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Relating upstream forest management to stream ecosystem condition in middle catchment reaches in Tasmania

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ABSTRACT

We investigated the relationship between the extent of Clearfell, Burn and Sow (CBS) harvesting and conversion to plantation in catchments upstream of mid-catchment study reaches on instream biota and habitat. Study sites were situated in fourth order stream reaches with no adjacent forestry activity, so that impacts represented the accumulated effect of forestry activity in the upstream catchment. In-channel fine sediments increased and the proportion of aquatic insect taxa decreased with increasing percentage land area under CBS (PCBS), with substantive changes observed above 40% of catchment area under CBS. Two different diagnostic attributes for macroinvertebrate taxa (SIGNAL scoring and Flow Exposure Groups) showed different relationships with PCBS, indicating that reductions in flow may also partially drive the macroinvertebrate response to increasing PCBS. Relationships between % area under unsealed roads and PCBS on downstream macroinvertebrate fauna suggested that roading was a substantive co-contributor to the overall impact of upstream CBS operations. An increase of 1% of the upstream catchment area under unsealed roads was associated with a respective decrease of richness by 4–8 EPT species in study reach riffles. For study reaches with upstream catchments containing hardwood (*Eucalyptus nitens*) plantation operations only, there was also a significant increase in unsealed roading and instream fine sediment with increasing area of plantation, though the increases were considerably less pronounced than for CBS operations occupying similar relative catchment areas. There were no significant relationships between area of plantation and macroinvertebrate community variables, presumably reflecting the lower levels of sediment deposition we observed downstream in plantation-dominated catchments. Plantation dominated catchments, with lower roading density and lower erodibility basaltic soils, had smaller instream impacts relative to CBS-dominated catchments, which are generally characterised by a more prolonged and dispersed disturbance regime including intensive regeneration burns.

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1. Introduction

The impacts of forestry operations on streams have been well documented worldwide, with the results of studies into the consequences of forestry for stream integrity being increasingly incorporated into prescriptions designed to manage and mitigate impacts (Campbell and Doeg, 1989; Growns and Davis, 1994a; Reid et al., 2010). Primary impacts of harvesting on forest streams include changes to hydrology, geomorphology, sediment transport, nutrient dynamics, carbon budgets and stream habitats (Thompson et al., 2009). Secondary impacts can include changes in the diversity and community composition of algae, macroinvertebrates, fish and other vertebrates (Davies and Nelson, 1994; Collier and Smith, 2005; Thompson et al., 2009; Reid et al., 2010; Koch et al., 2006).

The impacts of forestry on stream habitat and fauna at the local (i.e. coupe or parcel) scale are influenced by a range of contextual factors such as geology, geomorphology, groundwater, soil and vegetation characteristics (Davies et al., 2005a; Gooderham et al., 2007; Smith et al., 2009). The intensity of any observed impact is also related to the type of operational activity and harvest equipment, proximity to water courses and timing of forestry operations. Both scale and position within a catchment are also important influences on the nature and magnitude of impacts

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(Martel et al., 2007). Studies which focus on coupe-specific impacts on stream reaches immediately adjacent to a forestry operation provide an important insight into direct and locally-constrained impacts on river health (Davies and Nelson, 1994; Growns and Davis, 1994a). However, local impacts occur within a broader catchment context, which can have a major influence on responses to local land use (Allan, 2004; Martel et al., 2007; Shearer and Young, 2011). The management of both riparian forest and roading also influences instream physical and biological impacts from both harvesting and other forest management activities (Lovett and Price, 1999; Boothroyd et al., 2004; Croke and Hairsine, 2006; Thompson et al., 2009; Reid et al., 2010).

The location of a forestry operation in a catchment affects its impact on stream health (Church, 2002; Gomi et al., 2002; Montgomery, 1999; Johnson and Host, 2010) by changing the spatial pattern and local intensity of organic and inorganic material transport, flow regimes and resulting invertebrate drift (Smith et al., 2009). A holistic approach to river and catchment management acknowledges that disturbance anywhere in a catchment can impact on stream integrity; that a local impact can represent the summation of catchment-wide activities; and that disturbance around watercourses in the upper catchment can have effects further down the watershed within the local contexts of geology, topography and climate (Allan, 2004; Johnson and Host, 2010; Magierowski et al., 2012).

The pattern of forestry-induced impacts on stream habitats and benthic macroinvertebrates has frequently been described from studies of steep headwater streams with substrates of large grain sizes (Campbell and Doeg, 1989; Dignan et al., 1996). Here, the influences of forest harvesting and roading are dominated by heightened delivery of fine sediments and exacerbated by flashy hydrological responses with extreme high flows and low baseflows, often coupled with increased insolation and stream temperatures (Davies et al., 2005a). The biological results of these phenomena are varied, and can include declines in macroinvertebrate diversity and loss of water quality sensitive taxa, such as mayflies, stoneflies and caddisflies (e.g. Davies and Nelson, 1994; Growns and Davis, 1991, 1994a; Henley et al., 2000). However, patterns of impact in headwater streams of quite different geomorphologies and stream powers may follow substantially different courses (Gomi et al., 2002; Jackson and Sturm, 2002).

Many upland Australian headwater streams are typified by fine-grain substrates and high levels of organic carbon storage, accompanied by relatively low stream power (Wasson et al., 1998). In such streams, forest harvesting, riparian disturbance and roading can increase the rate and magnitude of erosional responses to rain events, which may lead to channel adjustment, coarsening of bed material and export of coarse and fine particulate inorganic and organic material (Wood-Smith and Buffington, 1996; Boothroyd et al., 2004; Croke and Hairsine, 2006; McBroom et al., 2007; Lakel et al., 2010; Merten et al., 2010). The secondary responses of the macroinvertebrate community may be substantially different to those in higher order streams. For example, Davies et al. (2005a) recorded differences in instream channel morphology, sediment composition and habitats between upland first order streams at Ben Nevis, Tasmania, which were ascribed to the influence of clearfell logging 15 years previously. In their undisturbed state these streams were characterised by significant storage of sands, silts and organic matter, coupled with diffuse and shallow channel complexes. Logged streams had shifted toward a coarser grained, simpler and more incised channel form. Macroinvertebrate communities had shifted from a typically 'depositional' fauna dominated by nematodes, worms and microcrustaceans toward a more 'lotic' fauna typical of higher power, coarser substrate streams, with increased representation of stoneflies and mayflies, and reduced abundances of taxa associated with depositional habitats (Davies et al., 2005a,b).

Following on from this work, Smith et al. (2009) postulated a transition from predominantly 'degradational' responses to forest harvesting operations (in the geomorphological sense) in small headwater streams toward transient 'aggradational' effects further downstream. They predicted that sediment exported from forestry-impacted headwater streams would be deposited in reaches downstream, often transitorily, between periods of higher flow, with varying degrees of sediment accumulation and benthic biological response. To test their hypothesis, Smith et al. (2009) evaluated the effect of logging on habitat and benthic macroinvertebrate communities in stream reaches downstream of logging operations and in reference reaches (with no catchment logging history) in second to fourth order Tasmanian streams. While still headwater channels, these streams were significantly steeper than the upland streams evaluated by Davies et al. (2005a). The nature of the instream biological responses was similar to the first order streams studied by Davies et al. (2005a, b), despite the set of streams having varied geomorphological contexts (Smith et al., 2009). This supports a hypothesis that in headwater catchments in Tasmania at least, forestry-induced disturbance causes a shift to an instream macroinvertebrate community more typical of higher energy fluvial habitats found further down the stream network.

The study described here examined the impacts of historical upstream native forest harvesting and plantation operations on mid-catchment Tasmanian streams to further explore the downstream impacts postulated by Smith et al. (2009). Our sites were situated in fourth order stream reaches which had no logging activity in their immediate vicinity, so that any impacts represented the accumulated effect of logging activity in the upstream catchment. Sites were stratified by geomorphological type and selected to cover a range of disturbance intensity from historical operations upstream. We investigated the degree to which forestry operations in upper catchment areas have downstream effects on stream biota, including benthic macroinvertebrates, and threatened fauna (specifically *Astacopsis gouldi*). The present study had the following aims: to test the hypothesis of Smith et al. (2009) that sediment exported from forestry-impacted headwater streams deposited in reaches downstream, would be associated with impacts on benthic macroinvertebrates and stream condition; to describe the response of macroinvertebrate communities over a gradient of forestry intensity within the up-stream catchment (i.e. area under specific operational types); and to identify any areal thresholds above which forest operations within upper catchment areas affect downstream ecological condition.

2. Methods

2.1. Site selection

Our study focus was on "mid-catchment" streams, corresponding to fourth order reaches, *sensu* Strahler (1952) at a 1:25,000 map scale. The study area focused initially on the northern Tasmanian stream drainage system, which corresponds to the natural range of the Giant Freshwater Crayfish (*A. gouldi*). Approximately 600 distinct fourth order stream sections were identified within this area from which to draw potential study reaches.

Existing GIS data on forest type, forest operational history, land tenure and landuse were obtained from Forestry Tasmania (forest type, 2005, and forest operational history data 2007), Private Forestry Tasmania (forest type and forest operational history, 2007), Department of Primary Industries and Water Tasmania (land use, 2005/06 (ABARES, 2010), reservation status and roading 2007), and the CFEV (Conservation of Freshwater Ecosystem Values) project (stream drainage base layer data, river section catchment boundaries and associated attributes; DPIW,

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