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Wildfire and salvage harvesting effects on runoff generation and sediment exports from radiata pine and eucalypt forest catchments, south-eastern Australia

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ABSTRACT

This study examined the effect of wildfire and salvage harvesting on runoff generation and sediment exports from three small forest catchments in south-eastern Australia. In 2006, wildfire burnt a radiata pine catchment and two adjacent natural eucalypt forest catchments which formed part of a long-term hydrological research project. Subsequently, only the pine plantation catchment was salvage harvested. The combined effect of fire and salvage harvesting in the pine catchment caused a substantial increase in runoff compared to the burnt eucalypt forest catchments and pre-fire conditions, particularly in response to high intensity, short duration summer storms. Post-fire maximum suspended sediment concentrations from fixed-interval sampling greatly exceeded pre-fire values for both eucalypt and pine catchments, while sediment (suspended and bedload) exported from the pine catchment exceeded each of the eucalypt catchments by a minimum of 180 and 33 times. However, the export increase was probably closer to 320 and 71 times based on a survey of eroded channels in the pine catchment combined with measured post-survey exports. Notably, seven summer storm events accounted for approximately 80% of the pine catchment sediment yield. Hillslope process measurements indicated that the highest runoff velocities occurred in log drag-lines formed by cable harvesting, while soil water repellency was more extensive in the harvested pine catchment than in the adjacent eucalypt catchment. The latter effect probably resulted from higher burn severity in the pines combined with reduced soil moisture due to less shading after harvesting. Runoff modelling indicated that the log drag-lines acted as an extension to the drainage network and increased peak flows at the harvested catchment outlet by 48% for a high intensity summer storm event, while substantial reductions in modelled runoff were achieved through increasing the hillslope surface roughness coefficient. It is recommended that post-fire salvage operations should avoid the formation of log drag-lines when using cable harvest techniques and maximise surface cover to limit increases to runoff, erosion and catchment sediment exports.

1. Introduction

Wildfires are an important disturbance in forest ecosystems that can cause substantial hydrological and geomorphological change (Shakesby & Doerr, 2006). Following fire, salvage harvesting may be undertaken to recover burnt timber resources. However, post-fire salvage harvesting generally occurs at a time when the forest landscape is most vulnerable to increased runoff, erosion and impacts on downstream water quality (e.g. Kunze & Stednick, 2006; Lane et al., 2006; Reneau et al., 2007; Sheridan et al., 2007; Smith & Dragovich, 2008; Moody & Martin, 2009; Smith et al., in press). In addition, ecological consequences of salvage harvesting in natural forests may include the removal of critical habitat, impaired ecosystem recovery, and loss of soil organic matter and nutrients with implications for soil biota and plant growth (Karr et al., 2004; Lindenmayer et al., 2004). As a result, there has been considerable debate over the merits of post-fire salvage harvesting in terms of the economic benefit and environmental consequences (McIver & Starr, 2000; Beschta et al., 2003; Karr et al., 2004).

Impacts on runoff and erosion have been identified as one consequence of post-fire salvage harvesting (Karr et al., 2004). However, very few studies have quantified this effect in excess of burning alone (Silins et al., 2009). To date, this limited research has found that impacts from fire and harvesting generally result in only minor increases in sediment exports compared to burnt sites that have not been harvested (Van Lear et al., 1985; Cornish & Binns, 1987;

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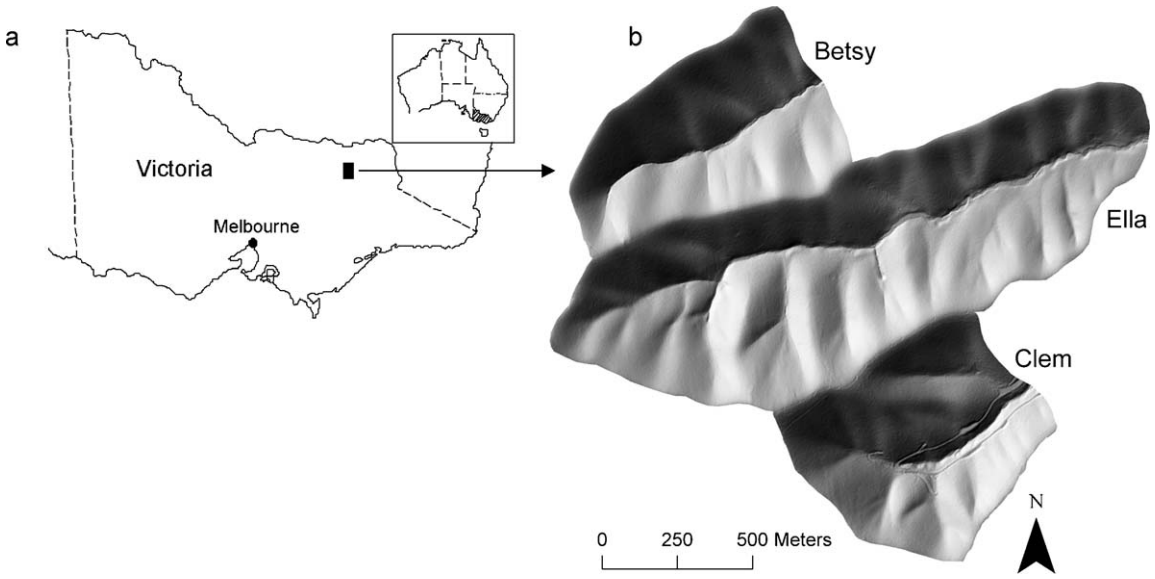

Fig. 1. (a) Location of Cropper Creek in Victoria and (b) hillshade DEM based on LiDAR survey of the three catchments.

Silins et al., 2009). In contrast, initial observations made in the present study suggested salvage harvesting after fire can have substantial impacts on runoff and erosion, indicating that the previous research cannot be considered generally representative of post-fire salvage harvesting effects for all natural and plantation forest systems. There is a need for studies of post-fire salvage harvesting effects on runoff, erosion and catchment sediment exports across different fire-prone forest types which quantify both the magnitude of impacts and identify specific harvesting effects that may exacerbate the post-fire response.

The present study examines post-fire salvage harvesting in a plantation forest of radiata pine (*Pinus radiata*) in south-eastern Australia. It is the only investigation of post-fire salvage harvesting impacts in wildfire-burnt plantations known to the authors. While salvage harvesting of plantation forests may present less concern about onsite habitat effects than native forests, the potential for reduction in soil productivity as well as downstream impacts on aquatic habitat and water quality are important forest management issues. Therefore, post-fire salvage harvesting in plantation forests requires an informed management approach that recognizes potential impacts and adopts mitigating strategies.

Wildfires in 2003, 2006–2007 and 2009 burnt large areas of forest across south-eastern Australia, which in Victoria alone exceeded three million hectares (Victorian Department of Sustainability and Environment, 2009). This included substantial areas of state forest and plantation, totalling 1.4 million and 28,750 ha, respectively, with most of the plantation forest (both softwood and eucalypt) burnt in 2009 (VAFI, 2009). In response to these fire events, salvage harvesting operations have increased with 3500 ha of burnt native forest salvaged since 2003 in Victoria, and a further 1000 ha expected to be salvaged in 2010 (VicForests, 2010). Specific information on recent post-fire salvage harvesting in plantation forests is not available, although large-scale salvage operations commenced following the 2009 fires in an effort to recover as much burnt plantation timber as possible.

This study is focused on the Cropper Creek research catchments, which are comprised of two natural eucalypt forest catchments and a third catchment planted with radiata pine. These catchments have been the subject of long-term hydrological monitoring which has yielded numerous publications on the hydrology of plantation and native forest catchments (Bren & Turner, 1979, 1980; Hopmans et al., 1987; Bren & Papworth, 1991; Bren & Hopmans, 2007; Hopmans & Bren, 2007). Following a wildfire in 2006, which completely burnt all three catchments, the pine catchment was salvage harvested. In response, a research program was initiated with the following objectives: (1) to quantify the effect of wildfire and salvage harvesting on runoff and sediment exports from the radiata pine catchment compared to pre-fire data for all three catchments and post-fire data for the eucalypt forest catchments and (2) to identify the hydrological processes contributing to any observed post-fire and harvesting changes in runoff and sediment exports.

2. Study area and project background

The Cropper Creek research catchments are located in north-east Victoria, Australia (Fig. 1). Two of the catchments, Ella (113 ha) and Betsy (44.3 ha), are covered by native forest comprised of predominantly broad-leaf peppermint (*Eucalyptus dives* Schauer), narrow-leaf peppermint (*Eucalyptus radiata* Sieb.) and brittle gum (*Eucalyptus mannifera*) on hillslopes and candlebark (*Eucalyptus rubida* Labill) in riparian areas. The third catchment, Clem (46.4 ha), was cleared in 1980 and replanted with radiata pine, while a 30 m undisturbed native forest riparian buffer strip (2.7 ha) was retained. The catchment geology is comprised of late Ordovician sandstones and shales, which are considered weak and erodible. Elevation ranges from 431 to 786 m, while soils are highly porous clay-loams and slopes range from 10 to 30° with most 20–25° (Bren & Papworth, 1991).

Annual average rainfall is approximately 1412 mm, most of which falls in winter and spring as low intensity (5–20 mm h^{-1}), long duration events compared to summer rainfall, which occurs mostly in high intensity (20–60 mm h^{-1}), short duration convective storms (Bren & Hopmans, 2007). Streamflow in the catchments is highest in winter and spring, with recession in late spring to the low flow period over summer and autumn. Ella and Betsy cease to flow over prolonged dry periods in summer, whereas Clem has flowed throughout the period of long-term monitoring (Bren & Hopmans, 2007). The high infiltration capacity of soils resulted in little overland flow generation in the unburnt state, with storm hydrographs generated by sub-surface outflows (Bren & Turner, 1979).

The Cropper Creek research project was established in 1975 to investigate the hydrology of the three catchments and the effect on water yield and water quality of the subsequent conversion of Clem to radiata pine (Hopmans et al., 1987; Bren & Papworth, 1991). Fol-