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Dynamic floodplain vegetation model development for the Kootenai River, USA

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A B S T R A C T

The Kootenai River floodplain in Idaho, USA, is nearly disconnected from its main channel due to levee construction and the operation of Libby Dam since 1972. The decreases in flood frequency and magnitude combined with the river modification have changed the physical processes and the dynamics of floodplain vegetation. This research describes the concept, methodologies and simulated results of the rule-based dynamic floodplain vegetation model "CASiMiR-vegetation" that is used to simulate the effect of hydrological alteration on vegetation dynamics. The vegetation dynamics are simulated based on existing theory but adapted to observed field data on the Kootenai River. The model simulates the changing vegetation patterns on an annual basis from an initial condition based on spatially distributed physical parameters such as shear stress, flood duration and height-over-base flow level. The model was calibrated and the robustness of the model was analyzed.

The hydrodynamic (HD) models were used to simulate relevant physical processes representing historic, pre-dam, and post-dam conditions from different representative hydrographs. The general concept of the vegetation model is that a vegetation community will be recycled if the magnitude of a relevant physical parameter is greater than the threshold value for specific vegetation; otherwise, succession will take place toward maturation stage. The overall accuracy and agreement Kappa between simulated and field observed maps were low considering individual vegetation types in both calibration and validation areas. Overall accuracy (42% and 58%) and agreement between maps (0.18 and 0.27) increased notably when individual vegetation types were merged into vegetation phases in both calibration and validation areas, respectively. The area balance approach was used to analyze the proportion of area occupied by different vegetation phases in the simulated and observed map. The result showed the impact of the river modification and hydrological alteration on the floodplain vegetation. The spatially distributed vegetation model developed in this study is a step forward in modeling riparian vegetation succession and can be used for operational loss assessment, and river and floodplain restoration projects.

1. Introduction

Vegetation models have been developed to simulate vegetation dynamics considering factors such as competition, shade tolerance, and hydrologic variables including flood frequency, flood duration, and depth to ground water table to study the impact of an altered hydrologic regime (e.g., Pearlstine et al., 1985). During recent years, a variety of ecological models have evolved to address changes in vegetation species as consequences of modification in environmental variables and hydrological alterations (e.g., Braatne et al., 2007, 2002; Carmel et al., 2001). Different models were developed for analytical and management tools to assess the potential effects of human-induced disturbances upon wetlands and vegetation (e.g., Baptist et al., 2004; Glenz, 2005; Poiani and Johnson, 1993). These vegetation models are developed based on the concept that vegetation establishes on an elevation gradient and the floodplain physical processes such as flood frequency, inundation duration, shear stress, and velocity are driving forces to create suitable habitat. Most models are based on two major concepts: static equilibrium and dynamic-transient (Korzukhin et al., 1996). First, one assumes that the state of vegetation is in static equilibrium with environmental conditions. Later, one assumes that the vegetation is in a dynamic-transient stage with changes in biotic and abiotic conditions (Merritt and Cooper, 2000). A species- or community-based approach is typically used in predictive vegetation modeling (Zimmermann and Kienast, 1999).

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Vegetation models are developed based on ecological processes of riparian and wetland systems. Riparian ecosystems and their dynamics are mainly governed by hydrology, although disturbance, climatic condition, moisture condition, soil types, and nutrients play important roles. Riparian systems are transitional semi-terrestrial areas (Naiman et al., 2005) regularly influenced by fresh water and usually extend from the edge of the water to the edge of the upland community. Periodic disturbances in riparian zones provide spatial and temporal heterogeneity, life history traits, and the availability of regeneration habitat (Nakamura et al., 1997). Intensity, timing, duration, and frequency of disturbances govern the erosion and deposition processes that create open channel bars and islands where riparian vegetation colonize (Dykaar and Wigington, 2000). Generally, riparian zones are classified based on a variety of environmental characteristics that strongly influence plant communities such as different recurrence interval floods (Goodwin et al., 1997).

Wetlands are also considered a component of riparian ecosystems, even though they differ significantly in spatial context, disturbance regime, hydrology, and ecology (Naiman et al., 2005). Wetlands are inundated or saturated by surface or ground water for a long duration of the year, and develop when inundation of wetland plants produce anaerobic processes and force rooted plants to adapt to flooding (Keddy, 2000). The wetland represents both aquatic and terrestrial environments; hence, they are difficult to delineate precisely (Keddy, 2000).

Succession and retrogression, also termed as recycle, are complex and key processes in riparian ecosystems (Formann et al., in preparation; Naiman et al., 2005). Recycle takes place due to different levels of disturbances (e.g., flood, fire, grazing, etc) and is influenced by many factors (e.g., nutrient, soil, moisture, climate, etc). Succession is a systematic unidirectional process of vegetation change, in which vegetation types replace each other sequentially until stable vegetation is reached (Johnson and Miyanishi, 2007). Retrogression occurs when the effects of disturbances, also known as environmental stress, destroy or reduce the community structure or change species composition in reverse succession. One of the common disturbances in riparian vegetation dynamics is flooding on the river floodplain, which is key for creating new habitats and destroying existing vegetation by changing morphodynamics, erosion, and deposition (Bendix, 1998).

Various ecological models have been developed to assess the ecological losses attributed to dams, levees, and river management, but most of them have been based on transect or cross-section data (e.g., Braatne et al., 2002) and the static equilibrium concept (e.g., Auble et al., 1994). The development of vegetation and topography can take up to several decades to reach a state of dynamic equilibrium and thus the static equilibrium concept may not be a valid assumption (cf. Formann et al., in preparation). Dynamic-transition models based on temporal and spatial scales are important tools and are often used to predict potential future vegetation, since ecological systems are dynamic, changing over a variety of spatial and temporal scales due to disturbance.

The current approach to analyze loss of riparian ecosystems due to human influences, such as dam operations is to measure riparian vegetation loss at a specific location (transects) and time, and later extrapolate to a larger area (e.g., Braatne et al., 2007; Jamieson and Braatne, 2001; Merritt and Cooper, 2000; Polzin and Rood, 2000). The method that considers spatial and temporal distribution of vegetation may be suitable to systems that are diverse and differ significantly in spatial and temporal scale. A dynamic vegetation model may be a proper tool to assess ecological losses and to manage or restore a riparian ecosystem in the future.

The primary objective of this study is to develop a rule-based spatially distributed vegetation model to predict dynamic succession and retrogression of the plant species based primarily on scour disturbance, shear stress as an indicator of mechanical stress and flood duration as an indicator of physiological stress. A dynamic rule-based spatially distributed vegetation model "CASiMiR-vegetation" was developed in this research to simulate vegetation dynamics on the floodplain based on simulated physical parameters, literature and field observed data. "CASiMiR" stands for Computer Aided Simulation Model for Instream Flow Requirements. This paper describes the structure, development and model test at a braided reach of the Kootenai River in the Northern Idaho (Fig. 1), USA.

2. Study area

The Kootenai Basin is an international watershed (41,910 km^2) originating in southeastern British Columbia, Canada (Fig. 1). The Kootenai River from Libby Dam to Kootenai Lake can be divided into

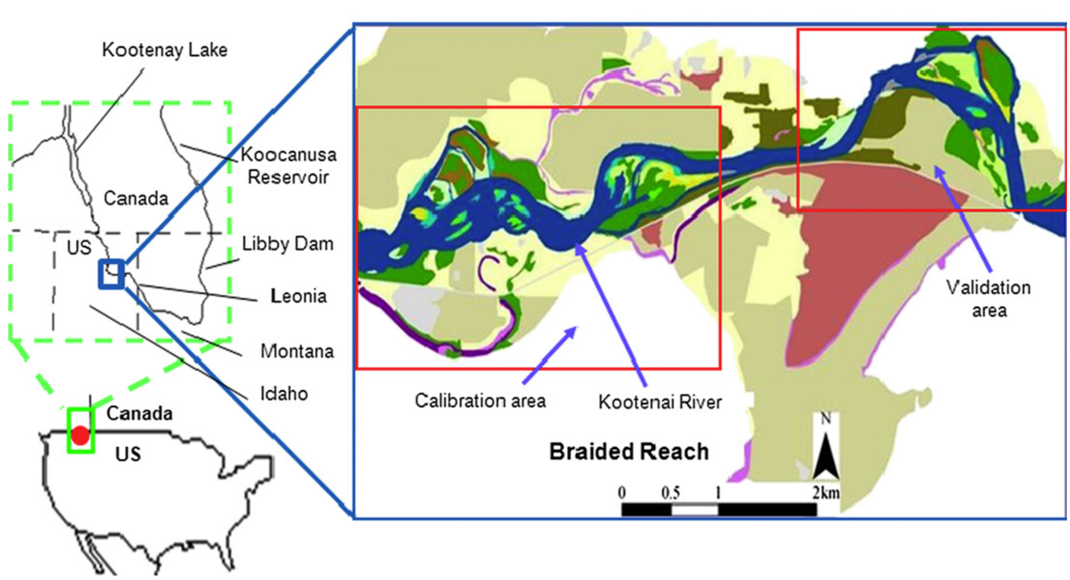

Fig. 1. Study site including calibration and the validation area at the braided reach, which is located just upstream of the town of Bonners Ferry, Idaho.