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CHANGES IN SEDIMENT SOURCES FOLLOWING WILDFIRE IN MOUNTAINOUS TERRAIN: A PAIRED–CATCHMENT APPROACH, BRITISH COLUMBIA, CANADA

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Abstract. This paper describes a study examining the potential of mineral magnetic, geochemical and organic properties to determine if a 2003 wildfire in a catchment in British Columbia, Canada, caused a change in the sources of the suspended sediment transported in the channel relative to a nearby unburnt (reference) catchment. The results show that some of the properties offer the potential to determine sediment sources in the unburnt catchment. However, the 2003 wildfire modified the concentrations of some properties and this can either compromise or enhance their ability as tracers in the burnt catchment. At present, the source tracing results are inconclusive. This has implications for the use of certain properties as fingerprints and raises important issues about approaches to sediment source identification.

Keywords: sediment sources, fingerprinting, wildfire, mineral magnetics, geochemistry

1. Introduction

Wildfires are a natural part of the behaviour of forest systems and are important for a variety of reasons. These include forest renewal and maintaining biodiversity. Wildfires are also important from a hydrological and geomorphological perspective, because they can alter soil hydrology and the rates of soil erosion, mass movement and channel bank erosion, which affect the delivery of water, sediment, carbon and chemicals to rivers. In turn, these changes have important implications for salmonid spawning gravels and other riverine habitats, and the chemical and ecological quality of freshwaters in forested catchments. While there is a reasonable amount of information available on the changes in soil hydrology and soil erosion rates at the plot and hillslope scales (e.g., Cerda & Lasanta, 2005) and on changes in sediment concentrations and fluxes at the catchment scale (e.g., Petticrew, Owens, & Giles, in press) to wildfires, there is much less information available on the linkage between hillslopes and channels in response to wildfires, and in particular on changes in the sources of the sediment being actively delivered to, and transported by, rivers. Such information is needed: to understand the landscape evolution of forested systems; for effective resource management; and for mitigating the effects of wildfire, especially given concerns over global climate change, such as the increase in the frequency of wildfires in many areas (Pausas, 2004).

Recent work (Blake, Wallbrink, Doerr, Shakesby, & Humphreys, 2006) has explored the use of mineral magnetic properties as sediment tracers in wildfire-impacted river basins since the Fe-mineralogy of soil can be altered during burning at high temperature (Rummery, Bloemendal, Dearing, Oldfield, & Thompson, 1979). Whilst the work demonstrated the occurrence of magnetic enhancement in burnt *versus* unburnt soil material, patterns were complicated by colluvial storage of previously burnt material and potential variability in background (pre-burn) magnetic assemblages. Blake et al. (2006) suggested that the inclusion of geochemical data may have reduced ambiguity in post-fire sediment source signatures, however, to date little work has focused on wildfire impacts on soil geochemistry in a tracing context. Work has chiefly been concerned with alteration of organic carbon, major nutrients (N and P) and exchangeable cations (e.g., Al, H, Ca, Mg, K, Na) in the context of forest recovery (Certini, 2005) where significant removal of C and mineralization of nutrients could offer tracing potential. Volatilisation of trace elements at high temperatures can also lead to changes in burnt soil chemistry as demonstrated by Marafa and Chau (1999) who observed a reduction in Mn, Fe and Zn following repeated burning of an upland soil in Hong Kong. The potential of these and other properties as post-fire sediment source tracers needs further exploration.

This paper describes some preliminary results of a field investigation into the effects of a wildfire event on sediment sources using a paired–catchment approach (i.e., a burnt and a nearby unburnt catchment) in British Columbia, Canada. This research had two objectives: (1) to use field observations to qualitatively determine any change in the main sediment sources due to the impacts of the wildfire; and (2) to explore *the potential* of sediment fingerprinting properties to provide a more quantitative indication of changes in sediment sources.

2. Study Area and Methods

2.1. Study Area

In summer 2003, unusually severe wildfires burnt in many locations across British Columbia (BC). The McLure fire, in the central interior of BC, near the town of Kamloops, burnt an area of ca. 260 km^2 affecting erosion rates and sediment delivery into several rivers, including Fishtrap Creek. Fishtrap Creek has a forested (Pines, Firs, Spruce and Cedar) catchment of 170 km^2 (135 km^2 to the gauging station, see Petticrew et al., in press) and is drained by several gravel-bed streams that form an important habitat for salmonid species. The Jamieson Creek catchment is located ca. 15 km to the south of Fishtrap. As Jamieson has similar characteristics of vegetation cover, topography, climate and geology to Fishtrap, but was not affected by the 2003 McLure fire, it serves as a reference catchment for comparing the effects of the 2003 fire in the Fishtrap catchment. The underlying geology in both catchments 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, respectively. The catchments have a distinct snowmelt regime with melting typically starting in early April and the main flood discharges occurring from late April to mid May (Petticrew et al., in press).

2.2. Methods

Following reconnaissance surveys of the study catchments, samples of source materials and suspended sediment samples were collected in both catchments during 2004. Composite suspended sediment samples were collected using time-integrated samplers (Biickert, 1999). These consisted of cylindrical gravel-filled traps (45 cm long and 7.5 cm diameter) with each end enclosed by 0.64 cm wire mesh. The traps were fixed to the channel bed using rebar stakes, with the sampler's long axis parallel to the flow. This enables flow to percolate through the traps whilst suspended sediment is deposited within the gravel pores. In both Fishtrap and Jamieson, three suspended sediment samplers (the sediment from which were bulked together) were installed at both an upstream and a downstream site. In both catchments, samplers were installed in April 2004 and emptied in June 2004 and September 2004, thereby providing composite samples of the suspended sediment transported during the periods April to June 2004 and June to September 2004.

Samples of source material were collected during April and June 2004. In both Fishtrap (n=14) and Jamieson (n=11) catchments, samples of topsoil (0–2 cm) and subsurface (>5 cm depth) material were collected from active slopes (i.e., those likely to erode and supply sediment to channels), and also from actively eroding channel banks. Each source material sample represented a composite of 5–10 subsamples collected within an area of ca. 10 m^2 to encompass local spatial variability in soil properties. In the case of the topsoil samples collected from Fishtrap, material was collected from the upper soil layers likely to have been modified by the fire, which consisted of exposed soil material in areas devoid of vegetation. In places, the upper layer of material included layers of ash >1 cm in depth, and in these situations the surface ash layer was carefully removed prior to sampling the scorched mineral surface beneath for identification of sediment source signatures.

Suspended sediment and source material samples were air-dried at 30°C, and disaggregated prior to screening to <500 μm. This fine fraction was analysed for low (χ_{lf}) and high frequency (χ_{hf}) magnetic susceptibility (using a Bartington susceptibility meter), geochemical (by spectrophotometry and ICP-MS after acid extraction) and organic properties (by total combustion), and absolute particle size characteristics (by laser granulometry).

3. Results and Interpretation

3.1. Qualitative Appraisal of Differences in Sediment Sources Between the Catchments

Despite the recent quest for quantitative approaches to determine the sources of the sediment transported in rivers (Walling, 2005), it is desirable that tracer-based studies should be both steered by, and evaluated in the context of, field observations of hydrological and geomorphological processes operating in the contributing catchment. The effect of the wildfire in Fishtrap Creek on changing the type and potential of soil erosion and sediment delivery processes were clearly apparent following reconnaissance surveys of both study catchments. The wildfire in Fishtrap Creek significantly reduced the vegetation cover, thereby exposing hillslopes and channel banks to erosion and sediment transport processes. Observations (Figure 1) demonstrated the *potential* for an increase in both topsoil and subsoil erosion relative to the unburnt Jamieson Creek, thereby justifying the need for further investigation. Field observations also facilitated sample selection by identifying likely active sources and enabled more targeted sampling.

3.2. Assessment of Mineral Magnetic, Organic and Geochemical Properties as Tracers

Having qualitatively confirmed that the wildfire has influenced erosion and sediment transfer susceptibility, the value of the proposed tracer properties as discriminators between sediment source types can be evaluated. An important first phase in this process is to determine which source material properties are able to differentiate between sources. Because this paper reports a reconnaissance field programme, source materials have been simply classified as either surface material (i.e., topsoil) or subsurface material (i.e., subsoil and channel bank material) for each of the burnt (seven topsoil and seven subsoil/channel bank samples) and unburnt (six topsoil and five subsoil/channel bank samples) catchments. The Mann–Whitney U test was used to examine which of the organic, geochemical and mineral magnetic properties were able to differentiate between the two source types. This was initially performed on the source material samples collected from Jamieson Creek, i.e., the unburnt samples. As there were no statistically significant differences in the particle size composition of the

Figure 1. Photographs showing exposed topsoil (a) and subsoil (b) material due to the wildfire in the Fishtrap catchment (photos taken by Phil Owens in July 2004).

surface and subsurface source material samples, no correction for particle size was undertaken at this stage. There were statistically significant (α=0.05) differences for certain organic (%C and %N) and geochemical (As, Co, Cu, Ni, P) properties, although there were no such differences in the basic mineral magnetic properties ($\chi_{\rm lf}$ and $\chi_{\rm fd\%}$). For %C, %N and P, values were greater in surface compared to subsurface materials, reflecting the inputs of these to the soil surface from vegetation and atmospheric sources. Most of the significant geochemical properties (e.g., Co, Cu and Ni) were greater in subsurface samples reflecting the influence of bedrock sources and weathering. Other elements (Cr, K and Na) were also greater in subsoil materials, although were not statistically different. Therefore, as %C, %N, As, Co, Cu, Ni and P are able to distinguishing between topsoil and subsoil material, they are suitable for sediment source determination.

It is also useful to assess the impact of burning on source material properties, as this may enhance or compromise their ability for source identification. This was tested by comparing the surface source materials from Jamieson (unburnt) with those from Fishtrap (burnt) underlain by similar Palaeozoic geology, so as to remove the potentially confounding effects of geological variation. Again, as there were no statistically significant differences in the particle size composition of the surface source materials in both catchments, property concentrations were, therefore, not corrected for particle size at this stage. A number of organic (%C), geochemical (Co, Cu, K, Mn, Na, Ni, P, Pb, Zn) and mineral magnetic ($\chi_{fd\%}$) properties were statistically different (α=0.05) between burnt and unburnt surface materials. In several cases (Co, Cu, K, Ni, P, Zn and $\chi_{fd\%}$) values were enhanced in the surface materials collected from the burnt catchment which could be due to the mineralization of litter with further inputs of canopy ash. Other properties (%C, Mn and Pb) evidenced a decrease in concentrations in burnt samples which may be due to vaporisation from surface layers that experienced high temperatures or leaching to subsurface layers.

3.3. Quasi–Quantitative Determination of Changes in Sediment Sources

From the comparison of surface *versus* subsurface materials in Jamieson, some organic and geochemical properties were able to differentiate between the two source types and thus could be used as fingerprints. The two bulk mineral magnetic properties were not able to differentiate the source types, although as the concentrations of the surface materials in Fishtrap were enhanced by the wildfire, this suggests that mineral magnetic properties do possess the potential for discriminating material affected by fire (Blake et al., 2006). Due to the limited number of source material and suspended sediment samples collected we have not used an unmixing model to provide quantitative estimates of sediment sources (Walling, 2005). However, it is possible to use bi-variate plots to make some semi-quantitative inferences of the sources of the suspended sediment being transported in the study catchments and explore whether the wildfire event has caused a change in the relative dominance of surface and subsurface sources. As an example, Figure 2 presents plots of concentrations of C against N and Cu against Ni for the two catchments. For the plots of C against N, in Jamieson there is a clear distinction between the surface materials and the subsurface materials, with the two sets of suspended sediment samples in the domain space occupied by the surface materials suggesting that this is the dominant source of the sediment transported in Jamieson Creek. For Fishtrap Creek, there is a similar situation although C concentrations in surface soils are substantially reduced due to the fire. The suspended sediment samples collected in June appear to be from surface materials, although those collected in September, while still suggesting a surface source, are different. The high organic contents of the September samples may be due to either (a) in-stream processes as a result of the reduced canopy cover overhanging the channel and the increase in light, and thus the occurrence of biofilms on the sediments, or (b) the occurrence of 'black carbon' due to the fire. For the plots of Cu *versus* Ni, again there is a reasonably good distinction

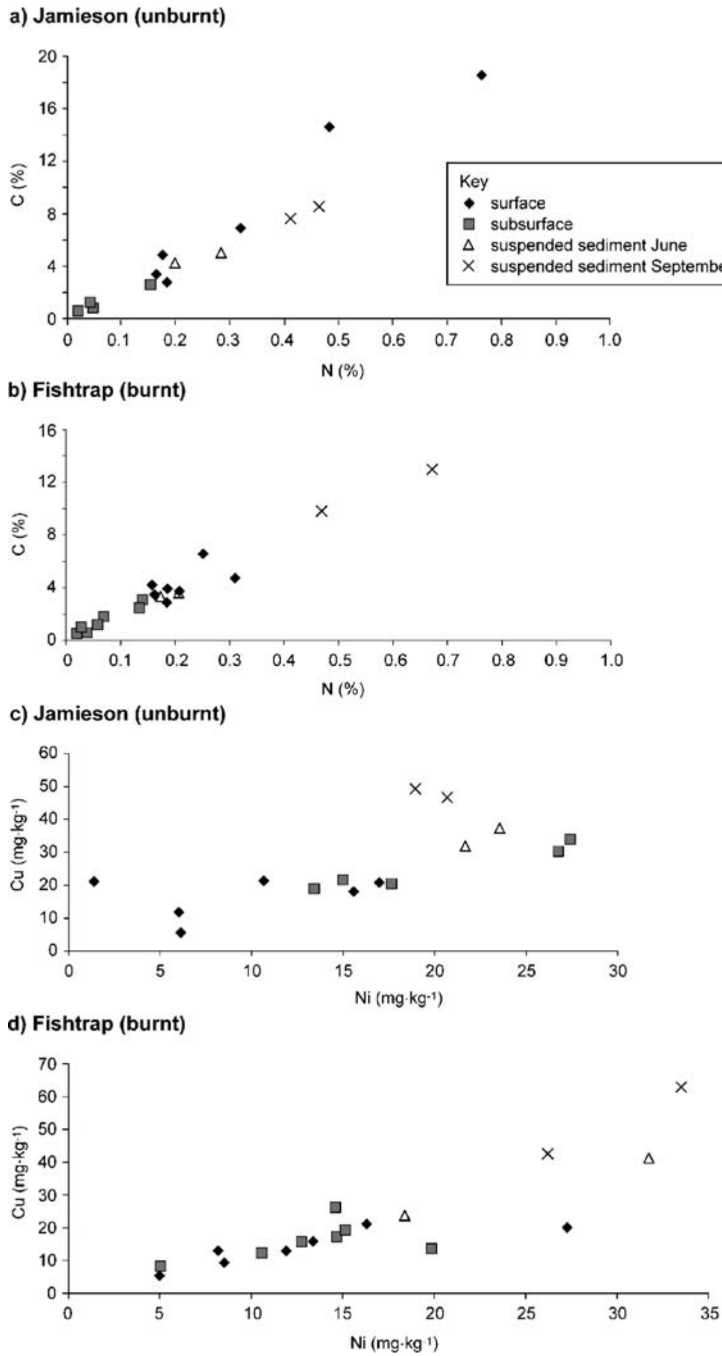

Figure 2. Plots of concentrations of C against N, and Cu against Ni for the source materials and suspended sediment samples (June and September 2004) collected from Jamieson (a, c) and Fishtrap (b, d) catchments.

between surface and subsurface source materials for Jamieson, with values for surface soils being lower for both properties. Although there is some overlap between the two groups, they are still statistically different. The suspended sediment samples are similar to subsurface samples, suggesting that this may be the main source. For Fishtrap, values of Cu and Ni for surface soils have increased due to the wildfire. There are also some subsurface soil samples with low values of Cu and Ni. These were collected from an area underlain by Mesozoic rocks. The effect of the wildfire in altering Cu and Ni concentrations, along with geological variations in Ni concentrations, means that it is not possible to distinguish between surface and subsurface materials, and thus it is not possible to determine with confidence the source of the sediment in Fishtrap.

4. Conclusion

The results show that some mineral magnetic, organic and geochemical properties offer the potential to distinguish sediment sources in unburnt catchments. However, the 2003 wildfire modified the concentrations of some properties and this can either compromise or enhance their ability as tracers in burnt catchments. The source tracing results presented above are to some extent contradictory and inconclusive. This underlines the fact that it is important to evaluate the controls on property concentrations and how these may change over time. It also raises important issues about source identification studies that use statistical approaches without detailed consideration of which fingerprint properties are being used in unmixing models, and if they are indeed appropriate.

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