Forest Ecology and Management 257 (2009) 931–940

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Biological consequences of clear-cut logging around streams—Moderating effects of management

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ARTICLE INFO

Article history:
Received 1 October 2007
Received in revised form 17 June 2008
Accepted 28 October 2008

Keywords:
Forestry
Riparian buffer
Species traits
New Zealand
Plantation

ABSTRACT

Effects of riparian harvesting on in-stream biota were monitored in five streams in exotic conifer plantations that differed in how logs were extracted, patterns in deposition of woody debris, and the degree to which riparian buffers were retained. Streams were sampled on three occasions in summer, once prior to harvesting and twice afterwards. Consistent effects of harvesting included an increase in the amount of woody debris in the channel, increased fine sediment and a trend towards higher algal productivity. Invertebrate communities changed dramatically in some streams. General patterns included an increase in small sized taxa and taxa with generalist diets in the first year after harvest, then a trend towards a greater representation of grazers and larger taxa the following year. Responses in particular taxa were highly variable between streams. Some of this variability was related to forestry management, the least dramatic changes occurring where a narrow riparian buffer strip was retained. Reduced impacts were also observed in streams where woody debris was piled over the channel. We suggest that management practices that maintain shading of the stream channel will moderate forestry effects, and that practices such as channel cleaning are likely to be detrimental.

1. Introduction

Intensification of management of both natural and plantation forests is an international trend in response to increased demands for timber products (Carnus et al., 2006). Forest industry growth is coupled with increasing concerns about environmental impacts (Carnus et al., 2006), requiring a broad understanding of the influences of forestry practices on ecological systems. Riparian harvesting of trees (defined here as harvesting within 20 m of the stream bank) can dramatically affect aquatic ecosystems by altering physical environment and biological processes (Broadmeadow and Nisbet, 2004). Clear cutting of riparian margins directly disturbs banks during the removal of logs and building of road crossings (Clenaghan et al., 1998; Stott and Mount, 2004) with consequences for channel form and sediment supply (Beschta, 1978; Boothroyd et al., 2004). At the catchment scale, deforestation has been associated with changes in hydrology, generating higher peak flows that alter sediment dynamics and disturbance regimes (e.g. Swank et al., 2001; Stott and Mount, 2004). In addition, riparian harvesting supplies large amounts of organic matter to the streambed (e.g. Ponce, 1974; Trayler and Davis, 1998). This results in debris dams and snags that can increase retention of fine organic matter, as well as increasing habitat complexity and flow heterogeneity (Bilby and Likens, 1980). These aspects of microhabitat can in turn influence the community composition of aquatic invertebrates and their accessibility to predators such as fish (Rutt et al., 1989).

Riparian forestry also has fundamental effects on basal resources at both the reach and catchment scales. Basal resources are those produced by aquatic primary producers (in streams, mainly algae, fungi and bacteria). Changes to vegetative cover above streams influences light availability with consequent increases in algal productivity and changes to algal species composition (Webster et al., 1983; Steinman, 1992; Stone and Wallace, 1998; Boothroyd et al., 2004; Thompson and Townsend, 2004a). Removal of stream-side vegetation may also influence habitat for the adult stages of aquatic insects, with influences on aquatic community structure (Collier et al., 1997). Increased light reaching the stream channel can also increase stream temperatures, with effects on rates of energy flow through aquatic food webs (Weatherley and Ormerod, 1990). Thermally, tree removal alters radiative inputs and outputs with a tendency to decrease the

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doi:10.1016/j.foreco.2008.10.025

lowest temperatures and increase the higher temperatures sometimes to lethal levels.

Introduction of woody material, disturbance of banks and increased terrestrial inputs have also been shown to influence nutrient dynamics (Likens et al., 1969), with further consequences for algal productivity (Stone and Wallace, 1998; Boothroyd et al., 2004). Effects on nutrient dynamics can be considerable and may last many years after harvest (Neal et al., 2004). Finally, introduction of large amounts of organic matter provides a food resource for stream invertebrates, either directly (Golladay et al., 1989; Bilby and Ward, 1991) or via incorporation into fungal and bacterial biomass (Tank and Dodds, 2003).

A synthesis of previous studies permits development of a conceptual model of expected changes to physicochemical conditions and stream invertebrate communities after harvesting in riparian zones (Fig. 1). Broadly, there are two effects which occur via introduction of woody material into the channel (1) effects on basal resources, namely an increase in detrital and algal resources, (2) changes in habitat, through alteration in the nature of the sediment, changes in channel morphology and introduction of woody debris. The combined effects of these changes in habitat have been shown to have impacts on invertebrate communities. A majority of studies have shown increased density and biomass of invertebrates after harvest (e.g. Duncan and Brusven, 1985; Stone and Wallace, 1998; Kedzierski and Smock, 2001; Nislow and Lowe, 2006). It is worth noting, however, that these studies are predominantly from North America, where stream fauna have co-evolved with the type of litter supplied during harvest. In parts of the world where plantation forests of exotic trees are the norm, such responses may not occur.

In addition to changes in habitat as a result of introduction of woody debris, harvesting can also have important effects on hydrology (e.g. Ormerod et al., 1993; Broadmeadow and Nisbet, 2004). Reduction in forest cover can act to increase 'flashiness' of flows due to increased rates of surface run-off. In addition, forest cover can have major effects on water interception (Fahey and Jackson, 1997), which are reversed following clear cut harvesting. Changes in hydrologic variability directly impact channel form and sediment retention, in addition to patterns of nutrient dynamics and retention. These factors, together with direct effects of changes in flow regime on species traits, impact on invertebrate communities.

Impacts of harvesting on community composition of aquatic systems have also been hypothesised, although no consistent pattern has emerged from previous studies. Inputs of woody debris into streams after harvest may be expected to increase habitat heterogeneity in terms of flow velocity, depths and availability of refugia from fish or invertebrate predation (Downes et al., 1998). Woody debris in aquatic systems may also be associated with high secondary productivity, in both undisturbed (Benke and Wallace, 1997) and harvested (Stone and Wallace, 1998) catchments. Relationships between productivity and diversity have long been hypothesised (Leigh, 1965) and, although no consensus has emerged, positive relationships are common in the literature (Hooper et al., 2005; Thompson and Starzomski, 2007).

In addition to changes in invertebrate biomass and diversity, post-harvest changes in the representation of different functional feeding groups within communities have also been described (Fig. 1). Increases in shredders (which directly consume coarse organic material), collector–gatherers (which feed on fine organic matter) and grazers (which feed on algae) have been described in a number of studies (e.g. Stone and Wallace, 1998; Death et al., 2003; Herlihy et al., 2005; Nislow and Lowe, 2006). However, other studies have shown minimal changes in communities (Liljaniemi et al., 2002), or changes that cannot be accounted for by changes in food availability alone (Davies and Nelson, 1994; Death et al., 2003). The emergence of quantitative analyses of species traits (Resh et al., 1994) allows a more sophisticated analysis of communities and a greater insight into mechanisms. Trait analysis allows an assessment of whether traits such as body size or certain life history characters are favoured by a disturbance. Such techniques are now being applied in a biomonitoring context and have proven to be more sensitive than traditional metrics (Doledec et al., 1999, 2006).

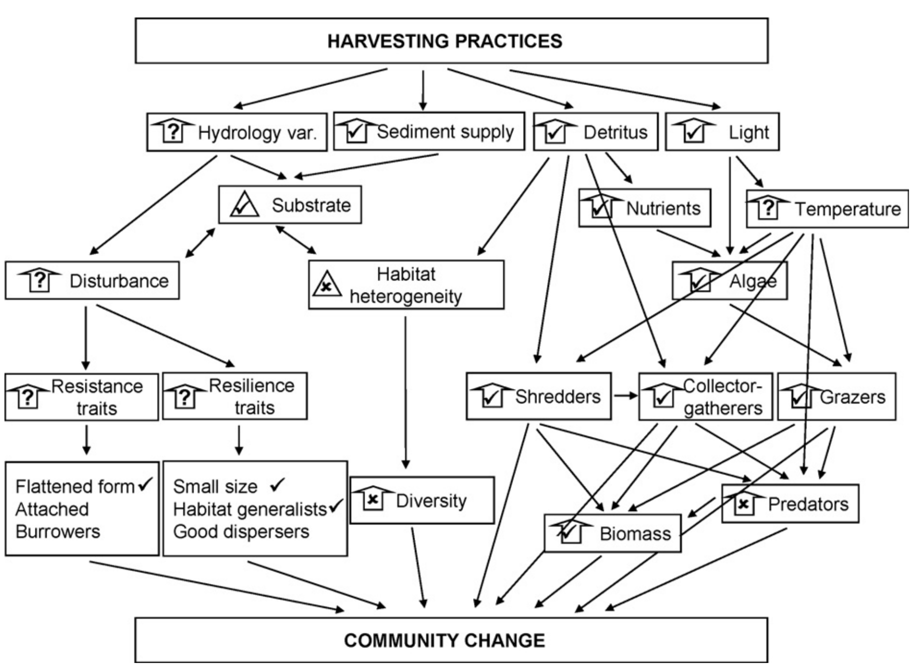

Fig. 1. Hypothesised responses in stream habitat and traits of invertebrate biota to riparian harvesting. Block arrows indicate hypothesised direction of change, triangles indicate hypothesised change where direction is unclear. Double headed arrows indicate reciprocal effects. Tick and cross symbols within the block symbols indicate whether the hypothesised change was supported or not by the current study.