Available online at www.sciencedirect.com
SCIENCE DIRECT®
ELSEVIER
Quaternary Research 65 (2006) 147 – 155
QUATERNARY RESEARCH
www.elsevier.com/locate/yqres

Influence of logjam-formed hard points on the formation of valley-bottom landforms in an old-growth forest valley, Queets River, Washington, USA

David R. Montgomery *, Tim B. Abbe [1]

Department of Earth and Space Sciences, University of Washington, Seattle, WA 98195, USA

Received 23 July 2005

Abstract

Field surveys and radiocarbon dating of buried logjams in the floodplain of an old-growth forest river demonstrate the formation of erosion-resistant "hard points" on the floodplain of the Queets River, Washington. These hard points provide refugia for development of old-growth forest patches in frequently disturbed riparian environments dominated by immature forest. Our surveys show that local bed aggradation associated with logjams not only influences channel patterns and profiles but leads to development of a patchwork of elevated landforms that can coalesce to form portions of the valley bottom with substantial (i.e., 1 to >4 m) relief above the bankfull elevation. In addition, logjam-formed hard points promote channel avulsion, anastomosing morphology, and growth of mature patches of floodplain forest that, in turn, provide large logs needed to form more logjam-formed hard points. Hence, our findings substantiate the potential for a feedback mechanism through which hard points sustain complex channel morphology and a patchwork floodplain composed of variable-elevation surfaces. Conversely, such a feedback further implies that major changes in riparian forest characteristics associated with land use can lead to dramatic simplification in channel and floodplain morphology.

Keywords: Woody debris; Fluvial; Floodplain; Terraces; Logjams; Aggradation

Introduction

Human activities greatly reduced the quantity of wood debris in fluvial systems around the world through direct removal of in-channel wood and clearing of riparian forests (e.g., Sedell and Froggatt, 1984; Swift, 1984; Triska, 1984; Benke, 1990; Collins and Montgomery, 2002; Collins et al., 2003). Wood debris can significantly influence the morphology of forest channels (e.g., Heede, 1972; Keller and Swanson, 1979; Gregory et al., 1985, 1993; Gregory and Davis, 1992; Nakamura and Swanson, 1993; Montgomery et al., 1995, 1996, 2003; Gurnell and Sweet, 1998), and sediment deposition around stable logjams can form alluvial surfaces (Abbe and Montgomery, 1996, 2003; Montgomery et al., 1996; O'Connor et al., 2003) and influence patterns of riparian forest development (Fetherston et al., 1995; Naiman et al., 1998; 2000). However, logs and logjams generally have been dismissed as a significant factor in the development of floodplains and terraces (e.g., Kochel et al., 1987; Piégay and Gurnell, 1997; Piégay et al., 1999; Gurnell et al., 2001; Wegmann and Pazzaglia, 2002). Conventional explanations for floodplain development predict relatively uniform topographic surfaces formed by either deposition of bed load material in the wake of channel migration or overbank deposition of fine-grained sediment that settles from suspension during floods (e.g., Wolman and Leopold, 1957; Lewin, 1978). Formation of alluvial surfaces or terraces above the elevation of channel banks are generally attributed to changes in climate or tectonics that alter the discharge, sediment regime, or base level (e.g., Richards, 1982; Knighton, 1998). Here we present evidence for the role of logjam-formed "hard points" on creating and maintaining valley-bottom surfaces that shelter patches of old-growth forest within dynamic, disturbance-prone riparian environments. Our field observations and dating lead us to recognize an end-member model for formation of complex, multi-elevation floodplains due to intrinsic dynamics of forested valley bottoms without changes in climate, sediment supply, or base level.

* Corresponding author.
E-mail address: dave@ess.washington.edu (D.R. Montgomery).
[1] Present address: Herrera Environmental, Inc., 2200 Sixth Ave., Suite 1100, Seattle, WA 98121, USA.

0033-5894/$ - see front matter
doi:10.1016/j.yqres.2005.10.003

Study area

The 1190-km^2 Queets River basin is located on the western slope of the Olympic Peninsula, Washington. Continuously forested for at least the last 17,000 yr (Fonda, 1974; Whitlock, 1992), the unregulated Queets River drains a watershed with large areas of old-growth forest. Development within the Queets River valley is limited to a gravel road, a National Park Service campground, and 19th-century homestead sites abandoned in the 1930s prior to establishment of Olympic National Park. Old-growth temperate rain forest blankets much of the watershed and mature conifers grow in numerous, distinct patches across a valley bottom dominated by younger deciduous forest (Fetherston, 2005).

Previous work in the Queets River basin showed that large logs and logjams redirect flow and divert the course of the river (Abbe and Montgomery, 1996, 2003). These studies showed how deposition of logs large enough to resist transport can alter local flow hydraulics and initiate formation of a logjam and deposition of an associated alluvial surface well above the channel banks. Through this simple process, logjams obstructing the channel can become buried in bars, mantled by overbank sedimentation, and covered by forest to eventually become integrated into the floodplain (Abbe and Montgomery, 1996). Exposure of buried logjams in eroding river banks lying beneath old trees has led to the hypothesis that logjams can form stable "hard points" that can limit future channel migration paths and create long-term sites of forest refugia (Abbe and Montgomery, 1996, 2003; O'Connor et al., 2003).

Based on several-meter-long sediment cores from small channel-like depressions at a site along the Queets River, Greenwald and Brubaker (2001) reported deposition of coarse sand capped by silt on what they termed the first and second terraces at 3.5 and 8 m elevation above the river, respectively. Radiocarbon dating of *Picea sitchensis* and *Tsuga heterophylla* needles at the base of the core from the lower terrace yielded a limiting calibrated age of 477 ± 60 yr B.P., somewhat older than a ≈350-yr-old *T. heterophylla* growing on the same surface. Similarly, a radiocarbon date on needles from the base of the core from the higher terrace yielded a limiting calibrated age of 550 ± 95 yr B.P. Greenwald and Brubaker (2001) concluded that these deposits record either the largest flood in the past half millenia or "a substantial shift in the position of the river channel" (Greenwald and Brubaker, 2001, p. 1382).

Hyatt and Naiman (2001) inventoried large woody debris in four reaches of the Queets River and estimated wood depletion rates by assuming a steady-state wood loading. Their sampling concentrated on wood pieces larger than 0.6 m in diameter and longer than 5 m in length, which they erroneously termed "key pieces" in applying an arbitrary size criterion to a functional classification. [In use since at least the 1880s (Gillespie, 1881; Deane, 1888), the term key piece refers to logs that form foundational structural members of stable logjams; recent work reported by Abbe and Montgomery (2003) has shown that key piece size scales relative to channel size.] Through cross-dating tree rings and radiocarbon dating, Hyatt and Naiman (2001) found that the age of 75 logs ranged from 1 to >1400 yr, with a mean age of 84 yr and a median age of 19 yr. From the cumulative age distribution, they calculated a depletion rate and inferred a mean residence time of ≈30 yr for logs in the Queets River. They further speculated that the oldest logs they had sampled had been recently exhumed after prolonged burial in floodplain sediments.

O'Connor et al. (2003) used historical maps and aerial photographs to document average channel migration rates for the Queets River of 7.5 ± 2.9 m yr^{-1} between 1900 and 1994. They reported that floodplain width narrowed where the river passed through Quaternary moraine complexes and calculated an average floodplain turnover rate of 300–400 yr, although much of the floodplain closest to the river is dominated by alder less than century old. Paralleling observations reported by Abbe and Montgomery (1996; 2003); O'Connor et al. (2003) described the influence of large logjams on local sediment deposition and avulsion and as potentially forming hard points that protect trees long enough to provide a source of new key members. O'Connor et al. (2003) further described clustered stands of *P. sitchensis* of greater diameter than the surrounding forest growing on alluvial surfaces rising 1–2 m above the floodplain of the neighboring Quinault River, a phenomenon which they attributed to nurse logs at sites of old logjams.

Together these prior studies are consistent with the logjam hard point hypothesis in which some percentage of stable logjams can resist erosion for centuries and protect conifer patches that, in turn, eventually provide a source for new key-member logs that can form new logjams.

Methods

Field surveys on the Queets River conducted from 1993 to 1996 included locating buried wood exposed in riverbanks and constraining the age of trees growing on the overlying alluvial landforms. Surveys by foot, raft, and canoe documented the geomorphic effects of individual logjams through topographic mapping and stratigraphic sections of alluvial deposits. Different types of wood accumulations were described and mapped along the main stem channel and in selected tributaries and floodplain side channels. Historical aerial photographs and repeated field surveys were used to assess, where possible, the longevity of individual logjams. Hydrologic records were used to evaluate the magnitude of peak flow events to which observed logjams were subjected. An optical level was used to survey profiles and cross sections of channels and floodplains. Surveyed channel profiles provide a means of measuring the vertical extent of aggradation upstream of logjams. Variations in the elevations of alluvial surfaces at sites throughout the watershed were documented in topographic transects surveyed across floodplains. Local rates of channel aggradation were measured by repeated surveys. Additional details of these field surveys are given by Abbe (2000).

Forty-nine samples for ^{14}C dating were collected at buried logjams identified in and sampled from channel-bank exposures in order to constrain a maximum age for each jam. We also obtained a minimum constraint on the age of each jam from the age of trees growing on the overlying alluvial surface.