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THE ROLE OF BEAVER IN REACH-SCALE FLUVIAL GEOMORPHOLOGY AND SEDIMENT STORAGE IN THE ADIRONDACK MOUNTAINS, NEW YORK

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INTRODUCTION

The return of beaver (*Castor canadensis*) to ecosystems throughout North America is profoundly affecting regional hydrology, ecology, and geomorphology. Beaver are cited as 'ecosystem engineers' and 'geomorphic agents' for their ability to enter a landscape and quickly adjust how water and sediment are routed through fluvial systems (Naiman, 1995). Several recent studies have investigated the impact of beaver on the geomorphology and hydrology of landscapes in the western United States (e.g., Persico and Meyer, 2009; Wohl, 2013; Levine and Meyer, 2014), but few have focused on the abundant beaver of eastern North America (Ruedemann and Schoonmaker, 1938; Burchsted and Daniels, 2014). This project investigates the role of beaver in the sediment budgets of small catchments (<10 km^2) in the central Adirondack Mountains of New York State. We leverage several decades of ecological monitoring of beaver colonies within Huntington Wildlife Forest (HWF), a 60 km^2 parcel managed by the State University of New York - College of Environmental Science and Forestry (SUNY-ESF). Our geomorphic perspective supplements past and ongoing ecological research at HWF, and it provides insight into natural upland erosion rates within the upper Hudson River watershed, an important resource for eastern New York.

To investigate the impact of beaver on small upland catchments, this Keck project first ground-truthed catchments we had identified as affected via GIS analyses of digital elevation models (DEMs) and remotely sensed imagery. Upon selecting Panther Brook (drainage area = 3.5 km^2) as an ideal study site we established a topographic baseline by surveying the stream's longitudinal profile from just above its base level (Catlin Lake) to within 300 m of the catchment's eastern drainage divide. At 50 m increments along our longitudinal survey, we evaluated grain size distributions and surveyed the volume of large woody debris (LWD) along cross valley or cross meadow transects - we also evaluated sediment thickness along these transects to begin informing our sediment budget for the catchment. Once back from the field, team members worked to synthesize our field observations with digital terrain analyses establishing: 1) quantitative metrics that describe how beaver-impacted reaches differ from reaches without active beaver or recent beaver activity; 2) links between the geomorphic parameters that we measured in the field and similar measurements that can be extracted directly from DEMs, so we might evaluate where beaver have played a significant role shaping reach-scale geomorphology in the Adirondacks and what unoccupied sites may be suitable for beaver reoccupation (or prone to reoccupation, depending on your management perspective); and 3) a preliminary sediment budget for Panther Brook that considers how significantly beaver ponds attenuate sediment transfer down system and how many years of upland sediment production may be stored in a beaver pond or beaver meadow. We hope that our work will begin to provide a baseline for how large a role beaver play in the catchment-scale geomorphology of the Adirondacks over decades to centuries, and thereby inform strategies for using beaver as stream restoration tools in the eastern United States.

BACKGROUND

Setting

Our study area is located along the southern edge of the High Peaks region of the Adirondack mountains, an area with maximum elevations greater than 1500 meters, and local relief exceeding 600 meters (Figure 1). Much of the region is underlain by high-grade Precambrian metamorphic rocks with pockets of less metamorphosed sedimentary rocks outside the High Peaks. During the last glacial period, the Adirondacks were overidden by the Laurentide ice sheet, stripping hillslope soils and locally depositing glacial till (Denny, 1974). As a result, upland soils can be quite thin, having developed from underlying bedrock over just the past few tens of thousands of years. The Adirondacks are undeniably an ancient mountain range, but there is some debate regarding how they have maintained their rugged relief despite their antiquity. In addition to localized uplift from isostatic rebound following the retreat of the Laurentide ice sheet, there is geodetic evidence for recent, ongoing uplift of the eastern Adirondacks (Isachsen, 1975), although the driving force behind this uplift is uncertain.

The Newcomb Campus of SUNY-ESF and Hungtington Wildlife Forest are located just west of Newcomb, NY, in the central Adirondacks. SUNY-ESF has managed this field station since 1932, and some of their Adirondack Long-term Ecological Monitoring Program (ALTEMP) projects have been active since the 1930s. The topography surrounding HWF is somewhat subdued in comparison to the adjacent High Peaks; maximum elevations are closer to 800 m near Newcomb. HWF contains five lakes, ranging in size from 38 to 217 hectares, and they are all within the upper Hudson River Watershed. Mean annual temperature is 4.4° C, and mean annual precipitation is 1010 mm (Shepard et al., 1989).

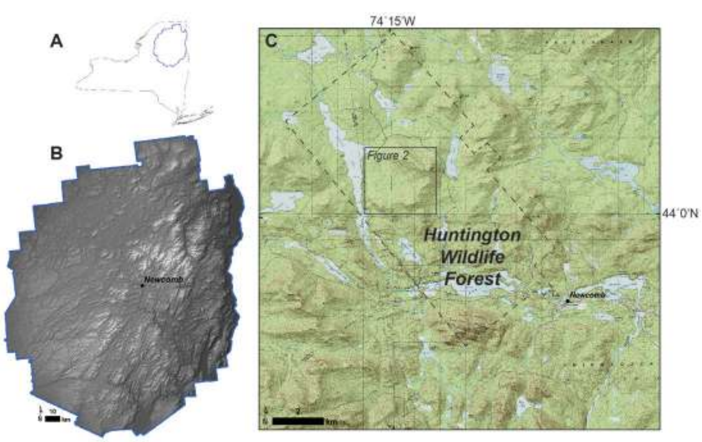

Figure 1. Setting of Huntington Wildlife Forest within the broader Adirondack Mountains. The blue line in (A) shows the boundary of Adirondack Park within northern New York. A digital elevation model draped over a hillshade in (B) clearly shows the rugged High Peaks region to the northeast of Newcomb. Huntington Wildlife Forest itself is located just west-northwest of Newcomb, NY (C). Note the extent of Figure 2 is outlined in Figure 1C.

Beaver as Geomorphic Agents

Prior to European contact, the beaver population in North America is estimated at between 60-400 million (Naiman et al., 1988; Butler 1995). Current estimates of beaver population put their number at 6-12 million, spread throughout most of their original geographic range (Naiman et al., 1988). Early studies of beaver's impact on landscapes' hydrology and geomorphology suggested that every water body in New York State must have been affected by beaver at some point prior to beaver extirpation by European settlers (Ruedemann and Schoonmaker, 1938). Ruedemann and Schoonmaker take their inference to the extreme in suggesting that nearly all valley fill in the Adirondacks is the result of intermittent beaver damming over the past 25,000 years. An analysis of sedimentation rates in beaver ponds within Glacier National Park in Montana, found beaver pond infilling rates of 1 m/yr following dam construction, which is far faster than other published rates for that region (Butler and Malanson, 1995). However, in Yellowstone National Park, total aggradation along streams that is attributable to beaver activity is commonly <2 m (Persico and Meyer, 2009), quite a different story than the thick beaver dam deposits proposed by Ruedemann and Schoonmaker for New York. Regardless of total sediment accumulation behind beaver dams, the long-term legacy of beaver ponds as sediment and carbon sinks is intimately tied to how frequently beaver dams fail and how pond sediments are eroded following dam failure (Levine and Meyer, 2014). In landscapes of the American West where over half of postglacial sediment in river valleys is associated with beaver activity, beaver meadows disproportionately serve as carbon sinks within those drainage networks (Polvi and Wohl, 2012; Wohl, 2013). Much of the recent work investigating the role of beaver in landscapes' sediment and carbon budgets has focused on beaver in the American West. This Keck project provides a new focus and perspective on similar processes in the Adirondack Mountains of the eastern United States.

APPROACH

Analysis of aerial photography and DEMs prior to our field effort yielded three potential target catchments for our month of field work in HWF during the summer of 2016: 1) Deer Pond Inlet; 2) Big Sucker Brook; and 3) Panther Brook. Upon arriving in the Adirondacks and exploring each option, we determined that both Deer Pond Inlet and Big Sucker Brook were either too recently occupied by beaver or currently occupied by beaver, so evaluation of reach-scale morphology and sediment distribution would not be possible since impounded sediment was still underwater. However, Panther Brook was a perfect field site since it has experienced intermittent beaver occupation over the last several decades, and all but one former beaver dam had breached leaving beaver meadow complexes high and (relatively) dry. Of additional interest were the inter-meadow stretches of Panther Brook comprising boulder reaches of exhumed glacial till. Panther Brook drains 3.5 km^2 and its primary channel runs approximately 3 km from near the basin's eastern drainage divide to the catchment's base level of Catlin Lake (Figure 2).

The baseline for all our datasets is our topographic survey of Panther Brook from just above Catlin Lake up to the stream's transition from fluvial to colluvial hillslope processes (Figure 3). Using a stadia rod, measuring tape, and hand level, our team surveyed a longitudinal profile at 10 m increments, measuring bankfull width and depth at each 10 m station, and flagging each 50 m station for later reoccupation. Our final survey station (2900 m) is located within 300 m of the basin's drainage divide, and above this station there is still evidence for occasional overland flow

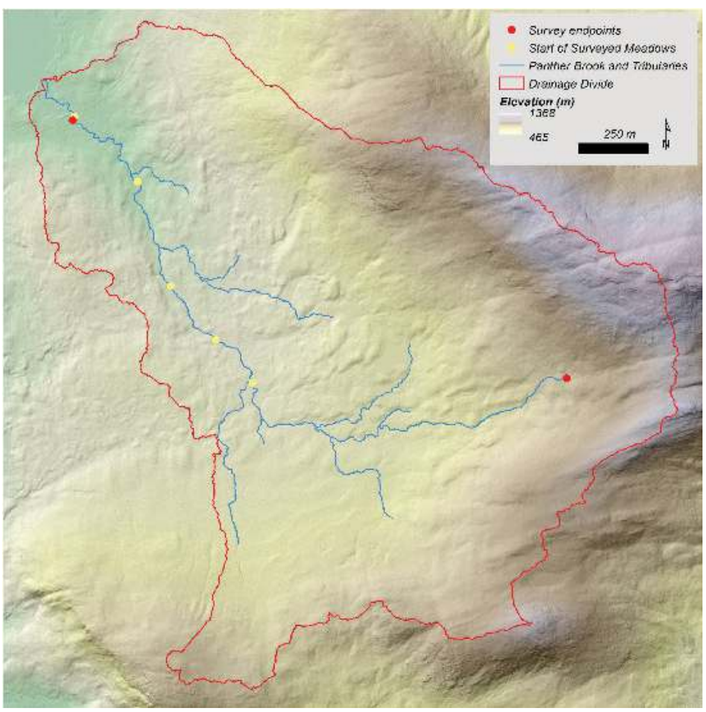

Figure 2. Panther Brook watershed in Huntington Wildlife Forest. Red line delineates the drainage divide for the 3.5 km2 catchment. Blue lines represent the stream network of Panther Brook assuming a threshold contributing area of 0.1 km2. Red dots are the start and end of our 2900 m longitudinal survey of Panther Brooks main channel, and yellow dots are the downstream boundaries of the five beaver meadows surveyed for sediment thickness. Base map is a DEM draped over a hillshade, both derived from 1 m resolution LiDAR data.

Figure 3. A summary of our field techniques for characterizing the fluvial geomorphology and sediment storage of Panther Brook. (A) Spencer O'Bryan looks 10 m upstream to a survey station occupied by Shyam Das-Toke and Sarah Granke. (B) Shyam holds the stadia rod while Sarah records survey notes. Take note that Panther Brook is incised into beaver meadow sediments through this lowest elevation beaver meadow. (C) Spencer measures LWD while Sarah augers beaver meadow sediment; Shyam records field data. (D) Spencer laboring at the bucket auger while Sarah and Shyam await their turn. Everyone alternated roles between augering, describing sediment textures and colors, and bagging samples.

during storm events, but no evidence for regular fluvial transport of sediment. From our final survey station, we surveyed four topographic profiles of the bounding hillslopes, noting soil depth with an Oakfield auger at 5 m increments along each survey transect. These headwater topographic and soil mantle surveys help inform reasonable bounds for sediment input rates needed for our Panther Brook sediment budget.

At each 50 m survey station we conducted three 100 pebble counts (Wolman, 1954) – one count at the station, one count 5 m below the station, and one count 5 m upstream from the station. We also stretched a measuring tape across the valley bottom or beaver meadow at each 50 m station and measured sediment thickness at 1-3 m intervals by hammering an Oakfield auger to refusal. Along the same tape, we measured the length and diameter of all LWD with a diameter >5 cm. For the five beaver meadows along the length of Panther Brook, we supplemented our Oakfield auger surveys with additional bucket auger transects along the long axis of each meadow and across the meadow short axis, bisecting each long axis. Sediment samples were collected at 20 cm depth intervals from each bucket auger station, and we described sediment texture and color in the field. We interpret the depth of refusal at each bucket augering station to be the contact between beaver-impounded sediment and pre-beaver floodplain or channel.

STUDENT PROJECTS

Our Keck group worked as a team of four in the field to collect the suite of datasets outlined above. Throughout our month together, each student worked to define a research question that might be answered using the data we gathered together. The student projects are complimentary perspectives on the impacts of beaver on the fluvial geomorphology and sediment budget of Panther Brook.

Sarah Granke (Pomona College) focused on using our detailed topographic and in-channel observations to develop a quantitative classification scheme for the reach-scale geomorphology of Panther Brook (Figure 4). She sees significant differences between reaches within incised meadows and reaches that connect meadow deposits in terms of mean channel gradients, relative bed roughness, and bed shear stress.

Figure 4. Characteristic reaches along Panther Brook. (A) Steep boulder reaches between beaver meadows. (B) Boulders disappear from view beneath the breached beaver dam just upstream from stadia rod station. The beaver dam is the overgrown berm to Shyam's left. Boulders always re-emerged from beaver meadow sediments at the upstream end of the meadows. (C) Just a few meters upstream from the breached dam in 4B a moderately incised Panther Brook flows through beaver meadow. (D) Panther Brook quickly transitions to mixed fluvial/colluvial reaches upstream from the uppermost beavers (survey station 2150 m), and continue to the end of our longitudinal survey.

Distributions of LWD do not track neatly with reach-scale morphology. Sarah adopts and adapts the reach-scale classifications of Montgomery and Buffington (1997) to describe the morphology of Panther Brook from base level up to the transition to colluvial transport. An important insight from Sarah's work is how beaver produce 'forced' morphologies that transform supply-limited upland streams into partially transport-limited systems with significant sediment storage – an effect with important management implications.

Shyam Das-Toke (Whitman College) analyzed longitudinal trends in grain size, shear stress, and total stream power to both characterize the beaver-affected reaches of Panther Brook and develop a set of geomorphic criteria for beaver habitability on upland streams in the Adirondacks. Importantly, Shyam identifies threshold values of shear stress and stream power in Panther Brook that set a limit on how channel gradient and upstream contributing area limit beaver's dam building. These thresholds may also be explored via DEMs and provide a way to search out areas that are either heavily impacted by beaver over the last decades to centuries or may be good sites for beaver reintroduction if lower gradients and more sediment storage are desirable. Shyam's work serves as an excellent point of connection between beaver stream restoration approaches in the western U.S. and the adaptation of those approaches to eastern U.S. streams.

Spencer O'Bryan (Carleton College) quantified sediment volumes for each beaver meadow in Panther Brook by combining our auger data from the field with digital terrain analyses in ArcGIS. Spencer interpolated auger depths for each meadow to approximate the contact between beaver-impounded sediment and the underlying floodplain or channel, then used GIS to determine the volume of sediment between that subsurface boundary and the current meadow surface. These analyses reveal a range of meadow volumes from ~3000-6000 m^3 along Panther Brook, which is significant considering the paucity of sediment storage sites between meadows. Spencer performed a sensitivity analysis of how many years of upland sediment generation each meadow stores. Using a lower bound of 15 m/Myr and an upper bound of 30 m/Myr for upland erosion rates, Spencer finds that the largest meadow could store 400-700 years of upland sediment generation.

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