Annual Report Vol. 40 (2017)

Are we overlooking the eco-geomorphic importance of wood in braided rivers?: A case study in Grand Teton National Park

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Abstract A decades-long body of research has hypothesized a fundamental incompatibility between braided rivers, which form due to a lack of bank cohesion and a highly-mobile channel bed, with vegetation, which stabilizes channel surfaces and hinders sediment mobilization. At the same time, many researchers have observed high densities of wood, occurring either as large jams or dense stands of mature trees, along the braidplains of multi-thread rivers worldwide. Here we seek to reconcile the perceived incompatibility of wood and braided rivers with the high densities of vegetation found along these streams using two multi-thread, gravel-bed rivers in Grand Teton National Park. In August of 2017, we completed topographic surveys along ~500 m reaches of Pacific and Pilgrim Creeks, tributaries to the Snake River in Jackson Hole. We seek to compare digital elevation models generated from these surveys with 2014 elevation data collected via airborne lidar to determine whether in-channel wood drives increases in bar density, depth variability, and in-channel habitat suitability for native salmonids. While the majority of our efforts following the August 2017 field campaign have been focused on lidar data processing and cleaning, our initial results indicate that wood is a dominant driver of bar formation in both Pilgrim and Pacific Creek, and may be the dominant driver of depth variability (e.g., pool scour) in gravel-bed braided streams in Grand Teton National Park.

Introduction

Decades of research has emphasized that in-channel wood, either as jams or living trees, is a fundamental driver of river evolution and in-channel habitat quality (Lisle, 1986; Fausch and Northcote, 1992; Abbe and Montgomery, 1996), yet nearly all of our knowledge regarding the eco-geomorphic importance of wood in rivers comes from work done on single-thread streams. This is surprising because multi-thread (e.g., braided) rivers comprise critical habitat in climatically- and developmentally-sensitive regions around the world (Bristow and Best, 1993; Tockner et al., 2009). The lack of research on the importance of wood in braided channels may be due to the prevailing hypothesis that wood and braided rivers are fundamentally incompatible, given that vegetation acts to stabilize river banks and thereby prevent development of the braided planform, where numerous channels diverge around a dynamic network of bars (Tal and Paola, 2007, 2010).

Given the assumed incompatibility between braided rivers and wood, it is notable, then, that many braided rivers contain tremendous volumes of wood, either as trees growing on the valley floor or in extensive wood jams composed of dead trees. Indeed, studies and field-based observation of braided channels indicate that wood is frequently found in multi-thread rivers, and bars are often associated with trees or woody debris jams in these settings (Piégay and Gurnell, 1997; Welber et al., 2013). These observations suggest an alternative hypothesis: that in-channel wood serves as a roughness element that promotes bar formation, thereby building and maintaining the braided planform in settings where single-thread rivers might otherwise prevail.

The Jackson Hole Valley in northwestern Wyoming holds perhaps the largest concentration of dynamic gravel-bed braided rivers in the contiguous U.S., owing to abundant sediment supplied by past glacial activity and the rapid uplift and erosion of the Teton Range (Erwin et al., 2011). Many of these braided rivers contain large volumes of wood, either as mature trees colonizing the valley floor and/or extensive wood jams. Over the winter of 2017, snowpack in the watersheds above Jackson Hole rose to more than 150% of normal levels (USDA, 2017), setting the stage for floods in the spring of 2017 that resulted in widespread geomorphic reworking of these rivers and an ideal opportunity for studying the role of wood in bar formation and habitat dynamics following these floods.

This study will address three hypotheses regarding the eco-geomorphic role of wood in braided rivers by using two tributaries of the Snake River in Grand Teton National Park:

- **H1.** Bars built during the 2017 floods will be more numerous, and dense, in areas of Pilgrim and Pacific Creek containing large volumes of in-channel wood.
- **H2.** Bar formation immediately downstream of wood will be observed more frequently than bar formation in areas not occupied by vegetation or wood jams.
- **H3.** Habitat availability and suitability (indicated by characteristic flow velocity and bed grain size) for Snake River cutthroat trout will be greater in areas marked by high volumes of in-channel wood.

Methods

This work focuses on three study reaches within two braided tributaries of the Snake River in Jackson Hole (Pilgrim Creek and Pacific Creek), which contain a great deal of wood either as mature trees on the valley floor (upstream reach of Pilgrim Creek), or as log jams composed of dead trees (Pacific Creek). Mueller and Pitlick (2013) note that Pilgrim and Pacific Creek have similar hydrologic and sediment supply regimes, thus leaving in-channel wood as the main variable between selected reaches in each system. Each of the study streams is further described below.

Pilgrim Creek is one of the numerous gravel-bed streams in the Jackson Hole Valley (Figure 1). It drains approximately 125 km^2 on the western edge of the Gros Ventre Range, emptying into Jackson Lake immediately above Jackson Lake Dam, meaning that sediment supply from Pilgrim Creek has implications both for reservoir storage capacity and dam operations that may affect the Snake River through Jackson Hole. Pilgrim Creek represents an ideal study setting for this work given its low summer base flows which mean that the stream and its braidplain are wadeable and can be surveyed for much of the summer and fall. The study reach of Pilgrim Creek is about 3.5 km long, and contains numerous mature cottonwood trees and wood jams scattered about the braidplain.

Pacific Creek drains approximately 440 km^2 and joins the Snake River 7 km downstream from Jackson Lake Dam (Figure 1). Like Pilgrim Creek, Pacific Creek drains the western slopes of the Gros Ventre Range, and contains a great deal of wood, this time mainly as dead and downed mature trees which form wood jams on the braidplain (Figure 1). Pacific Creek has been gauged by the USGS since 1945 and snowmelt floods occur with regularity between April and July and average around 90 m^3/s in discharge. Following the passage of these floods, baseflows average around 3 m^3/s during the summer months, meaning that a great deal of the river valley is either exposed and dry, or can be surveyed by wading.

Survey work is conducted using a combination of terrestrial laser scanning (e.g., lidar), and real-time kine-

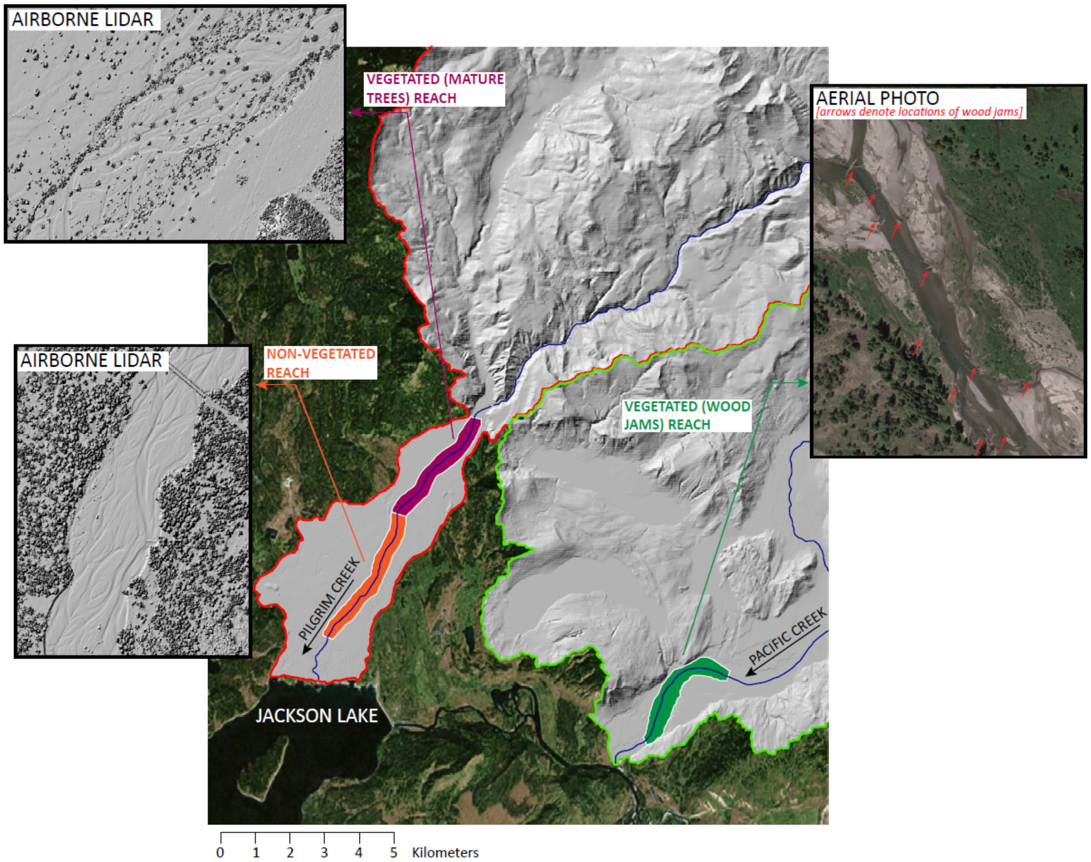

Figure 1. Study reaches on Pilgrim and Pacific Creek within Grand Teton national Park. The upstream (vegetated) reach of Pilgrim Creek and the reach on Pacific Creek were surveyed using lidar and RTK-GPS in August of 2017.

matic global positioning system (RTK-GPS) equipment, which both provide positional accuracies on the order of 10^{-3} m (Wheaton et al., 2010). While the vast majority of the study reaches can be surveyed using lidar, the attenuation of laser energy by water and subsequent loss of signal require any inundated areas to be surveyed via GPS (Wheaton et al., 2010). Both lidar and RTK-GPS collect point data, which are subsequently used to generate continuous elevation rasters, or digital elevation models (DEMs), across the survey area. In addition to these DEMs generated from 2017 survey data, DEMs from 2014 are available for the study reaches on Pilgrim and Pacific Creek; these elevation products were collected by the USGS for the majority of Jackson Hole. Elevation changes between the two survey periods are quantified via geomorphic change detection, or the differencing of the pre- and post-flood topographic datasets (Kasprak et al., 2015). The location of wood jams and mature trees can be obtained from the lidar datasets and aerial photographs, whose spatial resolution (pixel size less than 1 m) is sufficient for the detection of such features (Atha and Dietrich, 2016). These elevation datasets allow us to (a) address hypothesis **H1** by quantifying the number and spacing of bars built during the spring 2017 floods in both the vegetated and non-vegetated reaches, (b) test hypotheses **H2** by determining the percentage of bars that formed in proximity to wood in the study reach, and (c) test hypothesis **H3** by computing habitat quality and availability for native Snake River cutthroat trout (*Oncorhynchus clarkii*) using an existing ecohydraulic model parameterized with the topographic data.

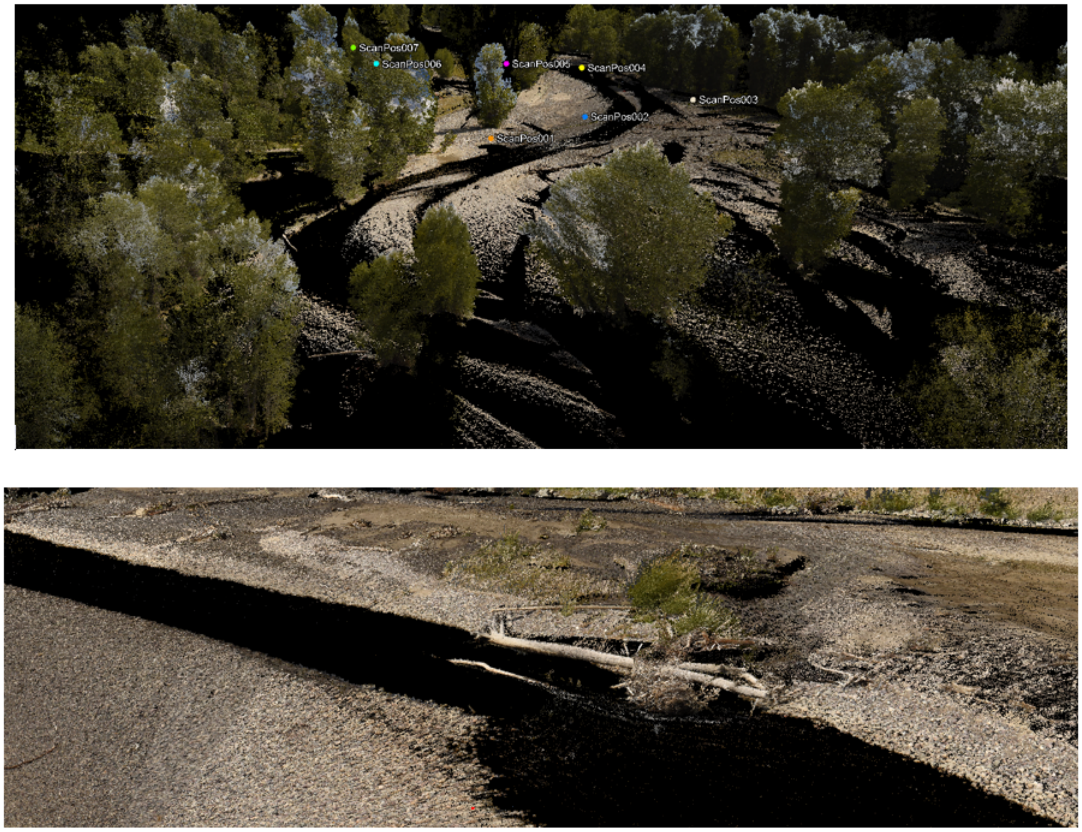

Figure 2. Oblique true-color lidar point clouds showing distribution of mature cottonwood trees on the braidplain of Pilgrim Creek (top panel) and a characteristic wood jam on the braidplain of Pacific Creek (bottom panel). In the top panel, lidar scan positions (i.e., instrument setup locations during the survey campaign) are noted. All lidar points are colored using photographs collected concurrently with the scans.

Preliminary Results

Topographic surveys using lidar and RTK-GPS were completed on ∼500 m reaches of Pilgrim and Pacific Creeks between August 21 and August 29, 2017. While we initially planned to survey an additional reach of Pilgrim Creek (downstream, non-vegetated reach; see Figure 1), the topographic complexity and vegetation density encountered at the upstream reach of Pilgrim Creek and the Pacific Creek study reach only allowed for surveys to be completed at those two sites during our permit period in Grand Teton National Park. At Pacific Creek, 385,898,229 elevation points were collected from 6 lidar scan stations, for an average point density of 3,563 points/m^2. At Pilgrim Creek, we collected 1,037,131,218 points from 18 scan stations, with an average density of 10,371 points/m^2. Control points were established at each site, with positional errors $<$ 1 cm, to georeference the resultant lidar point clouds in conjunction with a network of 8-18 reflective lidar survey targets temporarily emplaced at each survey reach. Figure 2 depicts typical lidar point clouds at each site, colored using wide-angle photographs collected simultaneously with the laser scanning campaign.

The majority of our work following the August 2017 data collection campaign has been focused on:

- *Point Cloud Coloring.* Wide-angle photographs were collected concurrently with laser scans via a Nikon D810 camera mounted atop the scanner. These photographs were used to color individual lidar points in true-color for subsequent point cloud examination and the location of trees and wood jams.
- *Point Cloud Registration.* Lidar point clouds were

initially collected in a local coordinate system; to shift the clouds to a global coordinate system (UTM, Zone 12 North), the locations of reflective lidar targets, collected in the field via RTK-GPS, were used for point cloud rotation, translation, and shifting.

- *RTK-GPS Fusion.* RTK-GPS data were collected at both study sites. These data comprised channel bathymetry in inundated areas not surveyed via lidar, along with topographic breaklines along the water's edge and along topographically-continuous surfaces (e.g., bank tops). RTK-GPS data were merged with lidar point data to produce seamless point coverage throughout the study reaches.
- *Point Cloud Cleaning.* Lidar data points depicting vegetation or spurious lidar returns from the channel bed or at the air-water interface were removed via an iterative roughness filtering procedure in Riegl's RiScan Pro Software.
- *2014 Lidar Acquisition.* Point data were downloaded from the US National Map Server for the 2014 USGS airborne lidar data collection effort and were subsequently processed to generate 0.75 m-resolution continuous digital elevation models at the study reaches, for comparison with the 2017 lidar data.

While digital elevation model differencing and geomorphic change detection is still ongoing, our preliminary analysis from field surveys indicate that bars along Pilgrim and Pacific Creek are most frequently found in association with either wood jams or live trees along the braidplains of both streams. These observations, taken from both field photographs and lidar elevation data, largely confirm **H1** and **H2** above. Furthermore, our initial results indicate that wood likely serves as a first-order control on the depth of braided rivers, consistent with findings of previous work on multi-thread streams in Europe (Bertoldi et al., 2011). Specifically, braided streams in Grand Teton National Park tend to form in wide, unconfined valley bottoms, and thus typically consist of wide and shallow channels, owing to the lack of bank cohesion and the relative ease of lateral migration compared to the energy required for bed incision. In both of our study reaches, the only locations where we observed pool formation or bed scour was in close proximity to wood jams, trees, or shrubs/grasses colonizing the braidplain. Given that depth heterogeneity in streams provides shelter for juvenile salmonids, we surmise that these areas will also prove to be hotspots of habitat quality and availability for trout, as articulated in **H3**.

Conclusions

A longstanding body of research has surmised a fundamental incompatibility between braided rivers, which arise due to a lack of bank cohesion and a labile channel bed, with vegetation, which serves to stabilize channel surfaces and hinder sediment mobilization. However, many researchers have also observed large volumes of wood, either as mature trees or log jams, in braided rivers worldwide, leading us to hypothesize that wood may in fact serve to promote and maintain channel erosion, bank scour, and the overall development of the braided planform.

In August 2017, we completed lidar and RTK-GPS topographic surveys along two ∼500 m reaches of braided streams in Grand Teton National Park. The majority of our efforts following the survey campaign have been centered around (a) lidar data quality control, georeferencing, filtering, and point cloud coloring, (b) RTK-GPS data fusion with lidar clouds, and (c) acquisition and processing of 2014 lidar point cloud data for comparison with 2017 data. Our initial results from field surveys and observations indicate that bars occur frequently in conjunction with wood jams and mature trees, and also that almost all instances of bed scour (e.g., pools) across both study reaches occurred exclusively in association with vegetation, suggesting that in highly mobile gravel-bed braided rivers like those in Grand Teton National park, wood represents the most important, and one of the only, controls on vertical channel change.

Future Work

Over the next several months, our work will center around direct comparisons between DEMs generated via lidar/GPS surveys in August of 2017 via geomorphic change detection, to address **H1** and **H2**, along with hydraulic and habitat suitability modeling using DEMs from 2017 in conjunction with stream gauging data that we collected concurrently with those topographic surveys, to address **H3**. We anticipate completing this effort and submitting a manuscript documenting our findings to *Earth Surface Processes and Landforms* by September of 2018.

Acknowledgements

This research was funded by a seed grant from the University of Wyoming and the National Park Service. Field assistance was provided by Matthew Meier, Richard Williams, Helen Williams, and Kate Olsen. Field accommodations were provided by the University of Wyoming's Research Station at the AMK Ranch, with particular assistance from Michael Dillon and Bonnie Robinson.

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