Landscape level changes in riparian forest ecosystems following flow regulation along the Missouri River, USA: implications for long-term natural resource management

Évolution de la ripisylve à l'échelle du paysage après la régulation des débits du fleuve Missouri (EU) : implications à long terme pour la gestion des ressources fluviales

Michael L. Scott[1], Mark D. Dixon[2], W.Carter. Johnson[3], Malia A. Volke[3]

[1]Department of Watershed Sciences, Utah State University, 5210 Old Main Hill, NR 210, Logan, UT 84322, USA (corresponding author: scottmikeski@gmail.com).
[2]Department of Biology, University of South Dakota, 414 E. Clark Street, Vermillion, SD 57069, USA. [3]Department of Natural Resource Management, South Dakota State University, SNP 138 Box 2140B, Brookings, SD 57007, USA.

RÉSUMÉ

Le fleuve Missouri est le plus long fleuve des États-Unis. Bien que le fleuve conserve des caractéristiques datant d'un passé prédéveloppé, la régulation du Missouri au milieu du vingtième siècle a modifié fortement le processus écologique qui maintenait l'intégrité biotique de ces forêts. Nous avons quantifié des changements dans l'étendue et l'âge des forêts de peupliers de 1892 à 1950 et de 1950 à 2006, à côté des sept cours comprenant les deux tiers supérieurs non canalisés de la Rivière du Missouri. La superficie de la forêt riveraine a décliné de 49% en général, 67% de la forêt restante a été établie avant le développement. La perte du banc de sable, les réductions de la largeur du canal et la petite proportion de la forêt de peuplier post-barrage reflètent les réductions sévères dans le recrutement de la forêt. La diminution de charriage, l'infrastructure humaine, et les problèmes avec la terre privée au-dessous des barrages rendent la circulation écologique logistiquement et politiquement complexe. Un inventaire de 30 placettes après 40 ans indique que l'intégrité des forêts est profondément menacée par les facteurs physiques et biotiques y compris l'incision du canal, la diminution des eaux souterraines, l'invasion des plantes exotiques, et l'introduction de pathogènes des arbres. La préservation de produits et services écologiques de ces placettes de peuplier est problématique. Le rapport coût-efficacité de plantations d'arbres à grande échelle pour contrebalancer la perte de la forêt n'a pas été encore évalué. Les deltas de réservoir à l'intérieur du bassin hydrographique constituent une opportunité pour l'établissement continu d'une succession de populations de plantes. Malheureusement, la plupart de ces caractéristiques n'ont pas encore été étudiées.

ABSTRACT

The Missouri River is the longest river in the United States and although the river retains some attributes of the pre-development past, river regulation in the mid-twentieth century has radically altered ecological processes that maintained the biotic integrity of these forests. We quantified changes in the extent and age structure of cottonwood forests from 1892–1950s and the 1950s–2006 along seven reaches comprising the unchannelized upper two-thirds of the Missouri River. Riparian forest area declined by 49% overall and of the remaining forest 67% established prior to development. Loss of sandbars, reductions in channel width and the small proportion of post-dam cottonwood forest reflect sharp reductions in forest recruitment. Sediment depletion, human infrastructure and private land issues below dams make prescribed environmental flows logistically and politically complex. Re-inventories of 30 stands after 40 years further indicate that the integrity of these forests is threatened by physical and biotic factors including channel incision, groundwater declines, invasion of non-native plant species, and the introduction of tree pathogens. Preserving ecological goods and services of remnant stands is problematic. The cost effectiveness of large-scale tree plantings to offset forest loss has not been evaluated. Reservoir deltas within the catchment offer opportunities for continued establishment of early successional plant communities, but these features remain largely unstudied.

KEYWORDS

Biological diversity, cottonwoods, flow regulation, Missouri River, restoration, riparian forest

INTRODUCTION

Large dams provide clear and tangible short-term socioeconomic benefits, which have come at the expense of longer-term and sometimes subtle ecological changes to riverine ecosystems. On a global scale, dams profoundly modify river hydrology as well as patterns of ecological diversity that are created and maintained by regionally distinctive fluvial geomorphic processes. Regional biodiversity also is threatened by the physical disruptions created by dams, constraining the ability of some species to adjust their spatial distribution in response to shifts in climate. Flow-controlled rivers are likely to be further stressed by projected future climate change, in turn, threatening water quality and quantity to meet human needs and maintain biodiversity and ecological goods and services. Because most large dams were constructed in the past half-century, we are only now beginning to understand the social and ecological scope of these changes. The response of long-lived organisms like riparian cottonwoods to natural or anthropogenic changes in flow regime can take decades or centuries to express themselves. Thus, a long-term and broad scale understanding of how riverine and riparian resources have responded to flow and land-use drivers of change is needed to inform future adaptive resource management strategies.

Given the lack of quantitative evidence regarding the historical status and trends of cottonwood forests along the Missouri River and the ecological status of current forests, our objectives were to provide a quantitative, landscape level assessment of long-term cottonwood forest dynamics along the upper Missouri River, USA. Such information can inform efforts by the U.S. Army Corps of Engineers to develop and implement plans for mitigating habitat loss and restoring cottonwood forests, in accordance with mandates to protect Bald Eagle habitat under the Endangered Species Act (USFWS 2003).

1. METHODS

1.1 Study site

The Missouri River traverses a wide range of climatic, topographic, and ecological conditions, crossing three physiographic divisions (Rocky Mountains, Interior Plains, Interior Highlands) and thirteen terrestrial ecoregions between its origin near Three Forks, Montana and its confluence with the Mississippi River near St. Louis, Missouri (Figure 1). Prior to extensive development, the river was geomorphically active and diverse, with a shifting sand-bed channel, islands and sandbars, heavy sediment loads and high turbidity driven by a dynamic and variable rain and snowmelt hydrograph. Fluvial geomorphic processes have been greatly altered by flow regulation throughout much of the Missouri catchment, with lowered peak flows, and declines in sediment transport.

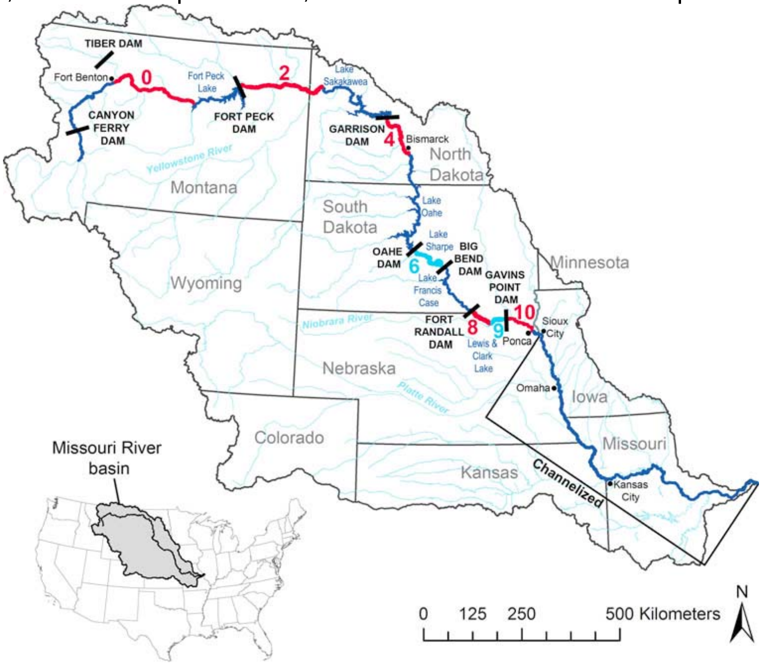

Figure 1. Study segment numbers and major dams. Reservoir segments are shown in light blue, remnant floodplain segments in red and locations of major dams in black.

1.2 Analyses

In a GIS platform, we quantified changes in landuse and the extent and age structure of cottonwood forests from 1892–1950s and the 1950s–2006 along the seven study segments. We obtained historical aerial photography from 2006, the 1950s (1951–58), and the 1980s (1980–87), and historical maps from the 1890s Missouri River Commission survey, for all study segments. Details of geospatial mapping and analyses are given in Dixon et al. (2012). Finally, using the same field methods to sample trees, shrubs and herbs, we assessed 40 years of change in vegetation structure and composition in 30 floodplain forest stands in Segment 4, initially sampled by Johnson et al. (1976).

2. RESULTS AND DISCUSSION

2.1 Landscape level change in riparian forest area and age structure

From the historical period to the present, riparian forest area declined by 49%, shrubland 52% and sandbar habitat by 96%. The loss of forest and shrubland was chiefly the result of inundation in the reservoir reaches and the expansion of agricultural cropland, which increased to an average of 43% of the total bottomland area mapped. Stands dominated by cottonwood represent 86% of the total woody riparian vegetation area with highest in the remnant floodplain segments, between the reservoirs. The majority of current cottonwood stands (67%) established before river regulation. Among stands <50 years old, the higher proportion of 25–50 year old stands represents recruitment that accompanied initial post-dam channel narrowing, whereas declines in sandbar and shrubland area and the low proportion of stands <25 years old suggest chronic declines in geomorphic dynamism and limited recruitment with recent river management.

2.2 Long term change in forest structure and composition

Results from the re-survey of riparian cottonwood forest stands in Segment 4 describe a number of predicted and unforeseen changes in these floodplain forests in remnant reaches, confined between reservoirs. Our results show: 1) a sharp decline in cottonwood regeneration; 2) a strong compositional shift toward dominance by green ash; and 3) large increases in invasive understory species, such as smooth brome (*Bromus inermus*), reed canary grass (*Phalaris arundinacea*), and Canada thistle (*Cirsium arvense*). These changes, and others, have been caused by a complex of factors, some related to damming (altered hydrologic and sediment regimes, delta formation, and associated wet–dry cycles) and some not (diseases and expansion of invasive plants and introduced pathogens).

CONCLUSION

Severe sediment depletion, human infrastructure and private land issues in below dam reaches make prescribed environmental flows in support of natural resource values (e.g., like more natural and extensive recruitment of cottonwoods), logistically and politically complex. At the same time, re-inventories of forest stands spanning a 40-year period indicate that the structural and compositional integrity of these forests are threatened by a variety of physical and biotic factors including channel incision, groundwater declines, loss of over bank flooding, altered fire regimes, invasion of non-native plant species, and the introduction of tree pathogens. Preserving ecological goods and services of remnant stands is problematic. The cost effectiveness of large-scale tree plantings to offset forest loss has not been evaluated. There is hope that deltas forming in the six large reservoirs within the Missouri River catchment may offer opportunities for the continued establishment of early successional plant communities, but these novel features remain largely unstudied.

LIST OF REFERENCES

Dixon, M.D., Johnson, W.C., Scott, M.L., Bowen, D.E., and Rabbe, L.A. (2012). Dynamics of Plains Cottonwood (*Populus deltoids*) Forests and Historical Landscape Change along Unchannelized Segments of the Missouri River, USA. Environmental Management, 49, 990-1008.

Johnson, W.C., Burgess, R.L., and Keammerer W.R. (1976). Forest overstory and environment along the Missouri River in North Dakota. Ecological Monographs, 46, 59-84.

U.S. Fish and Wildlife Service (USFWS) (2003) Amendment to the 2000 Biological Opinion on the Operation of the Missouri River Main Stem Reservoir System, Operation and Maintenance of the Missouri River Bank Stabilization and Navigation Project, and Operation of the Kansas River Reservoir System. Denver, CO and Fort Snelling, MN, USA.