Anthropocene 2 (2013) 65–75

Contents lists available at ScienceDirect

Anthropocene

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

An exception to island loss in the engineered Upper Mississippi River: History of land growth in Pool 6 and implications for restoration

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ARTICLE INFO

Keywords:
Island development
River regulation
Dam effects
Restoration
Upper Mississippi River System

ABSTRACT

Over 150 years of intense river engineering has radically altered the morphodynamics of the Upper Mississippi River System, with island loss a dominant trend and restoration efforts underway. In Pool 6 of the UMRS, deposition over the last 40 years has produced substantial island growth. To understand patterns of land growth in Pool 6, and what has enabled it, historical aerial photography and survey datasets were analyzed using a spatially nested approach. Between 1895 and 1931, land emerged around wing and closing dikes. Within the 29.9 km^2 managed channel, land area increased 22%, with a 40% increase in land area in the 3.65 km^2 lower pool. Following construction of the Lock and Dam system in 1936, which raised water levels, land area declined 45% in the pool and 78% in its downstream portion, or lower pool. Since 1975, land grew throughout the pool, and particularly in the lower pool. In this area, 0.37 km^2 of island area has emerged, increasing land area by 88% relative to 1975. Around one island complex in the lower pool, sediments have aggraded 2.2 m in 111 years, with the Lock and Dam having only a slight effect on aggradation rate. The location of wing and closing dikes in a wide secondary channel within an overall constricted river width appears to have contributed to island emergence and growth. Restoration efforts that mimic the conditions of Lower Pool 6 may enhance success at creating self-sustaining islands.

1. Introduction

Most of the world's large rivers are intensely managed and engineered by dams, levees, and other human-built structures (Gupta, 2007). The geomorphic effects of river management have been well documented (Williams and Wolman, 1984; Gregory, 2006; Hudson et al., 2008), and frequently include substantial loss of islands and mid-channel features from braided rivers (Gurnell and Petts, 2002; Collins and Knox, 2003; Surian and Rinaldi, 2003). In island-braided rivers, persistent and vegetated mid-channel features divert flow to secondary channels and backwaters, creating varied hydraulic conditions that allow for diverse physical habitats to be in close proximity to each other (Johnson et al., 1995; Petts et al., 2000; Gurnell et al., 2001). Thus, when islands are lost, loss of habitat and biodiversity may follow (Ward and Tockner, 2001). Increasing environmental concerns in engineered rivers have led to restoration efforts, including attempts to stabilize and rebuild islands (O'Donnell and Galat, 2007; Piégay et al., 2009). Questions concerning large river restoration include how to select the right project areas for a successful restoration (Ward et al., 2001; Palmer et al., 2005; O'Donnell and Galat, 2007). In this paper, a river reach where island growth has occurred in the context of intense river engineering is used to examine the dynamics of island development and implications for restoration strategies, particularly project placement.

The most common processes associated with island formation in braided rivers include lee deposition at a channel obstruction, gradual degradation of channel branches, and the stabilization of bars by accretion and vegetation (Osterkamp, 1998; Gurnell et al., 2001; Kiss and Sipos, 2007). Islands and channels in engineered rivers tend to either erode rapidly or remain relatively stable; rarely do they emerge and grow (Minagawa and Shimatani, 1999; Gurnell and Petts, 2002; Collins and Knox, 2003). However, in engineered river systems, geomorphic equilibration to management could result in island emergence, stability, or erosion, depending on the new hydraulic regime, sediment supply, and type of structures employed (Piégay et al., 2009). Loss of land increases connections between backwaters and channels, homogenizes terrestrial and aquatic habitats, and alters sediment and water distribution during high flows (e.g., Grubaugh and Anderson, 1988).

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http://dx.doi.org/10.1016/j.ancene.2013.10.004

Levees are used extensively in engineered rivers (e.g., Xu, 1993; Shields, 1995; Piégay et al., 2009; Alexander et al., 2012). By disconnecting the floodplain from the main channel, levees restrict the number of active channels and their movement. Levees effectively decrease a river's wetted width, increasing velocity, discharge, and water elevations during floods, and thereby altering erosional and depositional environments (Heine and Pinter, 2012). Levees also hinder movement of nutrient- and sediment-rich flood waters onto the floodplain, disconnect aquatic environments, and reduce ecological and habitat diversity (Ward and Stanford, 1995; Magilligan et al., 1998; Benedetti, 2003).

Wing dikes and closing dikes are structures designed to divert flow toward a main channel and away from side channels and backwaters. Wing dikes extend from a riverbank or island to the outside of the thalweg and usually point downstream, while closing dikes direct water away from side channels and backwaters. Together these features concentrate water into a faster moving main channel, increasing scour (Alexander et al., 2012). In an island braided system, the main channel becomes more defined and stable (Xu, 1993; O'Donnell and Galat, 2007; Pinter et al., 2010; Alexander et al., 2012). Wing dikes tend to expand and fix the position of land to which they are attached (Fremling et al., 1973; Shields, 1995). Scour often occurs immediately downstream of wing and closing dikes, but, farther downstream, reduced water velocities promote sedimentation (Pinter et al., 2010).

In large rivers, locks and dams are frequently employed to improve navigation. Upstream of a dam, raised water levels can submerge floodplain or island area, subject an altered shoreline to erosion, and inundate terrestrial and shallow water habitat (Nilsson and Berggren, 2000; Collins and Knox, 2003; Pinter et al., 2010). Extensive open water leaves terrestrial features susceptible to erosion by wave action, which is strengthened by increased wind fetch (Lorang et al., 1993; Maynord and Martin, 1996). Impoundment typically maintains a near-constant pool elevation that results in little vegetation below the static minimum water level, scouring concentrated at one elevation, and susceptibility to wave action (Theis and Knox, 2003). In the slack water environment upstream of dams, the stream's ability to transport sediments is reduced, potentially making dams effective sediment traps (Keown et al., 1986; Vörösmarty et al., 2003).

The island-braided Upper Mississippi River System (UMRS) has been managed since the mid-1800s, with levees, wing and closing dikes, and a system of 29 locks and dams, to improve navigation and provide flood control (Collins and Knox, 2003). This succession of engineering strategies has caused extensive alteration in the channel hydraulics and ecology of the UMRS (Fremling, 2004; Anfinson, 2005; Alexander et al., 2012). Extensive loss of island features in many parts in the UMRS, especially in the areas above each Lock and Dam, has been attributed to changes in sedimentation rates and pool elevations (Eckblad et al., 1977; Grubaugh and Anderson, 1989; Collins and Knox, 2003; Theis and Knox, 2003). Island loss is predicted to continue, particularly in a 160 km reach encompassing Pools 5–9, where erosion is thought to result from wind-driven waves (Fig. 1) (Theiling et al., 2000). However, within this reach, the area upstream of Lock and Dam 6 has experienced exceptional island growth, beginning in the 1960s (Fremling et al., 1973).

Improving the hydrologic and sediment regime, floodplain function, ecological functions, and current river management practices are often described as the desired outcomes of restoration (Ward et al., 2001; Buijse et al., 2002; Palmer et al., 2005). However, the scale and costs of restoration can combine to make large river restorations contentious and controversial (Ward et al., 2001; Palmer et al., 2005). On the UMRS, restoration and habitat enhancement efforts have been undertaken by the US Army Corps of Engineers (USACE). These projects have received over

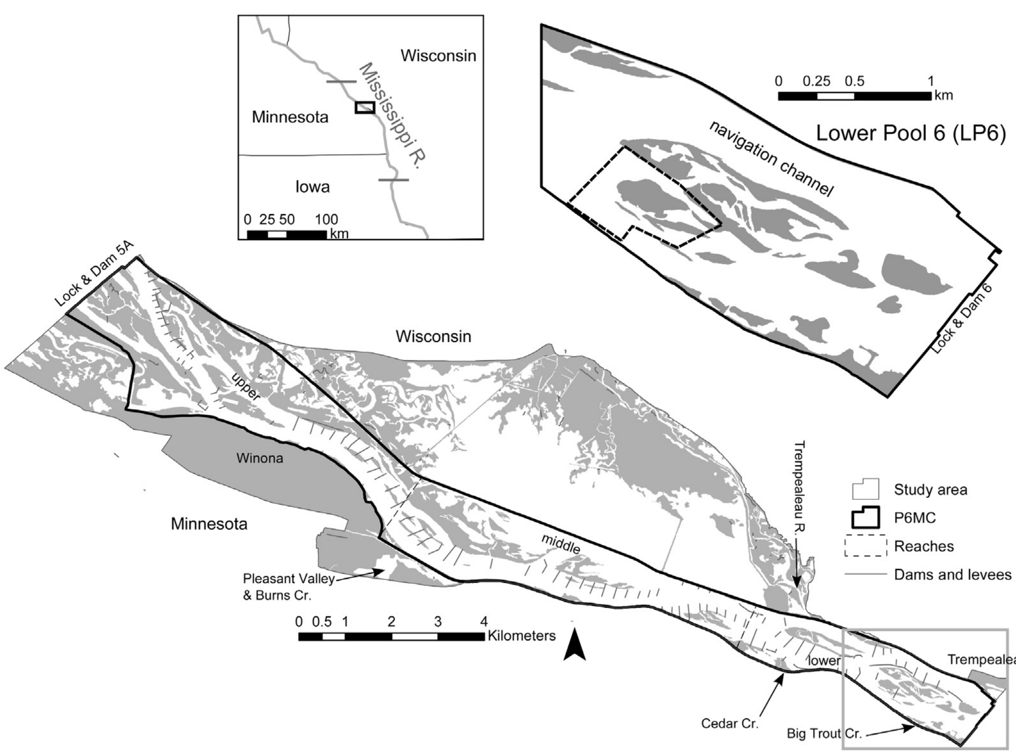

Fig. 1. Map of Pool 6, showing locations of land (gray) and water (white) as of 2010. The thick black line encloses the managed channel (P6MC), while areas outside the line are isolated by levees or railroad dikes. Thin black lines indicate wing dikes, closing dikes, and levees, while dashed lines separate the reaches identified in this study. The inset above the main map shows 2010 land and water in Lower Pool 6 (LP6), with the area in which bathymetric data were analyzed indicated by the heavy dashed line. On the inset of Minnesota, Wisconsin, and Iowa, the black box indicates Pool 6, while the lines across the river demarcate the extent of Pools 5–9, where island loss has been severe and is projected to continue.