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Research paper

Floodplain forest succession reveals fluvial processes: A hydrogeomorphic model for temperate riparian woodlands

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ABSTRACT

River valley floodplains are physically-dynamic environments where fluvial processes determine habitat gradients for riparian vegetation. These zones support trees and shrubs whose life stages are adapted to specific habitat types and consequently forest composition and successional stage reflect the underlying hydrogeomorphic processes and history. In this study we investigated woodland vegetation composition, successional stage and habitat properties, and compared these with physically-based indicators of hydraulic processes. We thus sought to develop a hydrogeomorphic model to evaluate riparian woodland condition based on the spatial mosaic of successional phases of the floodplain forest. The study investigated free-flowing and dam-impacted reaches of the Kootenai and Flathead Rivers, in Idaho and Montana, USA and British Columbia, Canada. The analyses revealed strong correspondence between vegetation assessments and metrics of fluvial processes indicating morphodynamics (erosion and shear stress), inundation and depth to groundwater. The results indicated that common successional stages generally occupied similar hydraulic environments along the different river segments. Comparison of the spatial patterns between the free-flowing and regulated reaches revealed greater deviation from the natural condition for the braided channel segment than for the meandering segment. This demonstrates the utility of the hydrogeomorphic approach and suggests that riparian woodlands along braided channels could have lower resilience than those along meandering channels and might be more vulnerable to influences such as from river damming or climate change.

1. Introduction

A number of recent studies have investigated how fluvial processes influence floodplain forest dynamics (Fierke and Kauffman, 2005; Latterell et al., 2006) and how hydrogeomorphic processes determine riparian vegetation patterns and successional trajectories (Auble et al., 1997; Robertson and Augspurger, 1999; Johnson, 2000). Prior research has often focused on the functioning of individual riparian ecosystem components but interdisciplinary research that combines hydrology, geomorphology and vegetation ecology is needed to understand and manage riparian landscapes (Richards et al., 2002). Subsequently, Ward and Tockner (2001) and Ward et al. (2002) considered landscape features and hydraulic processes in the study of riparian ecosystems, and Gurnell et al. (2012) and Perona et al. (2009) considered the mutual relationships linking hydraulics, geomorphology and riparian vegetation. The inter-dependencies among these components produce different spatio-temporal patterns of fluvial forms and riparian vegetation, in response to climatic and hydrodynamic influences (Dykaar and Wigington, 2000; Willms et al., 2006; Corenblit et al., 2009).

Hydrodynamic and morphodynamic processes account for riparian vegetation establishment and removal (Mahoney and Rood, 1998; Bendix, 1999; Bendix and Hupp, 2000; Dixon and Turner, 2006; Asaeda and Rashid, 2012). Sediment deposition from floods creates nursery sites for riparian recruitment and successful

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establishment depends upon the subsequent moisture pattern. Conversely, flood events remove vegetation through erosive scour (Bendix, 1999; Bendix and Hupp, 2000; Asaeda and Rashid, 2012). River flows recharge alluvial groundwater, especially in semi-arid climates, thus avoiding drought-induced mortality (García-Arias et al., 2013a). However, extended inundation produces root anoxia and mortality (Glenz et al., 2006). Ultimately, vegetation colonization, succession and mortality are the result of interrelated and somewhat antagonistic disturbance and resistance gradients (Egger et al., 2013). The interplay between these opposing drivers and their co-evolutionary development was defined by Corenblit et al. (2007) as the 'fluvial biogeomorphic succession' concept of riparian landforms and vegetation. This concept explains riparian succession as a bidirectional path with sequential phases dependent upon the hydrogeomorphic and ecological processes. A similar concept was formulated by Hauer and Smith (1998) who developed a "hydrogeomorphologic (HGM) approach" to classify riparian wetlands according to the fluvial processes influencing their formation.

Extending from these concepts, we hypothesized that vegetation characteristics including woodland age and developmental stage would provide observable indicators of fluvial processes and history. To test this, we collected field data to characterize vegetation occurrence and successional stage, and the associated fluvial processes, and to compare these with hydraulic model-based indicators of the underlying physical influences.

To provide the essential experimental variation, we investigated two different river channel forms and reaches along regulated versus free-flowing rivers.

2. Methods

2.1. Study sites

Our study included six river reaches in Montana and Idaho, USA and British Columbia, Canada (Fig. 1; Table 1). Downstream of the large Libby Dam and Koocanusa Reservoir, the lower Kootenai River

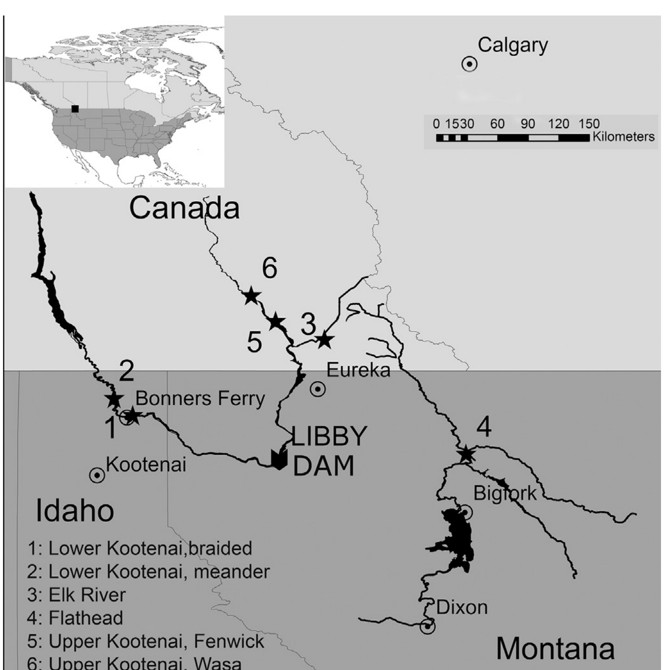

Fig. 1. Study sites situated in Idaho, Montana and British Columbia.

provided a braided reach upstream of Bonners Ferry (R1) and a meandering reach downstream (R2). Site R3 was located along the Elk River that flows into Koocanusa Reservoir and upstream of that reservoir, two sites were investigated along the upper Kootenay River, near Fenwick (R5) and further upstream near Wasa (R6). To provide an additional braided reach, a site was investigated along the North Fork of the Flathead River (R4). Study sites R1 and R2 were downstream of the Libby Dam while the other four study sites are along unregulated reaches. This study design allowed us to apply the hydrogeomorphic model to the six reaches while assessing two important factors, with braided versus meandering channel types, and regulated versus free-flowing reaches (Table 1).

2.2. Field data: physical habitat scales and vegetation

Study sites were cover-type mapped based on aerial photographs (1:5000; August 2006) and field visits, and divided into apparently homogeneous polygons related to species composition, plant community and vegetation structure. In August 2007, 76 plots were sampled across the study sites with selection as described in Mueller-Dombois and Ellenberg (1974), to include the full range of environmental and successional conditions. The following variables were recorded: plant species and community type, habitat type, succession phase, percent cover of tree species, and diameter at breast height (DBH) of the largest individuals of target trees. For selected trees, increment cores were removed for ring counts to estimate age, and heights were determined (Nikon Laser 550 AS). Target tree species included the deciduous black cottonwood (*Populus trichocarpa*), plains cottonwood (*Populus deltoides*), and quaking aspen (*Populus tremuloides)* and the coniferous white spruce (*Picea glauca)* and western red cedar (*Thuja plicata)*. Local field data were compared to vegetation surveys along these rivers by Hansen et al. (1995), Jamieson and Braatne (2001) and Polzin and Rood (2000).

Three physical habitat scales assessed morphodynamics (MDs), inundation duration (IDs), and depth to groundwater (DGWs) with categories of 1–5, following pre-determined criteria (Table 2). Scores of 1 indicate low morphodynamic activity, short inundation duration, and deep groundwater, while 5 indicates high morphodynamics, frequent inundation and shallow groundwater.

Field plot data were coordinated with the polygons from aerial photos. Vegetation types within each polygon were assigned to succession phases and grouped into succession stages. Succession *phases* include alternate vegetative states dependent on site-specific trajectories. For example, pioneer vegetation may transition into a community dominated by herbaceous weedy species (herb phase), or one dominated by shrubs (shrub phase). Both of these communities were grouped into the same successional *stage* (i.e. Transition stage I). The classification of succession types was derived from Naiman et al. (2005) and especially Egger et al. (2013), and included natural primary (^{PS}) and secondary successional (^{SS}) pathways. Successional phases included: initial phase (IP), pioneer (PP), herb (HP), shrub (SP^{PS}, SP^{SS}), early successional woodland (ESW^{PS}, ESW^{SS}), established forest (EFP^{PS}, EFP^{SS}), and mature (MS) phases. Non-natural vegetation types include grassland, farmland, and infrastructure.

2.3. Age analyses of successional phases

Increment cores of predominant tree species were used to determine the relationships between DBH and tree ages (Table 3). This allowed estimation of the oldest tree in each polygon and box plots were then used to compare maximum ages across different successional phases, and determine durations for each phase.