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Variation in stream organic matter processing among years and benthic habitats in response to forest clearfelling

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ABSTRACT

We assessed rates of organic matter (OM) processing in coarse gravel and fine benthic sediment, along with water temperature, in four clearfell harvested and two undisturbed headwater streams flowing through wet eucalypt forest in southern Tasmania, Australia. Clearfell forestry in Tasmanian wet eucalypt forest involves felling of all timber followed by a high intensity regeneration burn to provide a receptive mineral seedbed for seedling growth. Bacterial carbon production and cellulose decomposition potential (together referred to as OM processing) were measured seasonally 3–5 years before and 2–4 years after harvesting in each stream. We employed a staircase design (staggered harvesting treatments) within a multiple before–after control–impact design to distinguish harvesting effects from natural variation. Clearfell harvesting raised the yearly mean water temperature by between 0.25 °C and 0.94 °C, and raised the maximum water temperature by between 0.84 and 1.6 °C. Rates of cellulose decomposition were not significantly correlated with sediment temperature but bacterial carbon production showed weak, significant correlations with temperature in fine ($r = 0.20$, $P = 0.01$, $n = 137$) and coarse gravel sediment ($r = 0.39$, $P < 0.001$, $n = 137$). The response in OM processing to clearfell harvesting differed between years and among benthic habitats. In coarse gravel habitat, there was a significant decrease in rates of cellulose decomposition potential in the 2nd and 4th year after harvesting, and a significant decrease in bacterial carbon production in the 3rd year after harvesting. However, we found a significant increase in rates of bacterial carbon production of fine sediment habitat in the 2nd and 4th year after harvesting. The contrasting response of OM processing between habitats indicates that habitat-specific changes occur after clearfell harvesting, which inhibit attempts to quantitatively predict downstream cumulative effects. Scaling up the habitat-specific responses will not only require estimates of the relative abundances of the distinct habitats, but may also require research into how different spatial configurations of habitats may affect reach- and catchment-scale estimates of OM processing.

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1. Introduction

The processing of organic matter (OM) in freshwater environments is largely driven by the combined activities of aquatic fungi, bacteria and invertebrates (Cole, 1999; Findlay and Sinsabaugh, 1999; Gulis and Suberkropp, 2003). The processing of terrestrially derived OM by these organisms is particularly important in forested, headwater streams where it is the dominant source of energy for aquatic food webs and strongly influences particulate and dissolved OM fluxes to downstream aquatic and near-shore coastal ecosystems (Vannote et al., 1980; Wipfli et al., 2007). Measurements of OM processing in forested, headwater streams can thus provide important information on the functional integrity of the entire fluvial network (Wipfli et al., 2007; Young et al., 2008).

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Natural variation in the stream environment can alter rates of OM processing. For example, OM processing can be influenced by surface water and sediment nutrient concentration (Elwood et al., 1981; Gulis and Suberkropp, 2003; Bergfur et al., 2007), stream and sediment temperature (White et al., 1991; Marxsen, 2001; Menéndez et al., 2003; Clapcott and Barmuta, 2010b), changes in resource quality and/or consumer density due to light availability (Lagrue et al., 2011) and autotrophic activity (Rees et al., 2005; Rier et al., 2007). Seasonal changes in many of these variables can lead to different patterns of OM processing throughout the year. For example, during the winter months lower temperatures (Menéndez et al., 2003; Bergfur, 2007; Clapcott and Barmuta, 2010b) and greater stream flow (Laćan et al., 2010) can reduce OM processing.

Forest harvesting can cause large changes to the stream environment (Likens et al., 1970; Swank et al., 2001; Gravelle et al., 2009), with implications for OM processing. Elevated streamwater nutrients, altered temperature regimes, and sedimentation are just some of the altered stream variables mediating OM processing following harvesting (Benfield et al., 2001; McKie and Malmqvist, 2009; Clapcott and Barmuta, 2010a; Lecerf and Richardson, 2010). Understanding how forest harvesting influences aquatic OM processing is therefore important so that deleterious effects downstream, such as an altered energy supply, can be mitigated. To date, research on the impact of forest harvesting on rates of OM processing in forested streams is conflicting (Benfield et al., 2001; McKie and Malmqvist, 2009; Lecerf and Richardson, 2010), even within the same forest ecosystem (Kreutzweiser et al., 2008, 2010). These conflicting findings may be because small streams are structurally and functionally heterogeneous in space and time (Vannote et al., 1980; Gooderham et al., 2007). Without accounting for this variability it is difficult to isolate effects caused by forest harvesting from transient effects due to natural variability (i.e., accounting for time–treatment interactions) (Walters et al., 1988; Downes et al., 2002). To control for this time–treatment interaction, Walters et al. (1988) recommended a 'staircase design', where disturbances to treated locations are staggered over time.

Clearfell, burn and sow (CBS) forestry represents a major disturbance to headwater streams flowing through the wet eucalypt forests of southern Tasmania. CBS is a form of forest harvesting that involves the felling of all trees from a specific area (termed a coupe), the burning of this area to provide a receptive mineral seedbed, and the sowing of seed to ensure eucalypt regrowth (Hickey and Wilkinson, 1999; Forest Practices Board, 2000). There are no formal buffer strips, but a 10 m machinery exclusion zone (MEZ) is required around small headwater streams (Forest Practices Board, 2000). Despite this, the vegetation in the MEZ is often scorched and killed during the regeneration burn (Clapcott and Barmuta, 2010a) (Fig. 1). Previous space-for-time surveys in these headwater streams identified that CBS forestry causes a short-term (<5 years) increase in benthic bacterial and microbial OM processing, and that this was strongly associated with increased sediment temperature (Clapcott, 2007; Clapcott and Barmuta, 2010a). This study builds on this previous research but uses a staircase design (staggered harvesting treatments) within a multiple before–after control–impact (MBACI) design to distinguish deliberate treatment effects from transient effects due to natural variability (Walters et al., 1988).

We assessed rates of OM processing of coarse gravel and fine benthic sediment, along with sediment and water temperature, in four clearfell harvested and two undisturbed headwater streams flowing through wet eucalypt forest in southern Tasmania, Australia. Two complementary measures of OM processing were used: bacterial carbon production (BCP) assessed the activity of benthic bacterial communities (Buesing and Gessner, 2003a), and cellulose decomposition potential measured the activity of benthic microbial communities (aquatic fungi and bacteria) (Boulton and Quinn, 2000). Based on previous research, we hypothesised that CBS forestry would increase the short-term (<4 years) rates of BCP and cellulose decomposition potential, driven largely by elevated sediment temperature. To our knowledge, this study represents the first replicated study with staggered treatments contrasting OM-related measures of ecosystem processes before and after clearfell forestry carried out under industry best practice (Tasmanian CBS harvesting).

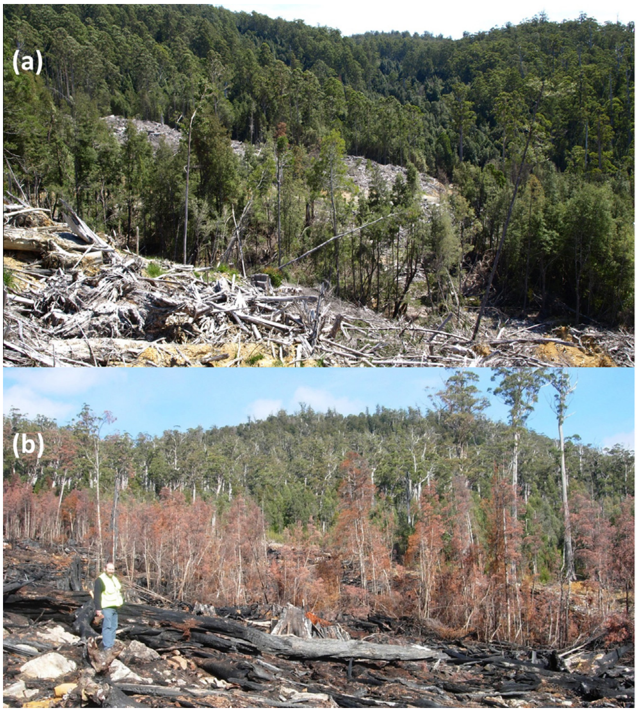

Fig. 1. A machinery exclusion zone (MEZ) of a Tasmanian headwater stream flowing through a CBS-affected coupe (a) <1 year since harvesting but prior to the high intensity regeneration burn and (b) 1 year after the high intensity regeneration burn.

2. Materials and methods

2.1. Study region and streams

The study was conducted in the Warra Long Term Ecological Research site (Neyland et al., 2000), which is situated within the Tasmanian Southern Ranges bioregion, as described by the Interim Biogeographic Regionalisation for Australia (Thackway and Cresswell, 1995). The study region has a rugged topography and a temperate climate with a mean annual minimum and maximum temperatures of 5.4 and 13.7 °C, respectively. Annual average rainfall exceeded 1600 mm during the study period (Bureau of Meteorology, 2012). The geology of the region is dominated by Permo–Triassic sediments and Jurassic basic igneous rocks (dolerite) (Sharples, 1994; Laffan, 2001). Soils are well to moderately drained and are generally acidic with a pH range of 4–6 (Thackway and Cresswell, 1995; Wells and Hickey, 1999).

In January 2004, six headwater streams were selected in old-growth wet eucalypt forest (Table 1; Fig. 2). Four 'treatment' stream reaches (streams A, B, D and E) were subjected to CBS forestry conducted under the provisions of the Tasmanian Forest Practices Code (Forest Practices Board, 2000). The forest coupes adjacent to streams A and B were harvested in March 2007 and burnt in April 2008, while the coupes adjacent to streams D and

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