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Impacts of wildfire and salvage harvesting on water quality and nutrient exports from radiata pine and eucalypt forest catchments in south-eastern Australia

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ABSTRACT

Salvage harvesting may represent an important additional impact on sediment and nutrient transfer in forest environments affected by wildfire. However, few studies have examined the effect of this management practice on stream water quality and catchment nutrient exports. In this paper, we investigate nutrient losses following post-wildfire salvage harvesting of a radiata pine plantation catchment compared to an adjacent natural eucalypt forest catchment that was also burnt but not harvested. The study catchments form part of the long-term Cropper Creek Hydrology Project (established in 1975) that is situated in south-eastern Australia. Post-fire monitoring (2007–2009) involved collection of both weekly and flow proportional water samples that were compared with previously reported data from samples collected prior to the fire (1997–2003). It was found that median values of total suspended solids (TSS) and turbidity returned to pre-fire levels within 3 years in both catchments, whereas maximum levels during storm events in the harvested pine catchment continued to exceed the eucalypt catchment. This reflected a previously reported large increase in post-fire sediment exports from the harvested pine catchment that was a minimum 180 times the eucalypt catchment over the study period. In contrast, the impact of harvesting on solute concentrations (nitrate-N, P, S, Cl, Na, K, Ca, Mg) was minor and most solutes returned to pre-fire levels within 2–3 years in both catchments. Nutrient exports from the pine catchment exceeded the eucalypt catchment by 102 times for particulate P associated with suspended material compared to 1.9–4 times for solutes. The post-fire changes in solute concentrations were generally similar for both catchments and the increase in solute exports was largely a result of greater discharge after the fire and harvesting compared to the burnt eucalypt catchment. The post-fire loss of particulate P in suspended sediment and bedload from the pine catchment for the study period was estimated at a minimum of 11 kg ha^{-1} and together with the estimated loss of P from burning and the removal of the pines represented approximately 6% of the total P in surface soil and fertilizer applied to the plantation.

1. Introduction

Wildfire is an important form of disturbance that can impact on sediment and nutrient transfer in forest environments (Neary et al., 2005; Shakesby and Doerr, 2006; Smith et al., 2011a). Post-fire increases in runoff and erosion coupled with fire-related changes to surface soil physical and chemical properties may contribute to enhanced sediment and nutrient delivery to streams (Benavides-Solorio and MacDonald, 2001; Moody and Martin, 2001; Certini, 2005; Sheridan et al., 2007; Smith and Dragovich, 2008; Blake et al., 2010). Ash may also make an important contribution to nutrient transfer soon after fire (Spencer and Hauer, 1991; Earl and Blinn, 2003; Ferreira et al., 2005). As a result, stream concentrations and catchment exports of various constituents (including suspended sediment, nutrients, solutes and trace elements) may experience substantial increases compared to unburnt conditions (Lane et al., 2006, 2008; Reneau et al., 2007; Mast and Clow, 2008; Noske et al., 2010; Smith et al., 2011a). Such changes may be most pronounced during short-duration stormflow events or snowmelt periods, and some constituents may remain elevated over background levels for a few years after fire or longer (Mayor et al., 2007; Bladon et al., 2008; Emelko et al., 2011; Rhoades et al., 2011; Ryan et al., 2011).

Salvage harvesting of burnt forest is a controversial management practice because it is considered to exacerbate wildfire disturbance of terrestrial and aquatic ecosystems (McIver and Starr, 2000; Beschta et al., 2003; Karr et al., 2004; Lindenmayer et al., 2004; DellaSala et al., 2006). Impacts on sediment and nutrient transfer in excess of the effect of burning alone represent one potential

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adverse consequence of salvage harvesting. While the debate has been largely focused on post-fire salvaging impacts in native forests, harvesting of burnt plantation timber may have detrimental impacts on downstream aquatic ecosystems and increased losses of soil nutrients have implications for site productivity and recovery.

Most research to date focuses on the separate effects of fire or harvesting on sediment and nutrient transfer rather than the combination of both these disturbances. Of those studies examining the combined effects of fire and harvesting, a number address the impacts of harvesting which is then followed by either wildfire or prescribed fire (Mackay et al., 1985; Mackay and Robinson, 1987; Wilson, 1999; Lane et al., 2004; Boerner et al., 2008; Loupe et al., 2009). However, pre-fire harvesting affects fuel loads and structure that may lead to differing fire intensities and therefore different burn effects on soil and surface properties that influence runoff and erosion processes as well as stream water quality. Comparatively few studies specifically examine the effect of wildfire followed by salvage harvesting on sediment and nutrient transfer. Reported impacts on catchment sediment exports ranged from minor change to large increases relative to burnt and unharvested sites (Silins et al., 2009; Smith et al., 2011b).

The few reports of water quality and nutrient exports following post-wildfire salvage harvesting indicate levels may remain unchanged or increase. For example, Mackay and Robinson (1987) detected no change in solute concentrations (Ca, K, Mg, Na, nitrate) after salvage harvesting of a burnt eucalypt forest catchment in southern New South Wales, Australia. Emelko et al. (2011) reported increased levels of dissolved organic carbon (DOC) and dissolved organic nitrogen (DON) following post-wildfire salvaging compared to burnt and unharvested as well as unburnt basins in southern Alberta, Canada. These authors noted post-fire levels of total suspended solids (TSS) and total phosphorus (total P) were comparable between salvaged and unharvested burnt catchments, which exceeded levels in unburnt reference catchments.

The present study examines the impacts of wildfire and salvage harvesting on water quality and nutrient exports from radiata pine (*Pinus radiata* D. Don) and eucalypt (*Eucalyptus* spp.) forest catchments. It is situated in the Cropper Creek research catchments, which are located in south-eastern Australia. Previously, Smith et al. (2011b) reported the effect of wildfire and salvage harvesting on runoff generation and sediment exports from the Cropper Creek catchments. The aim of the present study was to determine the combined effect of wildfire and salvage harvesting on nutrient losses from a radiata pine catchment compared to the effect of wildfire only in a native eucalypt forest catchment. This was quantified using post-fire stream concentration and catchment export data for various constituents from the radiata pine catchment which was compared to (a) pre-fire data for this catchment and the adjacent native eucalypt forest catchment and (b) post-fire data for the native forest catchment. In addition, information on soil P was coupled with export data from the pine plantation catchment to examine the net change in the store of surface soil P within this catchment. This provided further insight into the magnitude of the impact from post-fire salvage harvesting by placing P losses in the context of pre-fire soil P levels.

2. Study area and project background

The Cropper Creek research catchments are located in north-east Victoria, Australia (Fig. 1). The present study focuses on two of these catchments, which range in elevation from 431 to 786 m and have steep hillslopes mostly between 20° and 25° with aspects that range predominantly from N-NW to S-SE. The geology of the area comprises late Ordovician sandstones and shales, while soils are highly porous clay-loams. The native forest catchment Ella (113 ha) is covered predominantly by broad-leaf peppermint

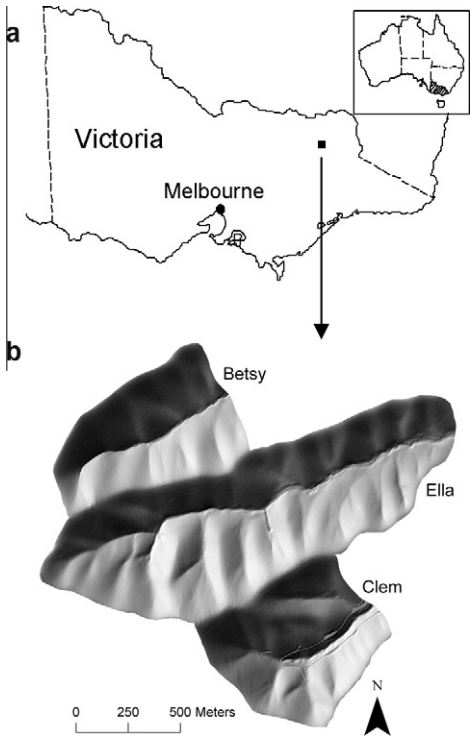

Fig. 1. (a) Location of Cropper Creek in Victoria and (b) hillshade digital elevation model (DEM) based on LiDAR survey of the three catchments.

(*Eucalyptus dives* Schauer), narrow-leaf peppermint (*Eucalyptus radiata* Sieb.) and brittle gum (*Eucalyptus mannifera*) on hillslopes and candlebark (*Eucalyptus rubida* Labill) in riparian areas. Clem (46.4 ha), the radiata pine plantation catchment, retains a 30 m native forest riparian buffer strip (2.7 ha). Annual average rainfall is approximately 1412 mm (based on 21 years of monitoring), most of which falls in winter–spring, while summer rainfall is characterised by high-intensity, short-duration convective storms (Bren and Hopmans, 2007). During the pre-fire monitoring period, streamflow maxima occurred in winter and spring, receding in late spring to the low-flow period over summer and autumn (Bren and Hopmans, 2007).

The Cropper Creek research project was established in 1975 to study the hydrology and water quality of three undisturbed eucalypt forest catchments and to evaluate the impact of conversion of one of the catchments to radiata pine on water yield, water quality and nutrient exports (Hopmans et al., 1987; Bren and Papworth, 1991). Following conversion to radiata pine in 1980, annual water yield increased during the first 6 years (Bren and Papworth, 1991), whereas only minor changes in TSS and various solutes (Na, K, Ca, Mg, Cl) were observed (Hopmans et al., 1987). Increases in nutrient exports were attributed to increased discharge following clearing, which returned to pre-treatment levels within 18 months (Hopmans et al., 1987). Following the first phase (1975–1987), a second phase (1997–2003) was initiated to evaluate longer-term changes and the effect of management actions (thinning and fertilisation) in the 17-year-old plantation (Bren and Hopmans, 2007; Hopmans and Bren, 2007). Comparison of water quality between Clem and Ella for these two periods indicated close agreement in solute concentrations except for higher levels of Ca in stream water of the radiata pine catchment throughout the study (Hopmans and Bren, 2007). During the second phase, treatment of the plantation with phosphate and nitrogen fertiliser raised levels of N and P slightly during the first 6 months before returning to antecedent levels. Total dissolved exports were estimated at less than 1% of the amounts of fertiliser applied (Hopmans and Bren, 2007).