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Muted responses of streamflow and suspended sediment flux in a wildfire-affected watershed

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ABSTRACT

In August 2003 a severe wildfire burnt 62% of Fishtrap Creek, a 158 km^2 watershed in central British Columbia, Canada. Streamflows were obtained for the period 1980–2010 and suspended sediment fluxes were determined for the period 2004–2010 for Fishtrap Creek and these were compared to data for nearby Jamieson Creek, which was not affected by the wildfire. Peak streamflows in Fishtrap Creek after the wildfire were not significantly higher than before the wildfire, although total annual runoff had increased. Perhaps the most important change in streamflows following the wildfire was that peak flows associated with the annual freshet occurred earlier in the year (by ca. 2 weeks). Following the wildfire, monthly total suspended sediment fluxes peaked in April in Fishtrap Creek and May in Jamieson Creek, which reflects the change in timing of peak streamflows in Fishtrap. Specific suspended sediment yields were low in the first year following the wildfire (2004), and peak values for the 2004–2010 monitoring period occurred in 2006. Average specific suspended sediment yields over the monitoring period were similar for both watersheds at 2.8 and 2.9 t km^{-2} year^{-1} for Fishtrap and Jamieson watersheds, respectively. The muted responses of streamflows and suspended sediment fluxes following this severe wildfire are due to the lack of winter precipitation and the low intensities of summer rainfall events in the first year following the wildfire. Greater winter precipitation and associated snowmelt in subsequent years coincided with vegetation recovery. The major changes in the wildfire-affected watershed were increased bank erosion and channel migration due to a loss of root strength and cohesion, which occurred 3–5 years after the fire. This work demonstrates that the hydrological and geomorphological responses of watersheds to wildfires are a function of the severity of the wildfire and the timing and nature of driving forces (i.e. rainfall intensity, winter precipitation and snowmelt) during the progression of vegetation recovery.

1. Introduction

In many forest and range landscapes, wildfire represents one of the main factors controlling landscape evolution through the promotion of enhanced erosion (e.g. Cerdà and Lasanta, 2005; Blake et al., 2010; Robichaud et al., 2010a), mass movements (e.g. Jordan and Covert, 2009; Kean et al., 2011; Smith et al., 2012) and channel bank erosion (e.g. Moody and Martin, 2001a, 2009; Ryan and Dwire, 2012). Globally, wildfires affect more land area than any other natural disturbance (Lavourel et al., 2007). For mountainous landscapes in western North America, wildfires may contribute 10–25% of long-term (Holocene) sediment flux and denudation (Swanson, 1981; Jackson and Roering, 2009). The exact magnitude of this contribution to denudation depends on vegetation/tree cover (i.e. fuel load) and climate (i.e. lightning strikes), and thus fire frequency (Swanson, 1981), amongst other factors. Interest in wildfires has also increased due to their role in delivering sediment and associated chemicals (e.g. nutrients and contaminants) to downstream waterbodies, with associated implications for water resources and aquatic habitats (Rinnie and Jacoby, 2005; Blake et al., 2010; Emelko et al., 2011; Smith et al., 2011a; Jordan, 2012). Wildfires tend to increase sediment delivery to, and sediment fluxes in, river channels, usually by several orders of magnitude (e.g. Scott and Van Wyk, 1990; Moody and Martin, 2001a; Major et al., 2007; Reneau et al., 2007; Moody and Martin, 2009; Silins et al., 2009; Rhoads et al., 2011; Smith et al., 2011a,b). However, several recent studies (e.g. Prosser and Williams, 1998; Neary et al., 2005a; Martin et al., 2011; Ryan et al., 2011; Dragovich et al., 2012) have identified more varied responses, and emphasised the potential dangers of a universal approach for determining landscape evolution and the associated implications for water resources and ecosystem health (Shakesby et al., 2007; Jackson and Roering, 2009). The complexity of disturbance–response regimes (Viles et al., 2008; Owens et al., 2010) in the context of wildfires is related to variations in the way that soils have been modified (i.e.

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variations in the depth, strength and persistence of soil hydrophobicity, effects on soil aggregation, variations in duff cover; Martin et al., 2011; Mataix-Solera et al., 2011; Bento-Goncalves et al., 2012), and complex relations between lack of, or changing, vegetation cover and the role of hydroclimatic drivers such as precipitation and snowmelt (Neary et al., 2005b; Shakesby and Doerr, 2006; Smith et al., 2011a). Robichaud et al. (2010b) identified that the nature and severity of watershed response to wildfires are a function of fire-related (e.g. burn severity, soil erodibility, soil water repellency, time since wildfire) and non-fire related (e.g. precipitation characteristics, topography, land use and management) factors.

For many regions of the world, the occurrence and severity of wildfires are expected to increase due to changes in climate (Flannigan et al., 2009; Spracklen et al., 2009), and human-induced activities associated with land and forestry practices, such as reduced wildfire suppression (Moreira and Russo, 2007). For example, increases of 74%–118% in wildfire season length, fire severity and area burned in Canadian forests have been projected by the end of the century (Flannigan et al., 2005). This concern has resulted in an increased interest in understanding how landscapes respond to wildfires in contrasting environments and settings. In particular, there is a need to understand the interaction between wildfire, and associated responses in vegetation cover, and hydrologic and geomorphic behavior. Such research is also likely to be of relevance to other forms of disturbance in forested landscapes, such as pine beetle infestations (e.g. Bewley et al., 2010) and certain forest harvesting practices (e.g. salvage logging; Silins et al., 2009; Smith et al., 2011b) where the hydrological and geomorphological functions of vegetation cover (e.g. interception, soil binding) are strongly affected.

Relatively few studies have examined the hydrological and geomorphological responses to wildfire in watersheds >100 km^2, especially in cases where the spatial extent of the wildfire was $>50\%$ of the surface area of the watershed (Shakesby and Doerr, 2006). Results from smaller watersheds may not be representative of larger watersheds due to contrasts in the dominant processes occurring (i.e. greater likelihood of mass wasting events and increased importance of channel processes in larger watersheds) and increased opportunities for sediment storage, and thus the attenuation of streamflows and sediment fluxes at larger scales. Furthermore, for most studies the duration of post-fire measurement and monitoring has been short (typically 1–5 years), and assessments of longer-term responses over medium timescales (i.e. 5–10 years or longer) are relatively rare. Generally, forest and watershed managers and policy makers tend to focus on the first year or two after wildfire, and have a lack of appreciation and understanding of longer-term response–recovery behaviour of wildfire-affected landscapes (Elliot, 2006). In order to address these research needs, we describe results from a longer-term study investigating streamflows and suspended sediment fluxes in a larger watershed affected by a wildfire in 2003. Our specific objectives are as follows: (i) to estimate streamflows and suspended sediment fluxes for the period 2004–2010; and (ii) to evaluate these fluxes in the context of variations in precipitation and snowmelt, and changes in vegetation cover. Based on the available literature, our hypothesis is that streamflows and suspended sediment fluxes increased dramatically in the first years (i.e. 1–2) following the wildfire and then returned to more normal, albeit still elevated, values in years 3–7 due to post-fire vegetation establishment and growth.

2. Study site and methods

2.1. Study site

In August 2003, the McLure wildfire burnt an area of ca. 260 km^2 north of the city of Kamloops in the central interior of British Columbia (BC), Canada. The fire was classified as a Rank 6 fire, which is the most extreme and hazardous category of fire behaviour in BC (Eaton et al., 2010a). The Fishtrap Creek watershed has a total area of 158 km^2, and the contributing area upstream of the Water Survey of Canada (WSC) gauging station is 135 km^2 (Fig. 1). The watershed was severely burnt in the lower reaches and moderately burnt in the headwaters, and total burn area was ca. 98 km^2 (62% of the watershed). Unlike many other documented wildfires in similar physiographic and biogeoclimatic environments, the riparian area along the lower reaches of Fishtrap Creek (including the floodplain) was severely burnt. Salvage logging occurred following the fire, especially between 2004 and 2006, and the area logged is estimated to be about 20% of the area upstream of the WSC gauging station based on annual records of harvesting activity in the watershed (V. Young, BC Ministry of Forests, Lands and Natural Resource Operations, pers. comm.).

Fishtrap watershed ranges in elevation from 370 m to 1620 m above mean sea level with a rolling plateau in the headwaters and steep slopes associated with channel incision into the plateau. The dominant biogeoclimatic zone is montane spruce and prior to the wildfire vegetation was dominated by mature lodgepole pine (*Pinus contorta*), Engelmann spruce (*Picea engelmanii*), subalpine fir (*Abies lasiocarpa*) and interior Douglas fir (*Pseudotsuga meniesii*). The mainstem of Fishtrap Creek and its main tributary, Skull Creek, are gravel-bed streams that form an important habitat for salmonids. The climate is sub-humid, with hot and dry summers and mild winters, and mean annual precipitation (1971–2000 period for Kamloops) and runoff are 487 and 180 mm, respectively. Mean annual temperatures at 370 m and 1620 m elevation are 7.5 °C and 2.5 °C, respectively (Eaton et al., 2010b).

The Jamieson Creek watershed (area 230 km^2) is located south of Fishtrap Creek watershed (Fig. 1) and was not affected by the McLure wildfire. As the Jamieson watershed has similar characteristics of vegetation cover, topography, climate and geology to Fishtrap watershed, it serves as a reference for comparing the effects of the 2003 fire in the Fishtrap watershed. There are, however, some noticeable differences between the two watersheds, in addition to watershed area: Jamieson Creek drains a plateau surface that is 100–200 m higher than Fishtrap watershed; and there is a road that runs alongside Jamieson Creek, especially in the main canyon. Both creeks drain into the North Thompson River, itself a major tributary of the Fraser River, which drains into the Pacific Ocean at Vancouver.

The underlying geology in both watersheds is dominated by Palaeozoic (Pennsylvanian and Permian) volcanic and metamorphic rocks, with outcrops of Mesozoic (Triassic and Jurassic) and Cenozoic (Miocene and/or Pliocene) rocks in the headwaters of Fishtrap and Jamieson watersheds, respectively. Soils are developed in glacial till or glaciofluvial deposits overlying bedrock and are generally well-drained (Gough, 1988). The main soils found in the watershed are brunisolic gray and podzolic gray luvisols (Alkali, Allie, Artison soil associations) with ortho humo-ferric podzols (Laurel and Helmcken soil associations) found in the valley bottoms (Gough, 1988). The watersheds have a nival streamflow regime, with melting typically starting in late March and the main flood discharges occurring from mid April to late May (Petticrew et al., 2006; Eaton et al., 2010a; WSC, 2012), with average discharge peaks for Fishtrap Creek of approximately 5 to 8 m^3 s^{-1} (Eaton et al., 2010a; Leach and Moore, 2010; WSC, 2012).

2.2. Data collection and analysis

Daily precipitation data for the period 1980–2009 were obtained from the Environment Canada gauge at McLure (Environment Canada, 2012; station ID 1165030; 51° 02′ 48″ N, 120° 13′ 18″ W; elevation 381 m; Fig. 1). Daily stream discharge (Q) data for the period 1980–2009 and 15 min raw data for the period 2004–2010 were obtained from the WSC gauging station on Fishtrap Creek (ID 08LB024; 51° 07′ 24″ N, 120° 12′ 34″ W; elevation 615 m; Fig. 1) through the Environment Canada website (WSC, 2012). The WSC gauging station at Fishtrap Creek is a triangular broad-crested weir with a central rectangular notch.

At Jamieson Creek, stage was recorded for the period 2004–2010 using a Keller pressure transducer installed in a stilling well fixed to the stream bank at a stable location (50° 53′ 100″ N, 120° 17′ 300″