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CHARACTERIZING BEAVER-INDUCED DIFFERENCES IN REACH-SCALE FLUVIAL MORPHOLOGY, HUNTINGTON WILDLIFE FOREST (HWF), CENTRAL ADIRONDACKS, NY

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INTRODUCTION

Changes in land use, variations in discharge, and extreme weather events are perturbations on historical time-scales to which streams must adapt. Response to these factors is reflected in shifts between phases of incision and aggradation. While incision is a natural process, recent rates of incision are increasing over shorter timescales globally (Simon and Rinaldi, 2006; Montgomery, 1997). Rapid incision can lead to lowered water tables, raised water temperatures, and/or disconnection from the floodplain, all of which degrade habitat for aquatic species. One proposed mechanism for remediating this incision to protect or restore habitats, is the reintroduction of beaver to systems from which they have been lost.

The stream in this study, Panther Brook, is located within the Huntington Wildlife Forest (HWF), an experimental forest in the geographic center of the Adirondack Mountains in New York State. It is the southern inlet to Catlin Lake, the largest lake within the HWF. It is a small, upland stream in the headwaters of the Hudson River. The stream is 3-km long and varies between heavily bouldered, canopy-covered reaches assumed to represent the stream prior to beaver activity or "unaffected;" to wide, flat meadows where the incised stream meanders through tall grasses and an abundance of fine-grained sediment. 9 beaver dams are present along the stream as well as 2 large beaver ponds that maintain high water levels in the research area, located at approximately 1450-m and 2050-m (Fig. 1). There is a record of beaver activity in the stream for the past few decades, dating as recently as 2014. However, as of summer 2016 all beaver activity had ceased and Panther Brook beaver dams were all observed to be relict and abandoned.

RESEARCH OBJECTIVES

The goal of this study is to determine the effect of beaver activity on reach-scale channel form, sediment distribution, and bed morphology by classifying and comparing beaver-affected reaches of Panther Brook to free-flowing, unaffected reaches. Additionally, this work seeks to diversify the geographic distribution of beaver-geomorphology studies. Most work on beaver as geomorphic agents has been conducted in the Pacific Northwest or Mountain West—Oregon, Washington, Montana, Wyoming, etc. (Levine and Meyer, 2013, Persico and Meyer, 2009, Pollock et al., 2007, Beechie et al., 2008). Very little work is centered on East Coast systems (Ruedemann and Schoonmaker, 1938, Burchsted and Daniels, 2014, Costigan and Daniels, 2012). However, the desire to utilize beaver as a mechanism of stream restoration is not limited to these regions. This creates an inherent need to expand geographically these types of studies if we hope to eventually see wide-spread application of beaver as a stream restoration tool.

METHODS

Field Methods

We conducted a longitudinal survey of Panther Brook that included both channel geometry measurements (bankfull width and depth, channel bed elevation, meadow width), grain size measurements, and large woody debris (LWD) measurements. See Figure 1 for the completed survey. Bankfull depth was determined as the base of the trimmed and exposed meadow tops. We surveyed with a stadia rod and hand level at a 10-m resolution, with some exceptions in the case of extensive beaver ponds or dams altering the surveyable distance. Flags were placed every 50-m to mark positions of grain size distribution and LWD measurements. Grain size measurements followed the procedures of Wolman (1954). Additionally, at each 50-m mark we measured the length and diameter of all LWD present that had a diameter of at least 5 cm. Wolman pebble counts were conducted until we observed a distinct transition from fluvially dominated transport to colluvial, a few hundred meters above the last beaver pond at 2050-m. We measured both in channel and out of channel LWD that occurred on a transect perpendicular to the channel. Diameters were measured at the largest part of the sample. Each reach was then categorized as either a “boulder reach” or “meadow reach” to separate beaver activity from a lack thereof.

Calculations

I used field measurements to calculate 5 variables for each reach. The variables are channel gradient (S), median grain size (d_{50}), bankfull shear stress (τ_0), relative roughness (d_{90}/D), and volume of LWD. Channel gradient for each reach was calculated from the elevation values and measured in our longitudinal survey.

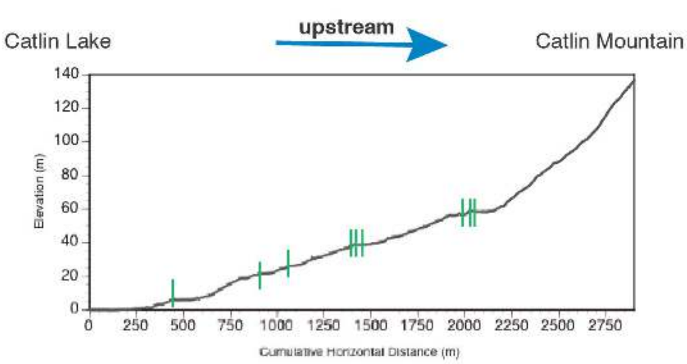

Figure 1. Longitudinal Profile of Panther Brook. Compiled from our field survey data. Note the numerous dams present symbolized by the green vertical bars in the profile. 0 is the start of our survey, just upstream from road near the inlet to Catlin Lake, moving upstream to 3000 m near the drainage divide on Catlin Mountain.

Bankfull shear stress is calculated as τ_0=ρgRS,

(EQ. 1)

where ρ is the density of the fluid, g is the acceleration due to gravity, R is the bankfull hydraulic radius, and S is the channel gradient. The hydraulic radius is a measure of the water depth in a channel defined as the cross-sectional area of flowing water divided by the length of wetted perimeter (Leopold and Maddock, 1953). However, bankfull depth (*D)* is commonly substituted in for R, as was done in this study, making the equation for bankfull shear stress

$$\tau_0 = \rho g D S$$

(EQ. 2)

τ_0 aims to describe the erosive power of the stream or energy of the system. By calculating shear stress values for a reach affected by beaver versus an unaffected reach we can gauge the degree to which the presence of beaver activity is lessening the stresses driving channel incision. Lastly, volume of individual LWD was calculated by treating each piece as a cylinder.

RESULTS

Parameters of channel gradient, relative roughness (d_{90}/D), and bankfull shear stress show a clear distinction between what we determined to be beaver-affected (meadow) reaches and beaver-unaffected (boulder) reaches. In terms of channel gradient, beaver-unaffected reaches are on average more than twice as steep as beaver-affected reaches. Channel gradients in boulder reaches range from 0.003 to 0.115 with a mean of 0.0451; while, meadow reaches range from 0.001 to .0485 with a mean of 0.0173. Median gradients are 0.0470 and 0.008 respectively (Fig. 2A). Relative roughness of the channel bed also shows that boulder reaches are on average twice as rough as meadow reaches. D_{90}/D in boulder reaches range from 0.0450 to 0.785 with a mean of 0.217; while, meadow reaches range from 0.00135 to 0.302 with a mean of 0.0567. Median gradients are 0.161 and 0.0263 respectively (Fig. 2B). The largest difference appears to be in terms of bankfull shear stresses acting in the two reach types: boulder reaches of Panther

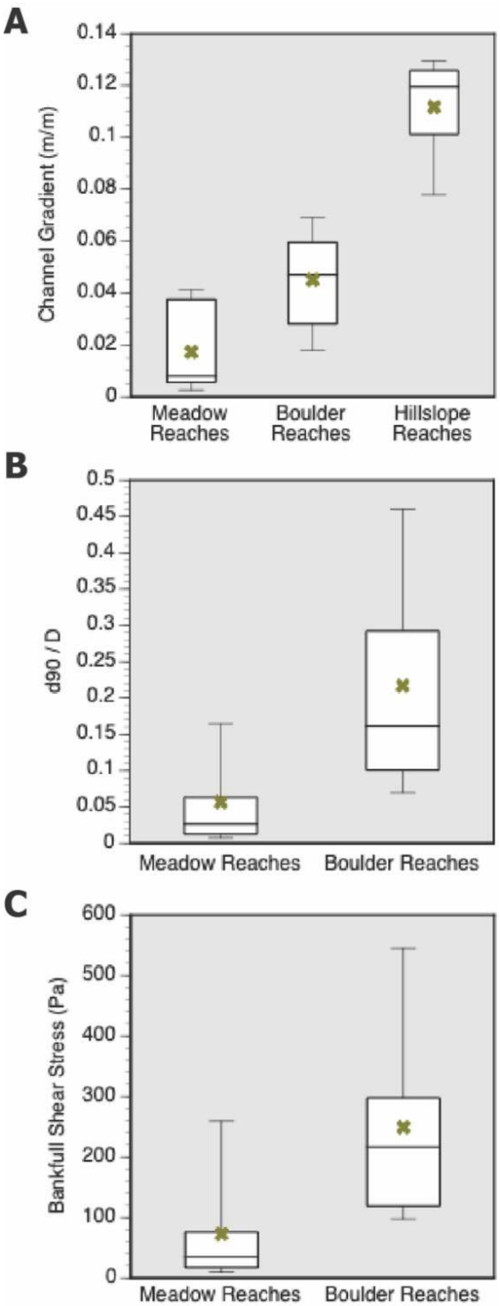

Figure 2. Hydraulic Characteristics of Panther Brook. 2A) Box and whisker plot showing differences in channel gradient between boulder and meadow reaches. There is a sharp difference between hillslope reaches and the two other classes. There is also a distinct contrast in the ranges and average slopes of channel reaches between meadow and boulder classes. Boulder reaches without beaver activity, which the meadows have, are markedly steeper with an average gradient more than double that of the meadow class. 2B) Similar to the trend in channel gradient, meadow reaches reflect overall lower values of d_{90}/D or relative roughness of the channel bed. There is no data for the hillslope reaches due to a lack of pebble counts in these reaches. These reaches were less clearly fluvially dominated and would only have experienced transport-capable flows in times of extremely high precipitation. 2C) Bankfull shear stress values display the same trend that is evident in channel gradient and relative roughness parameters. Meadow reaches experience lower shear stresses than boulder reaches in the same stream, though there is a large range for both classes.

Brook have a mean stress that is 3 times as high as the stresses in meadow reaches. Shear stresses in boulder reaches range from 33 to 723 Pa, with a mean of 249 Pa; while, meadow reaches range from 4 to 285 Pa, with a mean of 73 Pa. Median bankfull shear stresses are 216 and 35 Pa respectively (Fig. 2C). This is most likely a further reflection of the contrast in channel gradient between reach types as depth values do not differ significantly across types.

Relative roughness and channel gradient taken together (Fig. 3) demonstrate a clear grouping of meadow reaches at very low slopes and relative roughness values, with little heterogeneity. Slopes of meadow reaches and relative roughness generally never exceed 0.05 and 0.02 respectively. The boulder reaches, however, display greater heterogeneity.

Sediment distributions unsurprisingly show a trend of finer sediment in the meadow reaches than in boulder reaches. However, there is no distinguishing difference in median grain size between the various reach types, with each reach type hovering around an average of 0.5 cm. There is a greater heterogeneity in the maximum grain size values for the boulder reaches, showing systemically larger values than either the meadows or the hillslope reaches. Important to note is that the boulders present are a product of exhumed glacial till and are not being transported by Panther Brook. These boulders may likely be biasing the grain size distributions in the boulder reaches.

LWD does not display a predictable trend with sediment distribution. Large spikes are not correlated with grain size, bed roughness, or whether a reach is a boulder reach or meadow reach. Additionally, the volume of LWD does not fluctuate systematically with changes in grain size, suggesting different governing mechanisms. See Figure 4 for a representation of both grain size and LWD distributions.

DISCUSSION

Montgomery and Buffington Scheme Morphological Classifications of Meadow and Boulder Reaches

Boulder and meadow reaches are successfully distinguished by characteristics of channel gradient,

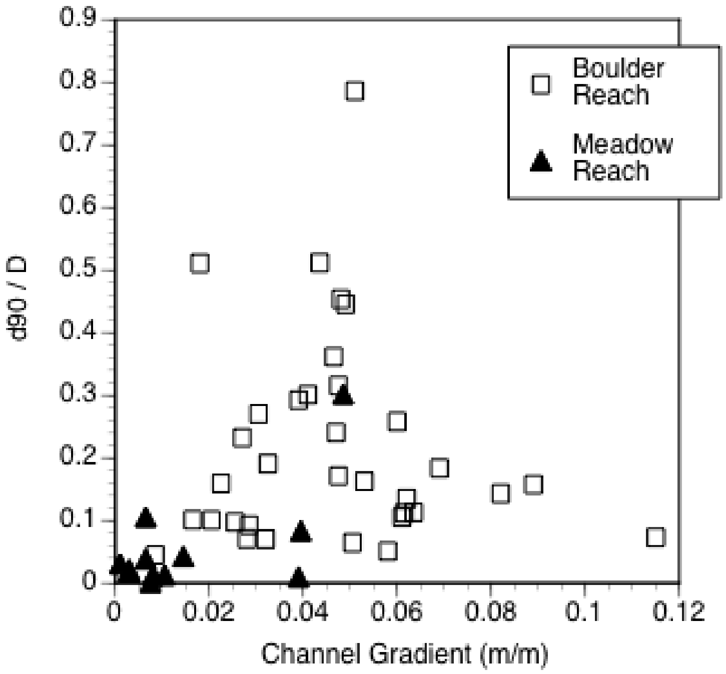

Figure 3. Plot of Relative Roughness vs Channel Gradient. Note the high density of meadow reaches near the origin showing the low roughness of their channel beds as well as the gently sloping nature of their beds. There is a spread with some meadow reaches exhibiting instances of steeper slopes and greater roughness but generally meadow reaches do not exceed slopes of 0.05 or relative roughness of 0.15. The boulder reaches, however, display a greater degree of heterogeneity.

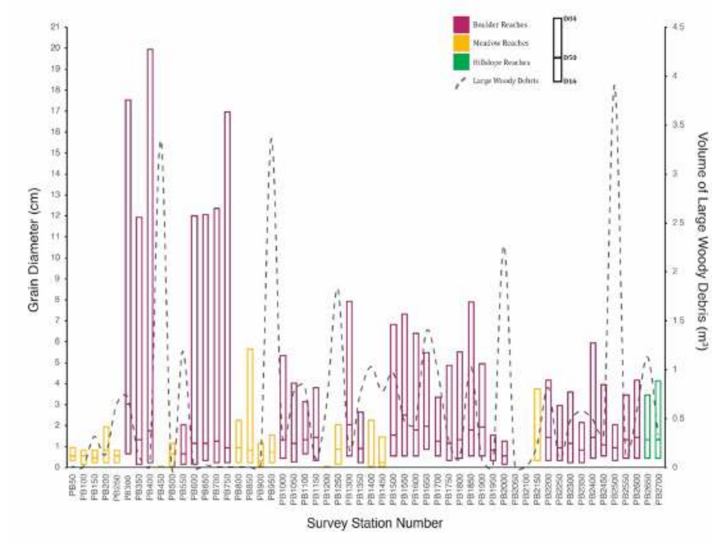

Figure 4: Grain Size and LWD Volume Distributions for Panther Brook. Boxes represent grain size distributions, where height of the box represents the spread from d_{16} to d_{84} and the middle line is the median or d_{50}. Yellow, purple, and green boxes represent meadow, boulder, and hillslope reaches respectively. Volume of LWD at each 50-m station is symbolized by the dashed gray line. Note that there is no distinguishing difference in median grain size between the various reach types, with each reach type hovering around an average of 0.5 cm. However, there is a greater heterogeneity in the maximum grain size values for the boulder reaches, showing systemically larger values than either the meadows or the hillslope reaches. Additionally, the volume of LWD does not fluctuate systematically with changes in grain size, suggesting different governing mechanisms.

relative roughness, and bankfull shear stress. Both reach types fall into a broad category of alluvial (as opposed to colluvial or bedrock). However as previously noted, above the second beaver pond Panther Brook does transition into a more colluvial transport regime. Further breakdown of alluvial reaches can be achieved via median channel gradient and relative roughness values (Montgomery and Buffington, 1997). The median slope value of 0.047, as well as field observations, of the boulder reaches suggests that these reaches are most likely step-pool morphologies. This is further supported by bankfull shear stress values in 200 Pa range. In contrast meadow reaches most closely fall into the pool-riffle morphological class. Pool-riffle reaches are characterized by slopes < 0.015, very low bankfull shear stresses, and relative roughnesses < 0.30 (Montgomery and Buffington, 1997).

There is a great deal of heterogeneity in the relative roughness values for the boulder reaches which may imply that there is variety of alluvial reaches present, that they are possibly a mix of step-pool and plane bed morphologies. This heterogeneity could also be a function of an attempt to group all boulder reaches together regardless of proximity to a beaver dam. Meadows occur upstream of dams and are clearly distinct morphologies. However, boulder reaches upstream of these meadows versus directly downstream of the meadow may represent distinct morphologies as well (Burchsted and Daniels, 2014). Heterogeneity may also reflect the fact that boulder reaches below meadows are subjected to the effects of dam breaches that are poorly accounted for.

This categorization is also supported by grain size distributions. Pool-riffle reaches are characterized by more uniform bed grain sizes in contrast to the heterogeneity in grain size that is evident in the larger range of grain sizes present in the boulder reaches (See Figure 3).

Morphological Implications on Sediment Transplant and Storage

The distinction in morphologies between the beaver-affected and beaver-unaffected reaches reflects a fundamental difference in processes shaping the two reach types. Lower shear stress, decreased bed roughness, and decreases in the steepness of channel gradient lead to processes that promote increased aggradation, by shifting the reach from a state that is supply-limited to a state that is transport-limited. Shifting from step-pool to pool-riffle morphology represents crossing a critical threshold for transport- (Q_c) and supply-capacity (Q_s) of the reaches. This is a threshold where $Q_c = Q_s$. A reach that was located at this equilibrium point would have enough stream power to transport all the sediment supplied to it, whereas one to the right of the threshold (pool-riffle) would have more sediment delivered to it than it could transport, thus triggering storage in the form of bars or development of extensive floodplains/meadows. See Figure 5 for a schematic of this Q_c—Q_s relationship.

Due to the fact that this shift is correlated to beaver activity, this may imply that without beaver colonies Panther Brook reaches would not cross this threshold and raises the question of whether sediment storage would be possible in a beaver-less Panther Brook. This suggests that their activity promotes a change in hydraulic and bed characteristics that can promote a transition from supply-limited stream reaches to a balanced reach. This supports the beaver-mediated stream restoration models proposed by Pollock et al. (2014). However, it should be noted that while Pollock et al. (2014) hypothesizes meters of long-term sediment aggradation and storage, such projections are out of the scope of this study and I hesitate to predict the longevity or volume of sediment accumulation due to beaver activity in Panther Brook or similar systems.

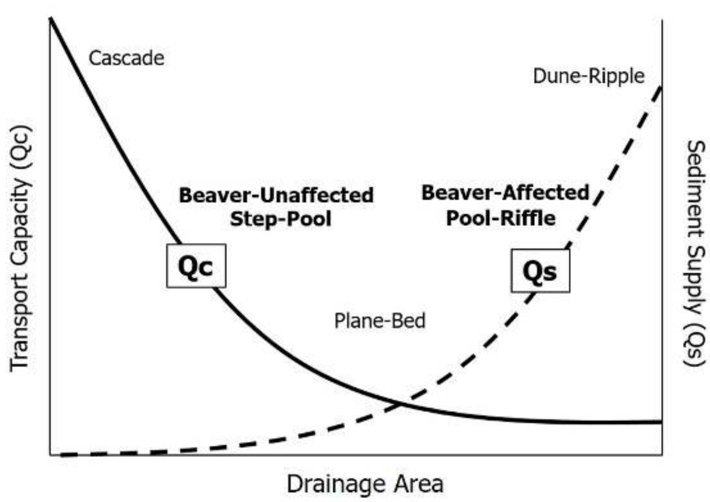

Figure 5. Schematic of Relationship for Transport- and Supply-Capacity for Different Reach Morphologies. Schematic updated from Figure 10 in Montgomery and Buffington (1997) showing relative trends in sediment supply and transport capacity for different reach morphologies. Note where "Beaver-Affected"/ Pool-Riffle falls relative to "Beaver-Unaffected"/Step-Pool. They lie across the equilibrium of Qc = Qs from each other reflecting the transition from a system that is supply limited to one that is transport limited, where aggradation and storage can occur.

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