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Hydrological response to wildfire, integrated logging and dry mixed species eucalypt forest regeneration: The Yambulla experiment

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ABSTRACT

Eucalypts are commonly planted hardwoods worldwide and *Eucalyptus* dominated forests naturally grow in the headwaters of many Australian water supply catchments. The hydrological effects of disturbances have been extensively reported for one species, *E. regnans* (Mountain Ash). The typical response to disturbance is unusual in that following an initial increase, with heavy seed dispersal and rapid regeneration, streamflow from these forests is greatly reduced. In New South Wales (NSW), native forests are dominated by different *Eucalyptus* species that typically grow in mixed-species and mixed-age stands that regenerate less vigorously. In this study the long term streamflow records from the six Yambulla catchments in southeastern NSW were analysed to assess the relative effects of wildfires, integrated logging operations and subsequent mixed species eucalypt forest regeneration on catchment hydrology.

In all five treated catchments an increase in total streamflow, baseflow and stormflow was detected following the 1979 wildfire and/or integrated logging activities that occurred at various intervals. A subsequent reduction of streamflow to below that of a mature stand was not detected in three of the catchments but was detected in the two that had been subjected to integrated logging followed by a wildfire, and a wildfire followed by salvage logging, respectively. The reduction, however, was minor and short-lived in each case meaning that overall there was a cumulative increase in streamflow in the post-disturbance period. These results contribute to a growing body of evidence indicating that catchment-scale hydrological responses to disturbance of mixed species eucalypt forests do not follow the unusual response often reported in wet Mountain Ash forests. This has important implications for the modelling and management of mixed species eucalypt hydrology.

1. Introduction

Eucalypts are commonly planted hardwoods worldwide and in Australia, from where they largely originate, *Eucalyptus* dominated forests naturally grow in the headwaters of many catchments used for domestic, industrial and agricultural water supplies (Webb, 2012). The hydrological effects of disturbances such as wildfires, or logging operations, and subsequent eucalypt forest regeneration have been studied in a number of small catchments, most notably in the wet Mountain Ash (*E. regnans*) forests of the Melbourne water supply catchments (Langford, 1976; Kuczera, 1987; Bren et al., 2010), moist mixed species eucalypt forests to the north of Sydney (Cornish, 1993; Webb et al., 2012), and in the Jarrah (*E. marginata*) and Karri (*E. diversicolor*) forests of southwestern Australia (Bari et al., 1996).

In a global context the hydrological response of Mountain Ash forests to disturbance (Langford, 1976) is somewhat unusual (Bosch and Hewlett, 1982) as the annual streamflow reductions evident have not been recorded in other forest types (e.g. Stednick, 1996; Brown et al., 2005; Cosandey et al., 2005; Ide et al., in press). The streamflow effect following disturbance of Mountain Ash forest is often referred to as the Kuczera (1987) response or 'Kuczera curves' (Bren and McGuire, 2012). Due to removal of the mature forest there is a marked reduction in evapotranspiration which results in an initial increase in water yield. The increase in water yield persists for a period of between 4 and 7 years. If the forest is left to regenerate, water yield then declines logarithmically to the pre-disturbance level. If a significant proportion of the catchment is disturbed and the forest regenerates, water yield is then reduced to below the pre-disturbance level. The maximum reduction in streamflow reported is 50% and this typically occurs at around 28 years after disturbance. Mean annual water yield then slowly returns to pre-disturbance levels as the forest ages (Kuczera, 1987). Subsequent work has confirmed the streamflow response

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as resulting from prolific regeneration of this highly intolerant species by seed and subsequent high rates of evapotranspiration (e.g. Haydon et al., 1996; Watson et al., 1999; Vertessy et al., 2001), though the magnitude and timing of water yield reduction following forest disturbance may not be uniformly experienced (Bren et al., 2010). Mountain Ash forests, however, represent just 0.2% of Australia's forests by area, and they are absent from the state of New South Wales (NSW) (Attiwill, 2002) which brings into question the relevance and significance of these findings for forest and water management across much of the continent.

In the Karuah hydrology project in moist mixed species eucalypt forests to the north of Sydney in NSW, preliminary findings of the effects of logging and regeneration on water yield suggested that the "Kuczera" response was extended from Mountain Ash to other *Eucalyptus* species (Cornish and Vertessy, 2001). Analysis of the longer term response has shown that it occurs in only some catchments and the water yield reduction experienced is significantly dampened (Webb et al., 2012). In the Tantawangalo study, also in mixed species eucalypts but in southern NSW, Lane and Mackay (2001) reported that in one catchment that was patchcut, streamflow initially increased but then declined to below the pre-harvest level after 4 years. However, in the adjacent selectively logged catchment there was an increase in streamflow but no recorded decline with forest regeneration. These results suggest that Kuczera-type models of forest water use may not be applicable outside of the Mountain Ash forests from where they were derived. However, until recently, in part due to community pressure, the Kuczera-curves or derivatives of them have been used in modelling to assess the potential effects of eucalypt harvesting in NSW on water resources (e.g., Webb, 2012).

The focus of this paper is the Yambulla long term replicated paired catchment study that was initiated in 1977 in southeastern NSW. The original aim of the study was to assess the hydrological effects of integrated logging using the 'alternate coupe' management system in dry sclerophyll eucalypt forests within the Eden management area. Integrated logging involves the harvesting of both sawlogs and pulpwood in a single operation and was introduced in 1969 to overcome problems of a declining sawlog timber resource whereby the majority of forests in the Eden region comprised large, defective trees of unmerchantable quality (Bridges, 1983). The predominantly Silvertop Ash (*E. sieberi*) and Stringybark (*E. globoidea*, *E. muelleriana*) forests require intensive disturbance to adequately regenerate and this may be from wildfire or logging to create an appropriate seed-bed and regenerative space. As a result initial integrated logging operations were conducted on forest compartments or management units of around 800 ha which were subsequently reduced to 200 ha in size. Later, in 1976 the alternate coupe harvesting system was introduced and involves limiting the area of disturbance to small coupes which average 15 ha in area (Bridges, 1983). Alternate coupe harvesting is a silvicultural practice carried out in a forest compartment whereby harvesting across the compartment takes place in two operations. Each coupe harvested adjoins an unharvested coupe and there is a period of at least 5 years between the completion of one harvesting operation and the commencement of another within the compartment.

Early treatments at Yambulla were marred by wildfires in January 1979 that burnt much of the research area. Mackay and Cornish (1982) reported streamflow increases in catchments that were burnt and logged while the later plot-scale sap velocity measurements of Roberts et al. (2001) within Yambulla State forest showed that plot transpiration was 2.2 mm/day in 14 year old Silvertop Ash forest, 1.4 mm/day in 45 year old forest and 0.8 mm/day in mature 160 year old forest. These data support the general Kuczera-type model of streamflow response to eucalypt disturbance. However, to date no long-term catchment scale data have been published on the effects of the 1979 wildfire, various logging operations and subsequent forest regeneration on streamflows in this landscape. The aim of this paper is therefore to analyse the long term streamflow records from the Yambulla catchments to assess the relative effects of wildfire, integrated logging operations and subsequent forest regeneration on streamflows. The results will be compared with those published from other comparable catchment scale studies. The experiment is novel in that it is one of the longest running studies in Australia investigating the catchment scale hydrological effects of eucalypt harvesting and/or wildfire with natural regeneration in a dry sclerophyll forest.

2. Material and methods

2.1. The Yambulla catchments

The Yambulla project was established in 1977 within five small catchments in Yambulla State forest (37°20′S, 149°35′E), located 50 km southwest of the township of Eden in southeastern NSW (Fig. 1). A sixth catchment was added to the project in 1979 following an extensive wildfire that burnt four of the original catchments (Mackay and Cornish, 1982). The catchments are between 75.9 and 225.1 ha in area and drain to the Wallagaraugh River within the Genoa River Basin (Table 1). The catchments range in elevation from 230 m to 475 m with a generally easterly aspect. The topography is undulating to steep with slopes primarily between 10° and 20°. The climate is temperate with an even rainfall distribution. For the period 1977–2011 mean annual rainfall within the control catchment (catchment 1) at Yambulla was 906 mm. At the nearby Australian Bureau of Meteorology Timbillica station (No. 069029) the long-term mean annual rainfall for the period 1910–2011 was 962 mm with a median of 923 mm and a co-efficient of variation of 0.28.

The underlying geology of the Yambulla catchments consists of the Wallagaraugh Adamellite which forms the eastern margin of the Bega Batholith intruded during the late Silurian to Early Devonian. The intrusion comprises coarse-grained pink felsic adamellite/granite that crops out in all of the catchments on the ridges and upper slopes (Lewis et al., 1994). The bedrock is considered impervious with minimal deep seepage losses of water (Moore et al., 1986a). Soils on the upper slopes and ridges are typically lithosols and brown and yellow earths, while yellow earths and yellow podzolics occur on the lower slopes. Below the lower slopes soils are yellow podzolics grading to humic gleys and gley podzolics in low-lying areas (Ryan, 1993). Average measured saturated conductivities range from 400 mm/h in the yellow duplex soils on undisturbed hillslopes to 16.1 mm/h in the gleyed duplex soils (Moore et al., 1986b). The mean soil depth across the catchments is 1 m (Mackay and Cornish, 1982) and in general the catchment soils are of low nutrient status (Turner and Lambert, 1986).

The natural vegetation of the catchments is classed as dry sclerophyll forest with a tall open structure and a dominant height of 25–30 m (Mackay and Cornish, 1982). The overstorey is dominated by Silvertop Ash (*E. sieberi*), Blue-leaved Stringybark (*E. agglomerata*) and Yellow Stringybark (*E. muelleriana*) which account for 40%, 20% and 10% of the canopy, respectively (Fig. 2). The remainder of the canopy is made up of species including Monkey Gum (*E. cypellocarpa*), Yertchuk (*E. consideniana*), White Stringybark (*E. globoidea*) and Messmate (*E. obliqua*). The understorey is generally sparse except for isolated patches of moderately dense stands of Black She-oak (*Allocasuarina littoralis*) on slopes and ridges, and dense thickets of Prickly Tea-tree (*Leptospermum juniperinum*) and Scented Paperbark (*Melaleuca squarrosa*) adjacent to drainage features (Mackay and Cornish, 1982).