



RESEARCH ARTICLE

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Geomorphic Controls on Floodplain Soil Organic Carbon in the Yukon Flats, Interior Alaska, From Reach to River Basin Scales

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Key Points:

- We assess geomorphic controls on floodplain soil OC in the Yukon Flats region in interior Alaska, an area of discontinuous permafrost
- Floodplain soil OC varies among geomorphic units (bars, fills, floodplain surfaces, and wetlands) and among study rivers
- Our results inform the scales at which it is important to assess floodplain soil OC in a region undergoing anthropogenic warming

Supporting Information:

- Supporting Information S1

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**Abstract** Floodplains accumulate and store organic carbon (OC) and release OC to rivers, but studies of floodplain soil OC come from small rivers or small spatial extents on larger rivers in temperate latitudes. Warming climate is causing substantial change in geomorphic process and OC fluxes in high latitude rivers. We investigate geomorphic controls on floodplain soil OC concentrations in active-layer mineral sediment in the Yukon Flats, interior Alaska. We characterize OC along the Yukon River and four tributaries in relation to geomorphic controls at the river basin, segment, and reach scales. Average OC concentration within floodplain soil is 2.8% (median = 2.2%). Statistical analyses indicate that OC varies among river basins, among planform types along a river depending on the geomorphic unit, and among geomorphic units. OC decreases with sample depth, suggesting that most OC accumulates via autochthonous inputs from floodplain vegetation. Floodplain and river characteristics, such as grain size, soil moisture, planform, migration rate, and riverine DOC concentrations, likely influence differences among rivers. Grain size, soil moisture, and age of surface likely influence differences among geomorphic units. Mean OC concentrations vary more among geomorphic units (wetlands = 5.1% versus bars = 2.0%) than among study rivers (Dall River = 3.8% versus Teedrinjik River = 2.3%), suggesting that reach-scale geomorphic processes more strongly control the spatial distribution of OC than basin-scale processes. Investigating differences at the basin and reach scale is necessary to accurately assess the amount and distribution of floodplain soil OC, as well as the geomorphic controls on OC.

**Plain Language Summary** Rivers transport organic carbon (OC) from the landscape to the ocean, but that carbon is deposited along the way in floodplains and remains there for varying lengths of time. River processes also create bare sediment surfaces on which carbon can accumulate, and that carbon can then be eroded by the river and transported downstream. Assessing the physical controls on floodplain soil carbon is important for understanding how carbon is transported from the landscape to the ocean and for determining the spatial pattern of carbon on the landscape. Soil carbon is particularly important in arctic and boreal regions, where climate change is modifying permafrost (perennially frozen soil) and releasing previously frozen carbon to the atmosphere. The hydrology and the amount of nutrients delivered to the Arctic Ocean by rivers are also affected by climate change, and floodplains are mediators of water and sediment fluxes. We look at OC concentrations between different floodplains and between different geomorphic (physical) environments in the Yukon Flats region in interior Alaska, an area with discontinuous permafrost. Our results indicate that OC varies among river basins and among geomorphic environments, highlighting the need to assess OC on different scales.

1. Introduction

Rivers are increasingly recognized as important and active components in the terrestrial carbon cycle, as sites of carbon processing, transport, and storage (Battin et al., 2009; Cole et al., 2007; Stackpole et al., 2017; Sutfin et al., 2016; Wohl et al., 2017). However, less attention has been paid to the geomorphic controls on and quantity of carbon stored in floodplain soils. In addition, most studies of floodplain soil organic carbon (OC) have been conducted in the temperate zone (Sutfin et al., 2016). Anthropogenic climate change has resulted in the disproportionate warming of the high latitudes, including Alaska, relative to other regions (ACIA, 2005; IPCC, 2014; U.S. Environmental Protection Agency, 2016). There is concern that

permafrost warming and thaw (Jorgenson et al., 2006; Romanovsky et al., 2010, 2013) may result in the release of subsurface OC into the atmosphere and cause further warming (Koven et al., 2011; Schädel et al., 2016; Schuur et al., 2008, 2015). High latitude permafrost zones store large amounts of carbon in the subsurface, in part due to reduced decomposition rates with cold temperatures (Davidson & Janssens, 2006; Jobbágy & Jackson, 2000), with estimates indicating that there are approximately 1,035 Pg ( $1 \text{ Pg} = 1 \times 10^9$  metric tons) in the top 3 m of soil (Hugelius et al., 2014). This is approximately half of the amount of carbon stored in the top 3 m of the subsurface outside permafrost regions (Jobbágy & Jackson, 2000), highlighting the importance of determining controls on the spatial distribution of carbon in the subsurface in high latitude regions.

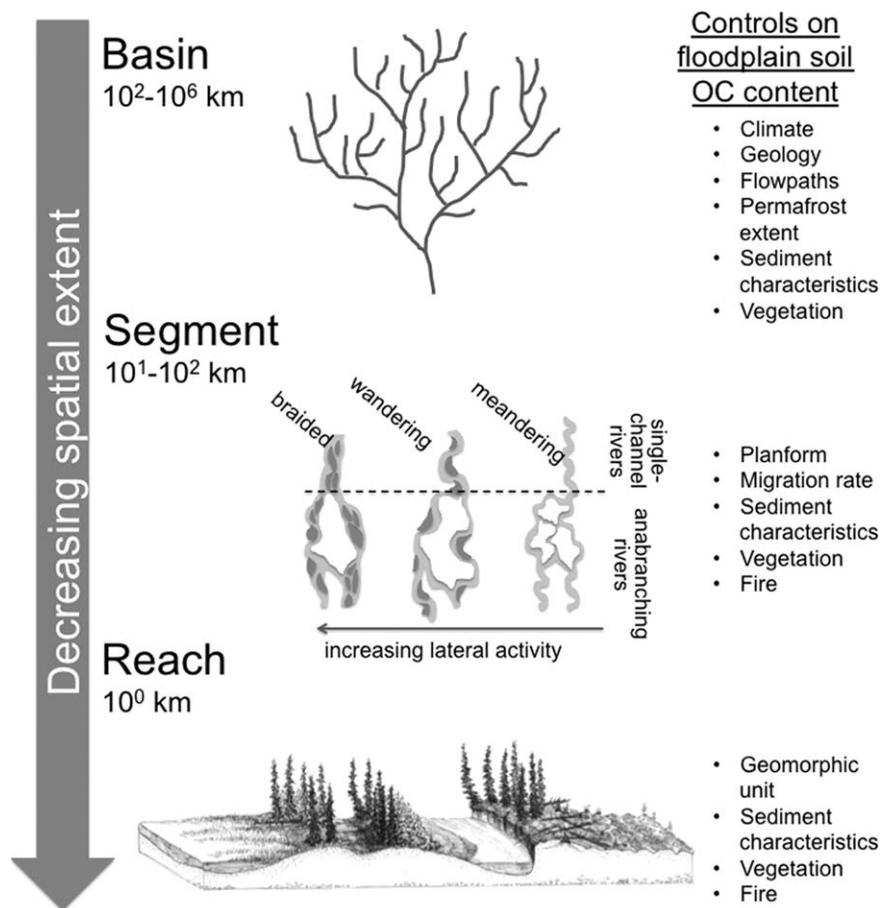
Geomorphic processes, such as channel migration, sediment loading to rivers, and bank erosion, may be altered as the climate continues to warm and permafrost thaws (Rowland et al., 2010), indicating the need to understand how geomorphology and river processes influence floodplain soil OC in order to detect ongoing and future changes. We investigate the geomorphic controls on OC concentrations (%) across a large region in the Yukon Flats (YF) in interior Alaska, an area with discontinuous permafrost in the boreal zone. Our study area includes the main stem Yukon River and four tributaries, allowing for the assessment of geomorphic controls on floodplain soil OC across spatial scales, from the reach to the river basin. To our knowledge, this is the first study to evaluate spatial variations in floodplain OC concentrations in relation to geomorphic processes across spatial scales, and one of only a very few studies of OC concentrations in the active layer (seasonally thawed layer) of a floodplain underlain by discontinuous permafrost in the boreal zone.

Floodplains act as temporary storage areas and exchange sites for sediment and nutrients moving from the terrestrial landscape to the ocean (Dunne et al., 1998; Junk et al., 1989). The Arctic Ocean receives large amounts of dissolved organic carbon (DOC) relative to other oceans (Dittmar & Kattner, 2003; Holmes et al., 2012; Stein & Macdonald, 2004), with the flux of DOC from Arctic watersheds more than double the flux from temperate watersheds (Raymond et al., 2007). Particulate organic carbon (POC) exports from high latitude rivers, although smaller than DOC exports (McClelland et al., 2016), may be buried in offshore sediments without being decomposed, resulting in a carbon sink in the ocean (Hilton et al., 2015). In addition, river POC can be thousands of years old, indicating that POC may be stored for long periods of time before reaching the Arctic Ocean and sourced from frozen river banks (Guo et al., 2007; Hilton et al., 2015). The terrestrial-aquatic carbon cycle in the arctic and boreal zones will likely be modified due to anthropogenic warming and associated permafrost thaw, as the active layer deepens and flow paths through the landscape change (Frey & McClelland, 2009; Striegl et al., 2005; Walvoord & Kurylyk, 2016; Walvoord & Striegl, 2007). For example, fluxes of DOC from the Yukon River decreased from the late 1970s to the early 2000s (Striegl et al., 2005). This reduction in exports may be due to increased proportion of baseflow relative to surface flow due to permafrost thaw (Walvoord et al., 2012). There is also evidence of active-layer thicknesses increasing within the Yukon Basin (O'Donnell et al., 2014). The change in flow paths could result in greater interaction between DOC and mineral soil and the release of carbon into the atmosphere due to microbial processing (Striegl et al., 2005). Decrease in DOC export could also result from an increase in adsorption of OC onto mineral grains as permafrost thaws and flow paths change (Frey & McClelland, 2009; Kawahigashi et al., 2006). Because floodplains mediate fluxes of water, DOC, and POC, understanding the geomorphic controls on floodplain soil OC and establishing baseline information on floodplain soil OC is imperative for understanding and detecting future changes to river exports.

### 1.1. Potential Geomorphic Controls on Floodplain Soil OC Across Spatial Scales

Existing studies of floodplain OC have been restricted to relatively small rivers or to small spatial extents on larger rivers (e.g., Cierjacks et al., 2011; Sutfin & Wohl, 2017). Investigating geomorphic controls over large regions on rivers with differing drainage areas facilitates the interpretation of geomorphic controls on floodplain soil OC at spatial scales ranging from a river basin (lengths of  $10^2$  to  $10^6$  km), to a river segment (lengths of  $10^1$  to  $10^2$  km), to a river reach (lengths of  $10^0$  km; Figure 1).

Systematic analyses of relationships between geomorphic controls and soil OC concentrations at differing spatial scales allow us to evaluate whether OC concentrations can be adequately estimated using a top-down approach based on basin-scale characteristics or whether it is more accurate to use a bottom-up approach in which OC concentrations characteristic of local patches are aggregated to estimate basin-scale



**Figure 1.** The varying spatial scales of influences on floodplain soil OC, from the river basin to the reach, with examples of factors that control soil OC at each scale.

OC. In addition, analyses across spatial scales inform our understanding of the geomorphic controls on floodplain OC concentration. Determining the spatial scale at which there is greater variation in OC concentrations, for example, could indicate which geomorphic processes exert the strongest influence on OC concentrations. Consequently, we address two primary questions in this research: How do differences in the spatial scale of analysis influence our quantification of OC concentration across large floodplains? How do differences in the spatial scale of analysis inform our understanding of the controls on OC concentrations in the mineral soil of floodplains?

Figure 1 highlights some controls on floodplain soil OC from a geomorphic perspective, although we recognize that floodplain soil OC is controlled by many complicated and diverse factors. Some controls cut across spatial scales. For example, floodplain soil OC generally increases with finer grain sizes (Appling et al., 2014; Hoffmann et al., 2009; Pinay et al., 1992), and sediment characteristics can vary between basins and segments, and within reaches. Similarly, soil OC can vary with surface vegetation (Appling et al., 2014; Jobbágy & Jackson, 2000; Van Cleve et al., 1993). River basins can have characteristic vegetation assemblages (e.g., boreal and tropical), but vegetation can also vary between segments and within a reach. Disturbances such as fire, occurring at the scale of a river segment or reach, can also impact floodplain soil OC by burning organic horizons and deepening the active layer via thawing permafrost (O'Donnell et al., 2011), which makes previously frozen carbon available for microbial mineralization.

At the river basin scale, climate can influence OC via temperature, precipitation, and resulting vegetation. For example, decomposition is generally slowed in cold, wet conditions, resulting in higher OC content (Chapin et al., 2012; Davidson & Janssens, 2006; Jobbágy & Jackson, 2000; Johnson et al., 2011). The geology of a river basin can influence OC in floodplains through controls on lithology and tectonics, and thus the

weathering, delivery, and grain size distribution of sediment entering river systems (Sutfin et al., 2016). In addition to influencing inputs to the floodplain surface, the vegetation of a river basin influences inputs of OC to the river network and OC exported from the basin. For example, the characteristics and quantity of exported DOC from Arctic river basins can vary with the relative proportions of wetlands or peatlands versus forests within the basin (Amon et al., 2012; Frey & Smith, 2005). Thus, vegetation and resulting riverine DOC concentrations and fluxes may also influence the character of floodplain soil OC due to floodplains acting as mediators of nutrient fluxes and sites of nutrient exchange. Subsurface flow paths within the drainage basin influence the travel time of water through the subsurface and the type of sediment through which water flows; these characteristics can influence OC inputs to the river network as well (Kawahigashi et al., 2006; O'Donnell et al., 2012; Walvoord & Striegl, 2007). Permafrost extent within a river basin can control floodplain soil OC through influencing drainage patterns in the landscape (Walvoord & Kurylyk, 2016), DOC loads in rivers (Frey & Smith, 2005; Kawahigashi et al., 2004), and the degree and extent of microbial respiration of unfrozen carbon within the soil (Schuur et al., 2008). In addition, permafrost influences the degree and rate of bank erosion (Costard et al., 2014), which can release OC from floodplains into the river network.

At the river segment scale, channel planform type and migration rate may influence OC within floodplains. Different channel planforms imply different magnitudes of lateral movement, with braided channels more laterally active compared to wandering or high-energy meandering channels, which are more laterally active compared to stable meandering or straight channels (Nanson & Knighton, 1996). Increased lateral activity and migration rate can result in more frequent floodplain disturbance and resetting of floodplain vegetation primary succession (Viereck et al., 1993). Erosion and redeposition of bare sediments can also restart the accumulation of OC in soil from vegetation inputs (Van Cleve et al., 1993; Zehetner et al., 2009). Channel planform can also imply differences in grain size. Braided rivers carry coarser loads in general compared to meandering channels (Schumm, 1981) and grain size influences OC content (Pinay et al., 1992).

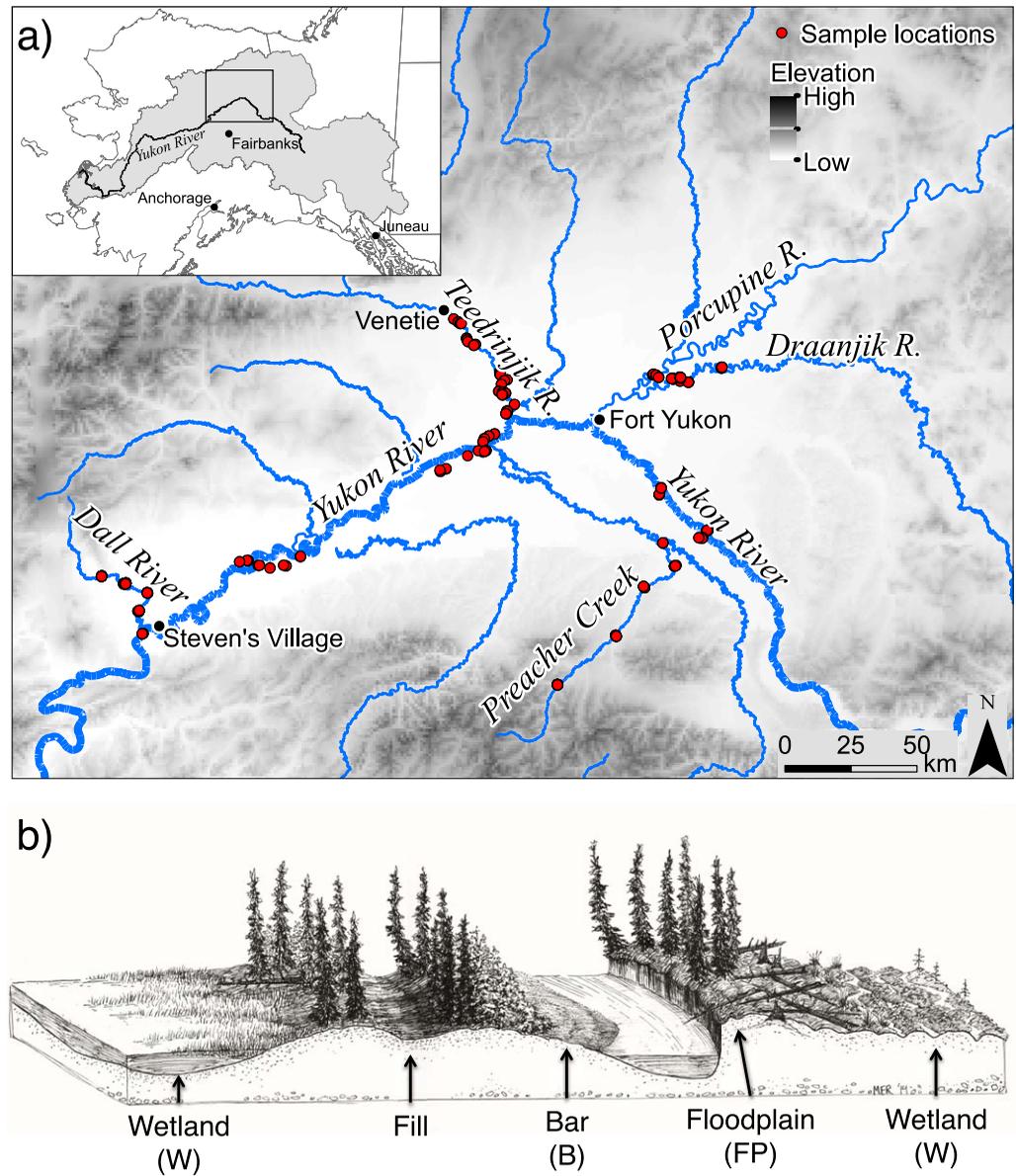
At the river reach scale, geomorphic units could influence OC via differences in grain size and soil moisture. Previous studies have indicated that depositional environments have higher carbon content compared to erosional environments (Pinay et al., 1992), and OC can increase with increasing distance from the channel (Cierjacks et al., 2011). These trends have been linked to variations in grain size, with finer depositional and overbank deposits containing more OC (Cierjacks et al., 2011; Pinay et al., 1992). Soil moisture can vary among geomorphic units within a floodplain, as different geomorphic units can be located at different elevations relative to the water table (Hughes, 1997; Taylor et al., 1999). Grain size differences among geomorphic units may also result in differences in soil moisture, as finer grain sizes are able to retain more moisture compared to coarser grain sizes (Dingman, 2008). Geomorphic units also reflect the time since surface formation and associated time for OC to accumulate, e.g., with higher floodplain surfaces formed earlier than bar surfaces. Vegetation at the reach scale reflects geomorphology, with floodplain primary succession occurring from bare alluvial surfaces created via river migration and vegetation reflecting processes of sedimentation, flooding, and fluvial disturbance (Viereck et al., 1993; Whited et al., 2007).

## 1.2. Research Objectives

We assess the geomorphic controls on OC concentration within the floodplains of five rivers over a cumulative distance of ~750 river km in the YF region, located in the central Yukon River Basin in interior Alaska. The large spatial extent allows for investigating controls at the basin, segment, and reach scales using statistical analyses of data from sediment samples within the YF floodplains. The basic research objectives are to determine whether (1) significant differences exist in floodplain soil OC concentration among river basins located in the same climate and with similar permafrost characteristics, (2) river planform influences OC concentration, with more energetic planform types (e.g., braided or wandering) containing lower OC concentrations, (3) significant differences in OC concentration are present among geomorphic units (e.g., bars, fills, higher-standing floodplain surfaces, or wetlands) at the reach scale, and (4) the magnitude of variation in OC concentration differs among scales. If differences exist, the final objective is to explain these differences and examine the implications.

## 2. Study Area

The YF region is a Cenozoic sedimentary basin with surrounding uplands, located in the boreal zone in interior Alaska (Figure 2a; Nowacki et al., 2003; Williams, 1962). The climate is continental subarctic, with winter



**Figure 2.** (a) Study area showing the floodplain sampling locations along five study rivers within the Yukon Flats. Clustering of samples facilitates examination of segment-scale controls. (b) Geomorphic units sampled in the floodplains of the Yukon Flats region. Illustration by Mariah Richards.

temperatures ranging from  $-34$  to  $-24^{\circ}\text{C}$ , summer temperatures ranging from approximately  $0$  to  $22^{\circ}\text{C}$ , and a mean annual precipitation of approximately  $170$  mm (Gallant et al., 1995). Lake sediments (silt and clay) almost  $90$  m thick underlie alluvial deposits in the basin (Williams, 1962). The YF did not experience Pleistocene glaciation (Gallant et al., 1995; Pewe, 1975). The region is located in the discontinuous permafrost zone (50–90% coverage; Jorgenson et al., 2008; Romanovsky et al., 2013), and the region contains many thaw and oxbow lakes. Permafrost extends to approximately  $90$  m below the surface near Fort Yukon, located near the center of the study region (Clark et al., 2009).

Soils within the region are classified as Entisols (young soils lacking well-developed horizons and formed in alluvium or outwash), Inceptisols (young soils with slightly better horizon development), and Gelisols (soils with permafrost within  $2$  m of the surface; Brabets et al., 2000). Vegetation within the floodplains includes shrub vegetation (willows [*Salix* spp.] and alders [*Alnus* spp.]), deciduous trees (balsam poplar [*Populus balsamifera*], aspen [*Populus tremuloides*], and birch [*Betula papyrifera*]), white spruce forest (*Picea glauca*),

mixed forests (spruce and deciduous), black spruce forest (*Picea mariana*), and wetlands (sedges and shrubs). Frequent fires influence vegetation dynamics, and fire return intervals range from 37 to 166 years, with a mean of about 90 years (Drury & Grissom, 2008). Floods in the YF can be caused by ice jams or from snowmelt (the spring freshet). Flood frequency is not well known in the region due to limited accessibility and the remote nature of the basin, but four ice jam floods have occurred between 1949 and 1994 in Fort Yukon (Nakanishi & Dorava, 1994) prior to the construction of a levee, and local observations and river stage data in Fort Yukon indicates there may have been as many as 15 overbank flooding events in the past 35 years along the river near Fort Yukon (NOAA, 2017). River flow declines through the summer to baseflow, which occurs throughout the winter underneath frozen river surfaces (Walvoord et al., 2012).

We conducted fieldwork along five rivers with drainage areas ranging from 2,200 to 508,000 km<sup>2</sup>: the Dall River (3,700 km<sup>2</sup>; sampled length ~ 80 river km), Preacher Creek (4,000 km<sup>2</sup>; sampled length ~ 160 river km), the Draanjik (Black) River (16,500 km<sup>2</sup>; sampled length ~ 75 river km), the Teedrinjik (Chandalar) River (29,000 km<sup>2</sup>; sampled length ~ 80 river km), and the Yukon River (508,000 km<sup>2</sup> at Steven's Village, the downstream end of the study region, sampled river length ~ 350 river km; Figure 2a). As the Yukon River enters the YF region, the planform of the river is braided, becoming a wandering anabranching river beginning after Fort Yukon (Clement, 1999). We use the term wandering to denote a relatively laterally active anabranching planform (Desloges & Church, 1989; Nanson & Knighton, 1996). Clement (1999) defines a transitional segment in between braided and wandering segments on the Yukon, occurring from Fort Yukon downstream for approximately 90 km. However, we lump this transitional reach in with the wandering segment, as our samples for this segment occur well downstream of Fort Yukon and the transition to fully wandering is gradual. The Dall, which empties into the Yukon River, and the Draanjik, which flows into the Porcupine River, are single-thread meandering rivers with finer bed sediments and steep, high banks. Preacher Creek is a wandering river through most of its course, becoming meandering just before joining Birch Creek, a major tributary of the Yukon. The Teedrinjik River is a wandering river near Venetie, which was the upstream extent of sampled reaches (Figure 2a). The Teedrinjik displays anabranching meandering and single-thread meandering planforms before flowing into the Yukon River.

### 3. Materials and Methods

#### 3.1. Fieldwork

In Summer 2014, we sampled along the Dall River and Preacher Creek. We stopped at intervals of tens of kilometers to sample sediment within the floodplain along a transect perpendicular to the channel. At intervals of 20–30 m along each transect, depending on the channel width at the transect location, we sampled floodplain sediment at intervals that captured the variation in geomorphic and vegetation type. Each transect was associated with one river reach. We sampled at five reaches along the Dall River (total sampled locations = 62) and four reaches along Preacher Creek (total sampled locations = 65). We sampled along the Draanjik, Teedrinjik, and Yukon Rivers in Summer 2015. The rivers sampled in Summer 2015 are larger and the floodplains more complex, thus we modified our sampling procedure from a sampling transect to a sampling block (designated as a river reach). Within a reach of river, samples were located within patches representing the vegetation and geomorphic types present along the river reach. We sampled four reaches along the Draanjik River (sampled locations = 43), five reaches along the Teedrinjik River (sampled locations = 63), and four reaches along the Yukon River (sampled locations = 74). Two samples were taken within each patch: one near the river bank and one sample 100 m into the floodplain. Samples were coded from both fieldwork years with the following identifications: river, reach, patch or point along a transect, sample ID number, depth ID number.

We also noted the geomorphic unit and surface vegetation of the sampled location. Geomorphic units include bars, fills (filled side channels and swales), higher floodplain surfaces that are not similar to any other geomorphic type, and wetlands that generally have permafrost or standing water (Figure 2b). All geomorphic units are located within the floodplain, and thus the wetland geomorphic unit denotes floodplain wetlands. The number of sampling locations in each geomorphic unit in each river basin is shown in supporting information Table S1. Vegetation types include deciduous forest/shrub vegetation, white spruce forest, mixed deciduous and spruce forest, black spruce forest (usually containing permafrost), and wetland vegetation (grasses and shrubs). We noted whether there was evidence of disturbance, such as charred

downed logs indicating recent fire, for each sampled location. In addition to capturing variability in geomorphic unit and vegetation type within the floodplains, we located reaches within different planform types if planform changed downstream along the river.

At each floodplain sample location, we separated the organic layer from the mineral sediment. We define the organic layer as material comprised of moss, litter, peat, and organic soil horizons above the boundary with mineral soil and excluding buried organic soil horizons (Pastick et al., 2014). At the beginning of the mineral sediment layer, we sampled with an auger (Summer 2014) or a sediment corer (Summer 2015) at increments of approximately 18 cm. The total sample depth at each location ended once we reached frozen soil (50.8% of sampled locations), gravels/cobbles/coarse sand (24.8% of locations), or 1 m in depth (18.2% of locations), or if we were unable to retrieve more due to wet conditions or unknown reasons (6.2% of sampled locations). The analyses presented in this paper focus only on the mineral soil samples, as this soil carbon stock is more stable over longer time periods (O'Donnell et al., 2011). In addition, the subsurface mineral soil is less subject to changes due to fire (O'Donnell et al., 2011). Organic layer depths varied by geomorphic unit, averaging 2.3 cm in bars, 3.4 cm in fills, 6.5 cm in floodplain surfaces, and 17.2 cm in wetlands.

### 3.2. Laboratory Analyses

OC concentration was determined by the Soil, Water, and Plant testing lab at Colorado State University. The samples were sieved to separate the <2 mm fraction from the >2 mm fraction, and the total carbon concentration (%) in each <2 mm sample was found with a LECO TruSpec CN furnace (Nelson & Sommers, 1982). Each sample was also analyzed for inorganic carbon concentration through treating the sample with 0.4 HCl and measuring the CO<sub>2</sub> loss gravimetrically (Soil Survey Laboratory, 1996). Subtracting the inorganic carbon from the total carbon resulted in the OC concentration (%). A very small number of near-surface samples thought to be mineral soil in the field with very high OC concentrations were reclassified as organic soil materials according to NRCS guidelines (Soil Survey Staff, 1999) and left out of these analyses.

Soil moisture was found by drying each sample for 24 h at 105°C and is expressed as the percent of mass lost divided by the initial, wet sample mass. We completed texture analyses on all mineral samples following USDA Natural Resources Conservation Service guidelines and the texture class was converted to an average percent fines (silt + clay) for that class using a texture triangle (Thein, 1979).

### 3.3. Statistical Analyses

We modeled OC concentration using a general linear mixed effects model in R to determine correlations between predictor variables and OC (R Core Team, 2014) with the lme4, lmerTest, and lsmeans packages (Bates et al., 2015; Kuznetsova et al., 2016; Lenth, 2015). The model included river, geomorphic unit, the interaction between river and geomorphic unit, the middle depth of each sample increment (cm), and the distance from the river channel (m) as fixed effects. We modeled the percent fines (silt + clay) and percent soil moisture as response variables using the same predictor variables above in order to determine whether there were significant differences in grain size and soil moisture among rivers and among geomorphic units. For each river on which multiple planforms were sampled (the Yukon and the Teedrinjik), we modeled OC concentration with planform, geomorphic unit, the middle depth of each sample increment (cm), and the distance from the river as fixed effects in order to determine whether there were significant differences in OC among planform types. The reach identification, patch or point along a transect, and the sample location (core location) were included as random effects in all models. The residuals of all models were checked for homogeneity of variances and response variables (%OC, %fines, and % soil moisture) were log transformed if necessary. To test for significance of fixed effects ( $\alpha = 0.05$ ), we used type III tests. To determine whether significant differences existed for pairwise comparisons within river and geomorphic unit, the Tukey method to adjust for multiple comparisons was used. The associations between OC concentration and % fines and OC concentration and soil moisture were determined through visual inspection of plots.

In order to assess whether there are peaks in OC at depth within the floodplain, we assessed the percent change for each sample relative to the overlying sample. We used the consistent criteria that a sample should be at least 50% greater than the overlying sample and at least 0.5% OC concentration in order to be identified as a peak of OC at depth (Appling et al., 2014). This assessment informs whether there are buried

OC layers within the soil caused by buried forest floors or the delivery of organics into the floodplain via flooding.

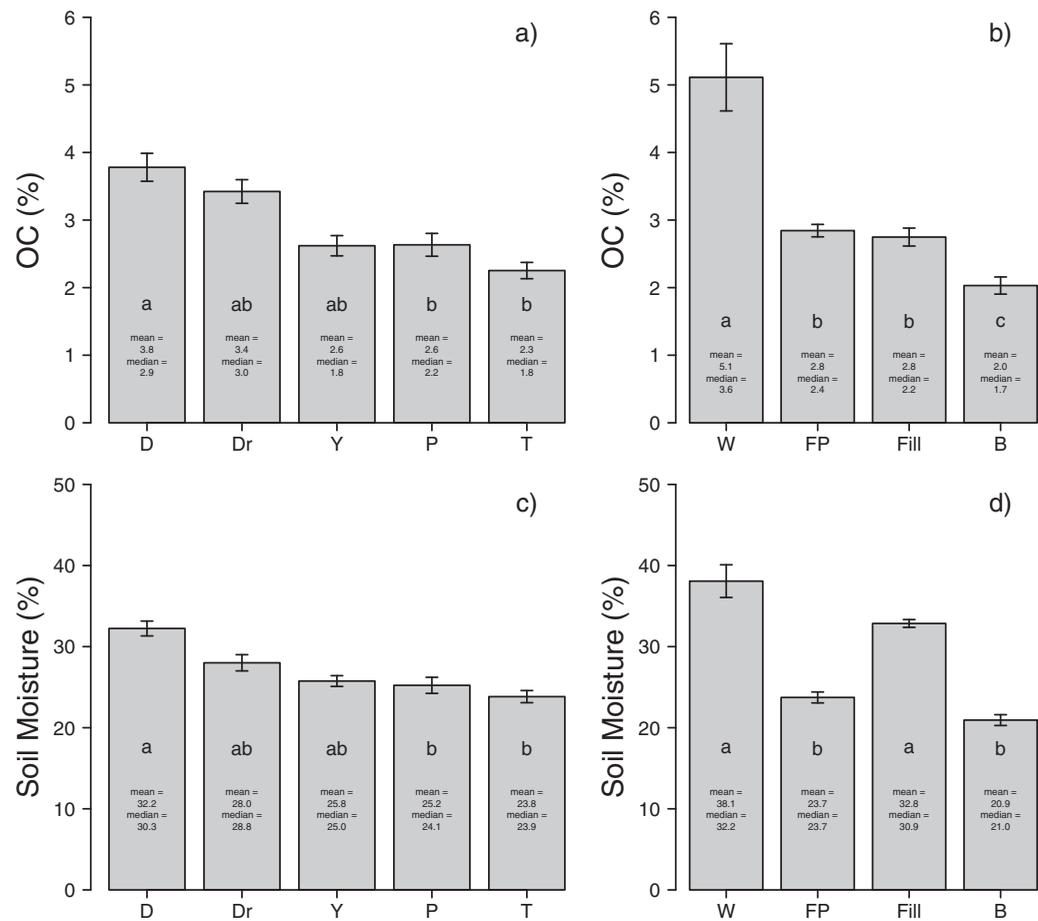
Because the vegetation types identified in the field are highly associated with geomorphic types, vegetation as a predictor variable was left out of the models. For example, deciduous/shrub vegetation was the only vegetation type on bars, black spruce forests were located only in wetlands, and white spruce forests were located only on higher-standing floodplain surfaces (supporting information Table S2). Vegetation on the surface is susceptible to fire disturbance, and thus the vegetation at the time of sampling may not accurately reflect the most dominant vegetation over the time scale of carbon accumulation in the mineral subsurface due to the influence of fire. Studies have demonstrated the vegetation within floodplains reflects river dynamics and flooding patterns (e.g., Whited et al., 2007), with primary succession starting from unvegetated bars to forested floodplain surfaces (Chapin et al., 2006; Viereck et al., 1993). Also, previous studies have suggested that vegetation may influence near-surface carbon storage, but not necessarily deeper carbon storage (Appling et al. 2014). As our focus is on deeper mineral carbon stocks, we focus on geomorphic units. In addition, we did not separate samples into those with recent evidence of fire and those without, in part because fire has more influence on organic layer carbon compared to deeper mineral sediment (O'Donnell et al., 2011), and our analyses are restricted to mineral sediment. Because fire is a frequent natural disturbance in the YF, our samples included locations with recent and past fires that we were not able to age or identify, and thus our analyses assume that fire can occur throughout the landscape at regular intervals.

#### 4. Results

The mean OC concentration and standard error of the mean of the entire data set is  $2.8\% \pm 0.1$ , with a median of 2.2% (basic summary statistics for OC%, % fines, and % soil moisture included in supporting information Table S3). Average depths reached for sampled locations by river and by geomorphic unit are included in supporting information Table S4. Two of the study rivers have different planform types along the sampled areas, the Yukon and the Teedrinjik Rivers, and OC concentration was modeled for each river using planform as a predictor variable. Planform does not significantly influence OC concentration on the Teedrinjik River ( $p = 0.29$ ) (supporting information Figure S1 and supporting information Tables S5 provides model summary). Along the Yukon River, the influence of planform depends on the geomorphic unit (supporting information Figure S1 and supporting information Table S6 provides model summary). Significant differences in planform types exist for two of the geomorphic units: bars have higher OC concentrations in the wandering segment ( $p = 0.025$ ), and wetlands have higher OC concentrations in the braided segment ( $p = 0.049$ ), but there are no differences between the wandering and braided segments in fill and floodplain surfaces ( $p = 0.141$  and  $p = 0.205$ , respectively).

Using the entire data set, river, geomorphic unit, and middle sample depth influence OC concentration (supporting information Table S7 summarizes model results for models of OC concentration, % fines, and % soil moisture). Pairwise comparisons among rivers indicate that the Dall River has significantly higher OC concentration than the Teedrinjik River and Preacher Creek (Figure 3). A comparison between the Draanjik River and the Teedrinjik River results in a  $p$  value of 0.072, which does not meet the significance level of 0.05 but indicates that differences may exist between the two rivers. The Yukon River OC concentration is not statistically different than any other river. Pairwise comparisons among geomorphic units show that wetlands have the highest OC concentration, followed by floodplain surfaces and fills, with bars having the lowest OC concentration (Figure 3). There is a greater difference in the highest and lowest OC concentrations among geomorphic units (wetlands = 5.1% versus bars = 2.0%) than among rivers (Dall River = 3.8% versus Teedrinjik River = 2.3%). The distance from the channel for the sample was not a significant influence on OC concentration. Summary statistics of OC concentrations, % fines, and % soil moisture by river and by geomorphic unit are included in supporting information Tables S8 and S9.

As sampling depth increases, OC concentration decreases ( $p < 0.0001$ ) (supporting information Table S7 and supporting information Figure S2), and the magnitude of the effect is strong relative to the variation in OC % across all samples ( $\beta = -0.185$ ; supporting information Table S7; note that OC model is log transformed). Analyses of potential peaks of OC in the subsurface indicate that there are very few sampling increments at depth that show large increases of OC relative to overlying samples. The percentage of samples in



**Figure 3.** (a) OC concentration (%) and (c) soil moisture (%) for rivers across all geomorphic units. D, Dall; Dr, Draanjik; Y, Yukon; P, Preacher; T, Teedrinjik. (b) OC concentration and (d) soil moisture for geomorphic units across all rivers. W, wetland; FP, floodplain; B, bar. Letters in bars indicate significant differences at  $\alpha = 0.05$ . Bars containing the same letter have no significant differences, while bars that do not share a letter indicate significant differences. Bars show the mean  $\pm$  the standard error. Values of means and medians are shown within bars.

which OC concentration is greater than 50% of the concentration in the overlying sample is 4.2% for Preacher Creek, 4.3% for the Dall River, 5.5% for the Draanjik River, 8.0% for the Yukon River, and 10.7% for the Teedrinjik River. These data support the model results demonstrating a decrease in OC concentration with increasing depth.

In order to determine whether different rivers or different geomorphic units have significantly different grain sizes, we modeled the % fines (silt + clay) using river, geomorphic unit, the interaction between river and geomorphic unit, the middle depth of each sample (cm), and the distance from the channel (m). As the middle depth of each sample increases, the % fines decreases ( $p < 0.0001$ ), although the effect is relatively small relative to the magnitude of changes in % fines ( $\beta = -0.185$ ; supporting information Table S7), indicating that a unit increase in depth has a relatively small unit decrease in % fines. Due to the significant interaction term of river  $\times$  geomorphic unit, the differences in % fines among geomorphic units depend on the river sampled, and the differences found in % fines among rivers depend on the geomorphic unit. Table 1 shows the significant differences among geomorphic units given each river and the significant differences among rivers given each geomorphic unit. Although the interaction term creates difficulties in interpretation, in general, Preacher Creek has coarser sediment than the other sampled rivers, except in the wetland geomorphic unit. In addition, except for the Draanjik River, bars have coarser sediment compared to other geomorphic units.

River, geomorphic unit, and the middle depth of the sample are significant predictors of % soil moisture (supporting information Table S7). As the sample depth increases, soil moisture decreases ( $p < 0.0001$ ). The

Dall has significantly higher soil moisture in samples compared to Preacher Creek and the Teedrinjik River, and wetland and fill geomorphic units are significantly higher in soil moisture compared to floodplain surfaces and bars (Figure 3). Summary statistics for % fines and soil moisture are included in tables S3, S8, and S9. As soil moisture and % fines increase, OC concentrations of samples generally increase (supporting information Figure S3).

### 5. Discussion

Returning to the research objectives, (1) there are differences in floodplain soil OC concentration among river basins in the YF, (2) river planform exerts some influence on OC concentration along the Yukon River in some geomorphic units, but not along the Teedrinjik River, (3) there are differences in OC concentration among geomorphic units (e.g., bars, fills, higher floodplain surfaces, or wetlands) at the reach scale, and (4) the magnitude of difference in mean OC concentration is greatest among geomorphic units as opposed to among study rivers (Figures 3), indicating that the magnitude of variation in OC concentration differs among scales. In addition, our analyses indicate that OC concentration decreases with depth but does not vary with distance from the channel (supporting information Table S7).

#### 5.1. OC in Floodplain Soil May Be Mostly Due To Inputs From Surface Vegetation, With Different Starting Points Depending on River Basin

The reduction of OC concentrations with depth suggests that much of the OC inputs to floodplain soil, across all geomorphic units, come from surface vegetation (i.e., autochthonous inputs) with little evidence for substantial buried organic horizons. Peaks of OC at depth relative to overlying samples occur only in 4–10% of all samples across study rivers. These few peaks may be buried forest floors or carbon-rich lenses from overbank flooding (Appling et al., 2014; Blazejewski et al., 2009). However, other studies have found stronger evidence of buried OC layers within floodplain soils (e.g., Blazejewski et al., 2009). OC concentrations in bar environments on the Dall and Draanjik Rivers (3.1% and 2.9%) are higher than OC concentrations in bars on Preacher Creek and the Teedrinjik River (1.7% and 1.4%), indicating that freshly deposited sediment on bars varies with river basin. Thus, although much of subsequent OC accumulation may come from surface vegetation, the starting concentration may depend on the river basin.

The slight upward fining in the floodplain (supporting information Table S7) may also influence the decrease of OC concentration with depth, as finer grain sizes are associated with more OC because finer grains better stabilize OC (Jobbágy & Jackson, 2000; Pinay et al., 1992). The upward fining indicates some signature of overbank flooding delivering fines to the floodplain over time, but the effect of increasing depth on % fines is relatively small. Because our measurement of % fines is based on texture classes, detections of upward fining in the floodplain may be limited, but we did not see strong upward fining in the field or with statistical modeling. Due to our samples being restricted to the active layer, we did not frequently reach coarse gravel layers that could be interpreted as coarse laterally accreted or channel fill deposits deep within the floodplains. Bars, which are lateral accretions, are sometimes coarser than other geomorphic units, although this depends on the river (Table 1). The relatively weak upward fining in floodplain soil

**Table 1**  
Summary of Significant Pairwise Comparisons ( $p < 0.05$ ) for Model of % Fines for River Given Each Geomorphic Unit and for Geomorphic Unit Given Each River

Geomorphic unit	Significant differences among rivers
Bar	Preacher < Yukon = Teedrinjik = Dall = Draanjik
Floodplain	Preacher = Teedrinjik < Draanjik
Fill	Preacher < Teedrinjik = Draanjik
Wetland	None
River	Significant differences among geomorphic units
Dall	Bar = floodplain < wetland
Draanjik	None
Yukon	Bar < fill
Preacher	Bar < floodplain = fill < wetland
Teedrinjik	Bar = floodplain < fill

supports the idea that OC accumulation results from vegetation inputs (indicated by a relatively strong decrease of OC with depth) and is not strongly controlled by upward fining.

The YF may be similar to the Tanana River floodplain, located in the boreal zone in interior Alaska, where soil carbon stocks increase with successional age of the floodplain surface and vegetation (Van Cleve et al., 1993). This suggests that river migration and erosion, as opposed to overbank flooding, are the dominant geomorphic controls on sedimentation, surface creation, and associated OC increases in the subsurface, at least within the active-layer sediment. Distance from the channel does not significantly influence OC concentration, which may reflect the fact that these floodplains are complex, with avulsions, secondary channels, and bars being accreted to the floodplain (Clement, 1999), resulting in floodplains with a patchwork of geomorphic units.

### 5.2. Planform Variations Along Rivers Is Not Strongly Correlated With OC Concentrations

The mixed results for the influence of planform on OC concentration (no difference among planform types on the Teedrinjik, and some differences on the Yukon depending on geomorphic unit) could indicate that planform categories are actually on a continuum in terms of fluvial process and form. The lower OC concentration on bars in the braided segment compared to the wandering segment on the Yukon could be partially explained by differences in grain size, as bed sediment fines slightly from the entrance to the YF to the end of the sampled extent (Clement, 1999). In addition, Clement (1999) found that migration rates decreased from the braided segment to the wandering segment within the Flats, and more frequent erosion of bars in the braided segment could result in less time for OC to accumulate from vegetation. The higher OC concentration in wetlands in the braided segment could be a result of the river in the braided segment migrating in a narrower band, with wetland geomorphic units occurring on slightly higher elevational surfaces that are more stable compared to those surfaces in the wandering segment, although this is speculative.

### 5.3. Basin-Scale Differences in OC Among River Basins

Because rivers are integrators of their upstream contributing area, the differences among study rivers could result from many factors. The Dall River has a higher OC concentration compared to Preacher Creek and the Teedrinjik River, and although the difference is not significant at a significance level of 0.05, the Draanjik River may have higher OC concentration compared to the Teedrinjik River ( $p = 0.072$ ; Figure 3). Grain size and soil moisture may play a role in these differences. Our results demonstrate that Preacher Creek generally has coarser sediment compared to the other study rivers, although the significant interaction between river and geomorphic unit makes these results somewhat difficult to generalize (Table 1). Difference in grain size has been an influencing factor for other studies of floodplain OC, with coarser sediment containing lower OC concentrations (Appling et al., 2014; Pinay et al., 1992; Sutfin & Wohl, 2017). The Dall River samples also have higher soil moisture than Preacher Creek and the Teedrinjik River, which could also influence OC concentration (Figure 3). Wetter soils tend to have higher OC concentrations until soils are fully saturated (Chapin et al., 2012; Jobbágy & Jackson, 2000). The associations between grain size and OC concentration and soil moisture and OC concentration are also shown in our sample data (supporting information Figure S3). In addition, soil moisture and grain size are related, as finer grain sizes are better able to retain moisture (Dingman, 2008).

Although planform does not influence OC concentration on the Teedrinjik River and partly influences OC concentrations on the Yukon River, planform may influence the differences among rivers. The Dall and Draanjik Rivers are single-thread meandering, whereas Preacher Creek and the Teedrinjik River are wandering rivers for at least some portion of the sampled extent. If much of the OC inputs into the floodplain come from autochthonous vegetation growing on the floodplain surface, the greater lateral mobility of Preacher Creek and the Teedrinjik River compared to the meandering Dall and Draanjik Rivers could result in less time for OC accumulation before river migration erodes the floodplain (Lininger et al., 2016).

Another difference among river basins that could influence floodplain OC concentrations is the DOC concentration of the study rivers. River samples from 2002 indicate that the Draanjik and Dall Rivers have high DOC concentrations (12.0–15.0 and 12.2 mg C L<sup>-1</sup>, respectively; Dornblaser & Halm, 2006). In contrast, the DOC concentrations on the Teedrinjik River have been measured at 1.6–2.5 mg C L<sup>-1</sup> (Dornblaser & Halm, 2006), and concentrations in Preacher Creek have been reported as 8.9 mg C L<sup>-1</sup> (O'Donnell et al., 2012).

The DOC of the Yukon River throughout the study region ranges from 5.6 to 6.9 (Dornblaser & Halm, 2006). High concentrations of DOC could result in adsorption of DOC onto mineral grains in transport (e.g., McKnight et al., 2002) that are then deposited on the floodplain in bars or via overbank flow. Because floodplain soil OC concentrations may be influenced by DOC concentrations within the river, the baseline concentration of OC within floodplain sediments may depend on differences in freshly deposited sediment, while the subsequent accumulation of more carbon in the floodplain could be the result of autochthonous inputs. The differences in bar OC among rivers support this inference.

The lack of significant difference between the Yukon River and the other study rivers could reflect its large drainage area. The Yukon River integrates sediment inputs and water fluxes from a large number of tributaries with varying characteristics, including the four tributary rivers in this study. Thus, the lack of statistically significant differences indicates that OC concentrations on the Yukon are influenced by the tributary contributions and by upstream inputs.

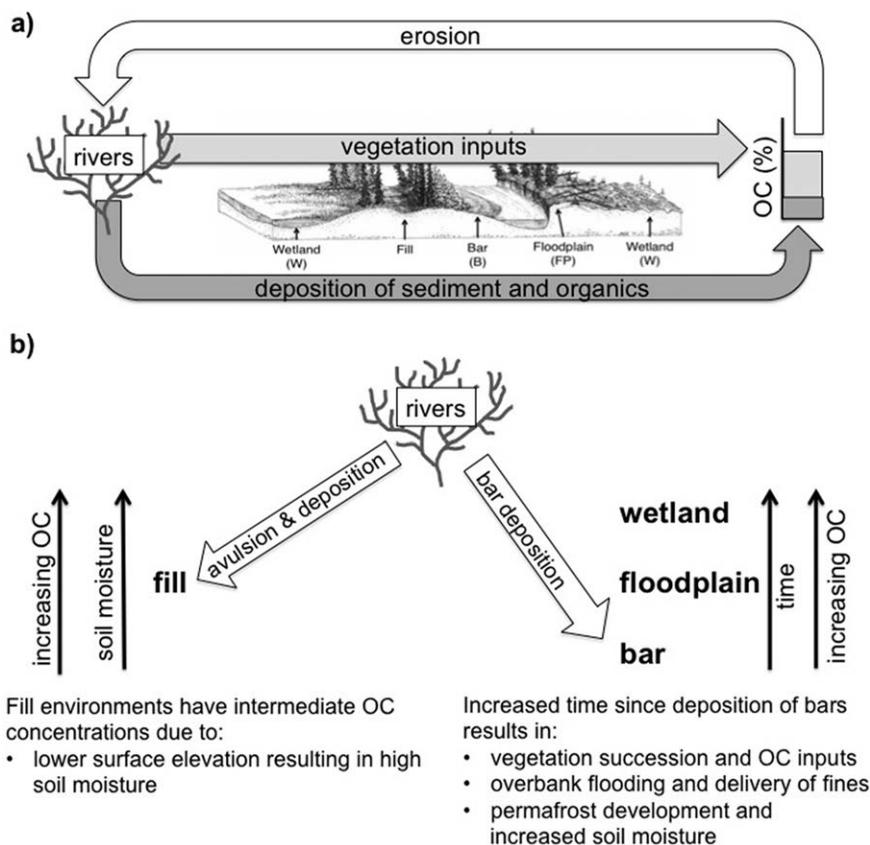
#### 5.4. Reach-Scale Differences in OC Among Geomorphic Units

At the reach scale, wetlands have higher OC concentrations than bar environments (Figure 3). Bars have coarser sediment and lower soil moisture compared to wetlands on most rivers (Table 1 and Figure 3), which likely contributes to this difference. In addition, wetlands in boreal floodplains of interior Alaska tend to be older surfaces, either with black spruce and a higher permafrost table (woody wetlands) or with herbaceous vegetation in thaw ponds or bogs. These older surfaces likely have had more time for OC to accumulate in the subsurface (Van Cleve et al., 1993). In addition, wetland environments in high latitude regions have reduced OC respiration rates due to wet and cold conditions, which inhibit mineralization and release of OC (Davidson & Janssens, 2006; Douglas et al., 2014). Floodplain primary succession in interior Alaska supports the assertion that wetlands are older surfaces. Surfaces with bar vegetation (shrubs and deciduous vegetation) develop after approximately 1–100 years depending on the type of vegetation, and woody wetlands with black spruce and bog vegetation may not develop for over 500 years after a surface is first created by river deposition (Chapin et al., 2006; Viereck et al., 1993).

The lack of difference in OC concentrations between fills and floodplain surfaces may also be informed by the time since deposition and creation. Fills have higher soil moisture compared to floodplain surfaces and bars (Figure 3), potentially reflecting a lower topographic position on the landscape. This suggests that these environments would have higher OC concentrations due to the association between soil moisture and OC. But, floodplain surfaces, which contain white spruce stands, are likely older than fills, which have a mixture of deciduous, shrub, and wetland herbaceous vegetation (supporting information Table S2). White spruce stands commonly do not develop on floodplains for 200–500 years (Chapin et al., 2006; Viereck et al., 1993), indicating that they may be older than filled secondary channels and have been able to accumulate higher concentrations of OC. In the Rhine River basin, channel fill environments have higher OC concentrations when compared to other types of overbank deposits, which contrasts with the results of this study (Hoffmann et al., 2009).

#### 5.5. Conceptual Model of Geomorphic Influences on Floodplain Soil OC

Figure 4 summarizes the main processes occurring in the Yukon Flats that contribute to OC concentrations in floodplain soil. Figure 4a demonstrates the two main pathways for OC to accumulate within the floodplain. Rivers deposit sediment and organics directly onto the floodplain, either via lateral accretion and bar deposition or via vertical accretion of finer sediments with overbank flooding (dark grey arrow). This direct river deposition contributes a certain amount of OC within the soil (dark grey OC bar), and this amount varies depending on river basin characteristics such as the grain size of sediment in transport and the DOC concentration within river water. Also shown in Figure 4a, vegetation provides inputs of OC into the soil (light grey arrow and OC bar). Vegetation inputs are likely the primary input of OC relative to either lateral accretion deposition in bars or overbank flooding, and this assumption is supported by the lack of peaks of OC at depth and the decrease of OC with depth within the samples. With channel migration and erosion of the floodplain, OC reenters the river network and is carried downstream. Figure 4a does not include mineralization of OC and the release of carbon into the atmosphere via microbial respiration because our focus is on the geomorphic processes occurring within the floodplain.

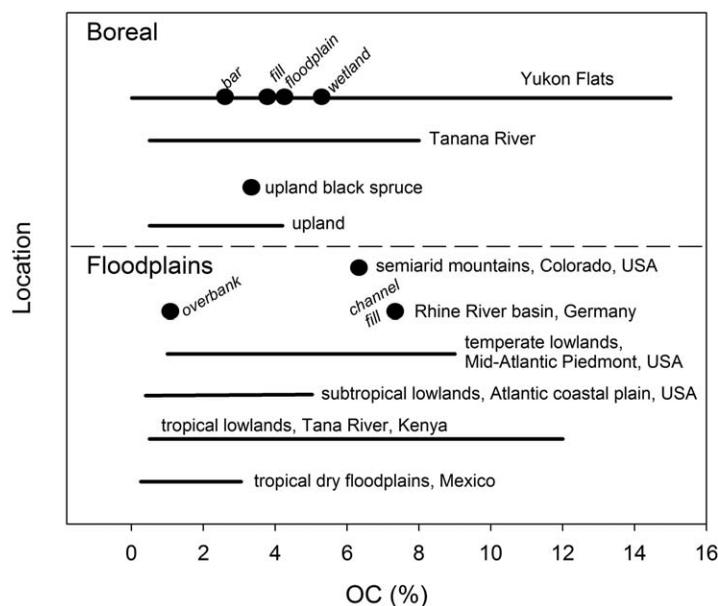


**Figure 4.** Conceptual models demonstrating the controls on OC within the floodplain in the Yukon Flats. (a) The primary ways in which OC is delivered to floodplain soil include direct deposition of sediment and organics by the river via lateral and vertical accretion (dark grey arrow and associated dark grey OC) and the creation of floodplain surfaces, vegetation growth, and the delivery of OC via vegetation inputs (light grey arrow and associated light grey OC). (b) Two scenarios demonstrate the mechanisms for OC accumulation within geomorphic units in relation to other factors that influence OC in the subsurface. See text for additional details.

Figure 4b demonstrates some of the influences on OC accumulation within different geomorphic units. Through lateral accretion and river migration, rivers deposit bars (right side of Figure 4b), which are coarser, drier, and contain less OC compared to other geomorphic units. The river slowly migrates away from the bars, which develop into other geomorphic units (floodplain and wetland). Over time, vegetation succession occurs, contributing more OC to the soil; overbank flooding may contribute fines to the soil, which help stabilize OC; and the permafrost table may rise, impeding soil drainage and reducing mineralization rates due to wet conditions. Channel migration rates, which differ among planform types, likely influences this process, because migration rates determine how long the surface will be stable before being reeroded by the river. All of these factors likely influence the increase of OC in the subsurface. Rivers also avulse, creating filled secondary channels, or scour low points on bars that are then filled (left side of Figure 4b). These fills are many times at a lower elevation in the landscape, and have higher soil moisture, which contributes to the OC contained in the soil.

**5.6. Comparison of OC Concentration Values With Other Environments**

The YF OC concentrations have a larger range (<0.5–14.96%) for mineral sediment compared to OC concentrations reported from non-floodplain locations in interior Alaska (Figure 5). Ping et al. (1997) report the percentage of OC in upland environments in interior Alaska, including a hillslope bog, glaciated upland forest, and forested outwash plain. Their values for mineral soil horizons range from 0.5 to 4.2%, with the highest in the hillslope bog location with mineral horizon OC concentrations of 1.9 and 4.2%, and the lowest OC% in a forested outwash plain with 0.5–2.8% in mineral horizons (Ping et al., 1997). The highest OC concentrations in our study were from wetland environments, with a mean of 5.1 ± 0.5% and a median of 3.6%.



**Figure 5.** OC concentrations in boreal regions and in floodplains in other climatic zones. Black dots indicate means, and lines indicate ranges. References for values are cited in the text and include Yukon Flats (this study), Tanana River (Van Cleve et al., 1993), upland black spruce (O'Donnell et al., 2011), upland (Ping et al., 1997), semiarid mountains, Colorado, USA (Sutfin & Wohl, 2017), Rhine River Basin, Germany (Hoffmann et al., 2009), temperate lowlands, mid-Atlantic piedmont, USA (Walter & Merritts, 2008), subtropical lowlands, Atlantic coastal plain, USA (Ricker & Lockaby, 2015), tropical lowlands, Tana River, Kenya (Omengo et al., 2016), and tropical dry floodplains, Mexico (Jaramillo et al., 2003).

O'Donnell et al. (2011) report a mean and standard error of  $3.4 \pm 0.7\%$  for mineral soil in black spruce stands from burned and unburned upland slopes in interior Alaska. These sites from the uplands may be most comparable to wetlands in our study, as both sites have permafrost and impeded drainage. Thus, wetlands with black spruce may have higher concentrations of OC compared to upland black spruce sites. However, the similarity between the OC concentrations in upland environments and the floodplains in the YF also provides support for the assertion that much of the OC in the subsurface in floodplains comes from surface vegetation inputs. For example, if vegetation is similar in upland and floodplain environments, the OC concentrations may also be similar. The larger range in OC in floodplains could reflect the diversity of geomorphic units (reflecting both river processes and differences in time since deposition) within the floodplains relative to upland locations or the different starting points of OC concentration. In the Tanana River floodplain, also located in boreal interior Alaska, OC concentration values range from  $<0.5\%$  in early successional vegetation to  $8\%$  in older, white spruce vegetation (Van Cleve et al., 1993), and these results are similar to this study. Floodplain lowlands in the boreal zone may have higher OC concentrations than mountainous rivers in the boreal zone, with  $1.3\text{--}1.5\%$  OC in floodplains of mountains in Alberta, Canada (Hoffmann et al., 2014).

Comparing the YF to floodplains in other regions, YF may have lower OC concentrations than semiarid mountain environments but may have similar or higher OC concentrations compared to other locations (Figure 5). Sutfin and Wohl (2017) report a mean OC concentration of  $6.3\%$  for floodplains in the eastern side of the Rocky Mountains, which is higher than the mean OC concentration of our study ( $2.8\%$ ). However, the median OC % from their study ( $3.7\%$ ) is more similar to the

median in the YF ( $2.2\%$ ). The higher OC concentrations in the Rocky Mountains could be due to higher primary productivity in the warmer climate compared to the boreal zone (Bradford et al., 2008). A comparison with temperate lowland floodplains such as the Rhine River Basin (Hoffmann et al., 2009) or the Mid-Atlantic Piedmont (Walter & Merritts, 2008) indicates that the YF may have higher OC concentrations (Figure 5). YF floodplains also contain higher or a larger range of OC concentrations than subtropical and tropical floodplains (Figure 5), which may reflect higher decomposition rates in warmer climates that enhance carbon mineralization in tropical and subtropical floodplains compared to boreal floodplains (Chapin et al., 2012; Jobbágy & Jackson, 2000).

**5.7. Implications**

Our results indicate that it is important to consider both large-scale differences among river basins and small-scale differences among geomorphic units when assessing floodplain soil OC concentrations. The patterns in OC concentration among geomorphic units are similar across study rivers, but different baselines of OC concentrations occur for separate river basins. In addition, the larger differences in OC concentration among geomorphic units (between wetlands and bars) compared to among study rivers (between the Dall River and the Teedrinjik River) indicate that reach-scale controls may have a stronger overall influence on the spatial distribution of OC within the floodplain. Segment scale differences in planform may be important to consider depending on the river studied, but are also dependent on geomorphic unit. Our results suggest that most of the OC accumulated in floodplain soil in the YF comes from autochthonous inputs of vegetation, although freshly deposited floodplain differs in OC concentration among rivers. Because vegetation reflects geomorphic processes and time since surface creation (supporting information Table S2; Chapin et al., 2006; Viereck et al., 1993; Whited et al., 2007), fluvial processes exert a strong control on OC concentrations within floodplains. The dominant influence of geomorphic units on OC concentrations also points to the opportunity to utilize high-resolution topography and remote imagery when assessing OC distribution and stocks within floodplain landscapes.

## 6. Conclusions

Floodplains act as sites of OC accumulation and storage, and as a source of OC to river networks. Determining the geomorphic controls on floodplain soil OC is important for assessing the spatial distribution of carbon in the high latitudes as permafrost warms and temperatures continue to increase (IPCC, 2014; Romanovsky et al., 2010). In addition, climate change and associated permafrost degradation will likely influence riverine fluxes of OC and geomorphic processes (Frey & McClelland, 2009; Rowland et al., 2010), highlighting the importance of understanding floodplain soil OC dynamics in the context of geomorphology. Studies suggest that flow paths, the relative contributions of groundwater versus surface water, and nutrient fluxes from the YF may be already changing due to anthropogenic climate change (O'Donnell et al., 2014; Striegl et al., 2005; Walvoord & Striegl, 2007), and the location of the YF in the discontinuous permafrost zone may make it highly sensitive to future changes.

We initially asked how differences in the spatial scale of analysis influence quantification of OC concentrations across large floodplains and how differences in the spatial scale of analysis inform our understanding of the controls on OC concentrations in the mineral soil of floodplains. We assessed OC concentrations at the scale of drainage basins, river segments, and river reaches. We find that there are few significant differences at the segment scale. There are differences among drainage basins, but the greatest differences in OC concentrations occur among geomorphic units within a river reach. This suggests that the most accurate way to quantitatively estimate floodplain OC concentrations across large floodplains is a bottom-up approach in which the distribution of individual units is mapped and the cumulative spatial extent of each unit is used with a median or mean value for OC concentration. We also infer that OC in floodplain mineral sediment results primarily from autochthonous inputs of floodplain vegetation, so that time over which the surface has been stable and type of vegetation, as these influence OC inputs, and grain size and soil moisture, as these influence OC retention within soil, all control OC concentration. This implies that the history of river erosion and deposition within a reach ultimately controls the spatial distribution and concentration of organic carbon in floodplain soils, even though direct riverine deposition of organic carbon may not exert the primary control on floodplain OC concentrations.

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