermillion. Numbers correspond to stand numbers and their respective locations. Stands 11, 12, and 14 are on Goat Island and represent different time periods of deposition. The larger box inside the reach scale map shows the area displayed within the bottom two images. The bottom left image is from the USDA National Agricultural Imagery Program (NAIP) with legacy geomorphic surface lithofacies mapped by Moreno et al. (2011) overlain on the NAIP image. The mapped lithofacies show legacy primary channels, secondary channels, and large deposits within a subreach of the study reach. The bottom right image is a digital elevation model (DEM) of the subreach delineated by a box on the NAIP image and on the reach scale map. The DEM has a 3-m resolution, and the legend increments are rounded to the nearest 10-m. The highest elevation of ~440 m is the white area at the south end of the DEM and represents the Nebraska bluffs. The white boxes are the stands sampled within that subreach and correlate to the stands within the small box in the reach scale map.