

Annual Report for “Geomorphic and Biogeochemical Functions of Beaver Meadows”

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Abstract

Beaver meadows are wet valley bottoms in which branching and rejoining channels, ponds, and wet meadows create a spatial mosaic of microenvironments. These meadows slow the downstream passage of flood waters and retain sediment and organic matter. The accumulation of sediment facilitates surface and subsurface water exchange, as well as microbial processing of nutrients. Our research examines how spatial size and activity level within a beaver meadow, as well as physical complexity, correlate with attenuation of downstream fluxes of water, sediment, and organic carbon. Focusing on 10 beaver meadows of diverse size and activity level within Rocky Mountain National Park and adjacent portions of the Colorado Front Range, we are quantifying response variables of spatial heterogeneity, flow attenuation, and storage of fine sediment and organic carbon and characterizing response curves for these variables using a combination of topographic and soil surveys, measurements of stream discharge into and out of beaver meadows at 15-minute increments throughout the summer, and total organic carbon analyses of beaver meadow sediments. Ongoing analyses indicate that spatial heterogeneity, proportion of surface water features and saturated soil, peak flow attenuation, and soil organic carbon content correlate with length of beaver occupation and level of contemporary activity. This research has significant implications for basic science and for environmental restoration.

Introduction

Beaver populations were much larger in North America prior to commercial fur trapping (Naiman et al., 1988). The large number of beavers historically present along forested river corridors throughout the continent created extensive dam and pond complexes known as beaver meadows (Morgan, 1868). Beaver meadows are wet valley bottoms in which branching and rejoining channels, ponds, and wet meadows create a spatial mosaic of microenvironments (Figure 1). These meadows slow the downstream passage of flood waters and retain sediment and organic matter (Westbrook et al., 2006). The accumulation of sediment facilitates surface and subsurface water exchange, as well as microbial processing of nutrients (Naiman and Melillo, 1984; Naiman et al., 1994). Beaver meadows from diverse geographic regions harbor high biodiversity and abundance of plants and animals relative to adjacent uplands and relative to other portions of the river network (Wright et al., 2002; Bartel et al., 2010; Hood and Larson, 2014).

Beaver meadows clearly have significant effects on local biodiversity and biogeochemistry, but the great majority of studies thus far have largely focused on (i) a single beaver pond or limited area of meadow and (ii) quantifying animal abundance, biodiversity, and nutrient storage, rather than examining the processes by which beaver dams alter biogeochemical fluxes and associated biota. We are taking a more mechanistic approach to studying beaver meadows that will allow us to understand how beaver dams interact with valley geometry to alter downstream fluxes and geochemical state of water, sediment, carbon, and nitrogen. Specifically, we are quantifying the physical surface (topographic, vegetative) and subsurface (soil texture, soil organic carbon content) spatial heterogeneity of beaver meadows.



Figure 1. Examples of flowing (upper) and ponded (lower) surface water in an active beaver meadow along North St. Vrain Creek in Rocky Mountain National Park, Colorado.

We are then examining whether spatial heterogeneity correlates with (i) state of activity of the beaver meadow (active, recently abandoned, long abandoned), and (ii) the degree to which the beaver meadow attenuates downstream fluxes of water, sediment, and organic carbon. The research summarized here is part of a larger, collaborative project to understand the processes and significance of active beaver meadows. Our colleagues are focusing on: fluxes of water and nitrogen through and within the meadows; microbial processing of nitrogen in soils; and aquatic macroinvertebrate diversity and abundance.

We are conducting site-specific measurements within the Colorado Front Range at ten beaver meadows of diverse spatial area and level of activity. Because beaver meadows can be relatively large features within headwater river networks (> 1 km in length and width), and

were historically present on every major headwater network in the study area, we can use our site-specific measurements to infer watershed- and landscape-scale effects of beaver activities.

One reason that research on biogeochemical and biodiversity effects of beavers, which largely dates from the 1980s, has focused on limited spatial areas is that large beaver populations and spatially extensive effects are now mostly absent from temperate latitudes. Two summers of mapping abandoned beaver meadows in Rocky Mountain National Park, and using shallow geophysical techniques to image the subsurface of selected meadows, allows us to quantify the former location, spatial extent, and volume of these features (Kramer et al., et al., 2012; Wohl, 2013) and provides a basis for scaling up our site-level results. The presence of numerous abandoned beaver meadows, for which we have historical records constraining date of abandonment (e.g., Packard, 1947), also facilitates a space-for-time substitution in which we can look at how physical and biogeochemical function of these meadows changes through time following abandonment by beavers. A pilot study that we undertook indicates that beaver meadows store large quantities of organic carbon in the form of decaying plant matter transported into the meadow from upstream portions of the watershed and produced on site by plant growth. Once beavers abandon a site and the dams fall into disrepair, wetlands drain, soil carbon is oxidized or eroded, and carbon storage declines substantially (Wohl et al., 2012).

We hypothesized that (i) physical complexity within beaver meadows correlates with storage of particulate organic carbon (POC), (ii) physical complexity and POC storage in abandoned beaver meadows are significantly less than storage in active beaver meadows and (iii) physical complexity and POC storage decline progressively with time since abandonment. In this context, physical complexity refers to the spatial heterogeneity of surface and subsurface

environments. Surface environments include channels, ponds, and beaver dams. Within an active beaver meadow, for example, we have observed: a perennial main channel; perennial and ephemeral secondary channels with differing degrees of surface and subsurface hydrologic connectivity (i.e., surface versus near-surface or hyporheic flow); active and abandoned ponds, with differing degrees of surface and subsurface hydrologic connectivity; and active and abandoned dams (Figure 1). Each type of surface environment potentially has finer scales of heterogeneity. Channels, for example, can have bedforms, diversity of grain size in the streambed, irregular banks, instream wood, and so forth. Subsurface complexity results from spatial differences in grain size and associated differences in hyporheic fluxes, microbial communities, and biogeochemistry. Greater physical complexity within valley bottoms typically equates to greater hydraulic resistance (John and Klein, 2004; Green and Westbrook, 2009), residence time for materials in flux and associated biogeochemical reactions (Burchsted et al., 2010; Westbrook et al., 2011; Polvi and Wohl, 2012), and habitat diversity and associated biodiversity (Hood and Larson, 2014).

Objectives

We are addressing several objectives as part of this research:

- within multiple beaver meadows, quantifying response variables
 - physical surface and subsurface spatial heterogeneity
 - storage of sand-size and finer sediment
 - storage of organic carbon in sediments
 - flow attenuation

- statistically testing for correlations between response variables and potential control variables of
 - ratio of size of beaver meadow to contributing drainage area
 - level of activity within the beaver meadow
- developing response curves between control and response variables (e.g., how does flow attenuation change in relation to area ratio?).

Methods

During the Summer 2015 field research, which was supported by a National Geographic Society research grant, we focused on three tasks. (1) After identifying 10 beaver meadows of diverse size and activity level, we instrumented each meadow with capacitance rods to measure discharge at the inlet and outlet of each meadow in 15-minute increments. These rods were in place during summer and autumn of 2015, and will be re-installed at each site in spring 2016. (2) Surface complexity was surveyed along transects perpendicular to the down-valley direction for 6 sites, with 10 morphologic units defined by their topography, vegetation and surface hydrologic connectivity. Morphologic units included main channel, secondary channels and ponds with or without perennial surface hydrologic connection, dams/berms, and three units of high ground. Surveys were conducted using laser theodolite and survey tape measure. (3) We used a soil corer to collect sediment samples that are being analyzed for grain-size distribution, bulk density, and total organic carbon content. Sampling targeted distinct portions of each beaver meadow in terms of vegetation type, surface topography, and soil moisture with respect to the defined morphologic units. We collected 55 samples across 3 beaver meadows. Additional sediment samples for the other 7 beaver meadows will be collected during Summer

2016. Sediment samples are also being searched for radiocarbon-datable material. Thus far, we have 5 radiocarbon samples to be analyzed.

Results

The meadow topographic surveys revealed greater meadow morphologic complexity and a larger proportion of surface water features in active beaver meadows, consistent with results from Polvi and Wohl (2012), Westbrook et al. (2006) and Green and Westbrook (2009). Meadows with longer continuous beaver occupation and greater population of beaver have greater complexity and more surface water storage than recently re-occupied meadows with smaller beaver populations (Figure 2). The North St. Vrain beaver meadow in Wild Basin supports multiple colonies of beavers that have been present in the valley continuously for the last 100 years. Glacier Creek was abandoned during the mid-20th century and has been re-occupied by beaver in recent decades. Our observations indicate a single colony occupies the meadow. Mill Creek in Hollowell Park shows evidence of recent beaver re-colonization and observation indicates the beaver occupy only a small portion of the meadow.

In addition, longer time since beaver abandonment leads to increasingly less complexity in valley bottoms (Figure 1). Cow Creek, which only lost its beaver population in 2013, has a similar proportion of surface water features as recently re-occupied Mill Creek at Hollowell Park. Hidden Valley also has a similar proportion of surface water storage, although it has been abandoned longer, because of the presence of a very shallow in-filling pond. Upper Beaver Meadows has been abandoned by beaver for longer than three decades and has almost no surface water features aside from the single-thread main channel.

Ongoing analyses of soil organic carbon (SOC) content indicates that SOC correlates with

soil texture and moisture level, such that the highest SOC values correspond to saturated, clay-rich soils. Proportion of saturated soil within a beaver meadow correlates with proportion of surface water features, suggesting that active beaver meadows will have higher SOC and total organic carbon storage than abandoned beaver meadows.

Ongoing analyses of flow measurements at the inlet and outlet of each beaver meadow indicate that the degree to which peak flow is attenuated over the summer months correlates with the relative size of the beaver meadow (i.e., ratio of the area of beaver meadow and the upstream drainage area) and with the spatial heterogeneity and proportion of surface water features in the beaver meadow.

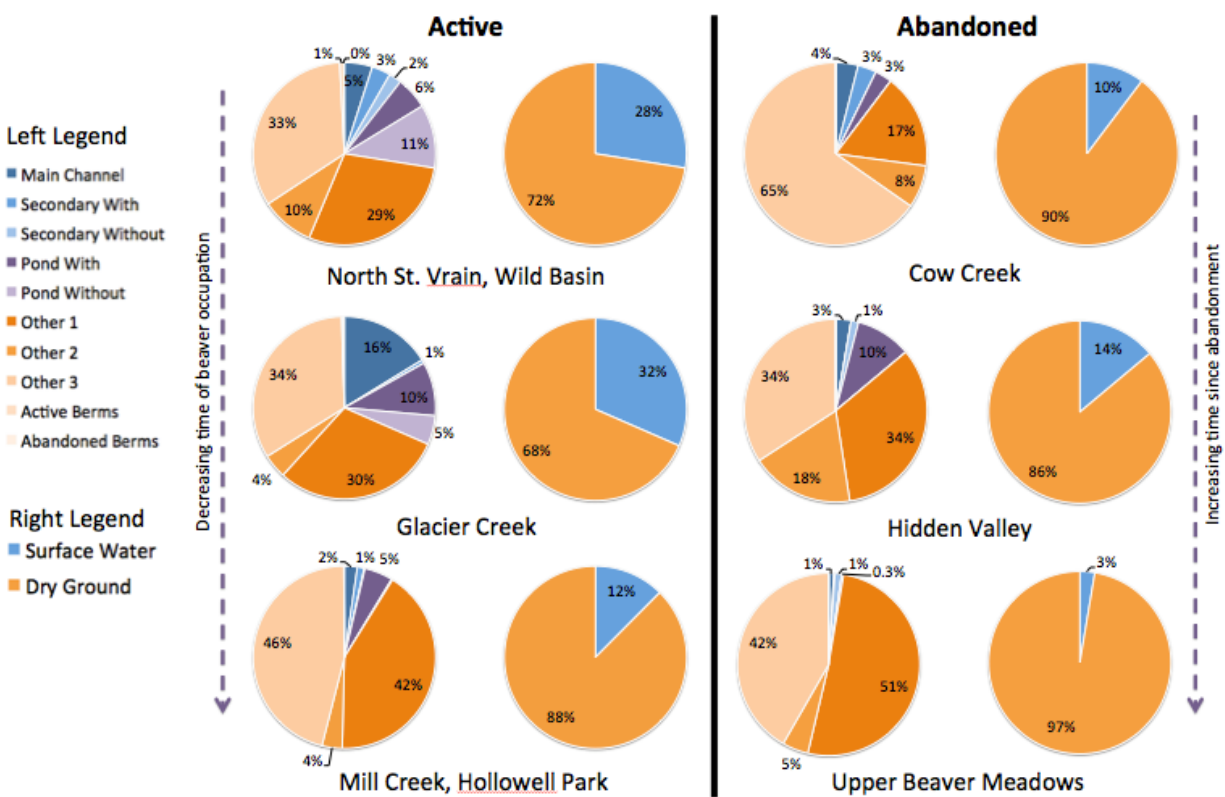


Figure 2. Results of the valley bottom complexity surveys for six locations in Rocky Mountain National Park. Currently active beaver meadows are on the left, and currently abandoned

meadows are on the right. For active meadows, complexity decreases with decreasing time of continuous beaver occupation. For abandoned meadows, complexity decreases with increasing time since abandonment.

Implications

This research has important implications for basic science and ecosystem restoration. Recent research indicates that river process and form can significantly influence the partitioning of terrestrially derived organic carbon among the atmosphere, geosphere, and ocean (Aufdenkampe et al., 2011), yet little is known of the specific river conditions that facilitate one form of carbon transfer relative to another (e.g., outgassing to the atmosphere versus storage in alluvial sediments). By examining geomorphic processes and carbon storage in beaver meadows, we are enhancing understanding of one formerly widespread type of river environment that is likely to be significant with respect to carbon dynamics. With respect to ecosystem restoration, resource management agencies (e.g., USDA Forest Service, US National Park Service) and environmental organizations are now starting to evaluate the potential for using beavers in river and riparian restoration (Polvi and Wohl, 2013; Pollock et al., 2014), and they are interested in being able to quantify the ecosystem services associated with the presence of beavers. Among these ecosystem services, are attenuation of floods, buffering during droughts, storage of fine sediment, and storage of organic carbon, all of which we are quantifying in our research. Although existing research suggests that active beaver meadows provide these services, we cannot currently quantify differences in the level of services provided between active and abandoned beaver meadows, making it difficult to economically evaluate the benefits of restoring beaver populations at a particular site or in a region. Beaver

meadows can also increase ecosystem resilience to discrete disturbances such as wildfire and prolonged changes associated with warming climate (Hood and Bayley, 2008). Again, we are currently limited in our ability to quantify these effects, but the watershed-scale component of our research will help to address this gap.

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