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Increase in woody debris nutrient pools in stream channels following selection harvesting in a northern hardwood forest

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ABSTRACT

Timber harvesting can influence the rate of transfer of organic matter from terrestrial catchments to streams, which may affect in-stream nutrient pools and dynamics. In the interest of developing sustainable forestry practices, the continued study of the effects of forestry on nutrient dynamics in aquatic systems is paramount, particularly in sensitive nutrient-poor oligotrophic systems. The goal of this study was to investigate the impacts of harvest-related woody debris on stream nutrient status in six streams located in the Canadian Shield region of south-central Ontario, Canada. Surveys showed greater large (> 10 cm) and small (< 10 cm) woody debris dry masses and associated nutrient (e.g. phosphorus, potassium, carbon, nitrogen) pools in streams located in three catchments that had been selectively harvested in 2013, one year prior to this study, compared with three catchments not harvested for at least 20 years. There was no difference in annual litterfall nutrient inputs amongst sites and nutrient pools in fresh woody debris could be more than 60-fold greater than annual inputs in leaf litterfall at the harvested sites, but were less than annual leaf litter inputs in non-harvested sites. Laboratory leaching experiments suggest that fresh woody debris may be an important short-term source of water-soluble nutrients, particularly phosphorus and potassium. This study suggests that woody debris from timber harvest is potential source of nutrients that may augment stream nutrient export over long time periods and may to some extent help explain the long-term patterns of declining TP and K observed throughout this study region.

1. Introduction

The input of organic matter (OM) from riparian vegetation (allochthonous) to streams is one of the most important linkages between terrestrial and aquatic ecosystems (Gregory et al., 2003; Vannote et al., 1980; Webster and Benfield, 1986). Allochthonous OM inputs can account for a large portion of nutrient inputs in streams (Bilby, 1981; Meyer and Likens, 1979; Triska et al., 1984) and leaf litter can form the energy base for many in-stream biotic processes in forested streams (Wallace et al., 1997; Vannote et al., 1980). Leaf litter is often stressed as the most important allochthonous input, as it makes up a large portion of OM inputs (Gregory et al., 2003; Kreutzweiser et al., 2004; Webster et al., 1990) and thus, a large portion of the associated nutrient flux (Bilby and Likens, 1980; Triska et al., 1984). Woody debris is often ignored in this respect, as it represents a relatively small portion of total allochthnous OM and nutrient inputs and is relatively resistant to decomposition (Triska et al., 1984; Webster et al., 1999).

Although the contribution of woody debris is generally small compared with leaf litter, several studies have shown that woody debris can represent a large portion of in-stream OM and nutrient pools, and may thus provide a long-term source of nutrients to stream water (Golladay et al., 1989; Triska et al., 1984). Woody debris can also generate a considerable amount of fine particulate organic matter (FPOM) during decomposition, which is easily transported, and may therefore contribute to nutrient export from streams (Elosegi et al., 2007; Ward and Aumen, 1986). While woody debris influx from riparian vegetation is a natural phenomenon, resulting from tree death and breakage and other disturbances such as wildfire and disease (Harmon et al., 1986; Wallace et al., 2001), natural rates of woody debris influx can be magnified as a result of anthropogenic disturbances, such as timber harvest (Ballie et al., 1999a; Bilby and Ward, 1991). Studies seeking to quantify the effect of timber harvest on in-stream nutrient pools associated with woody debris are very limited (Chen et al., 2005); and while many studies have demonstrated the release of soluble nutrients from leaf litter, including dissolved organic carbon (DOC), phosphorus (P), and nitrogen (N) (Duan et al., 2014; Wallace et al., 2008), relatively few have evaluated the leaching of nutrients from wood (France et al., 1997; Harmon et al., 1986).

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The impacts of timber harvest on nutrient dynamics in streams are not only dependent on the logging practices employed, but also the specific characteristics of the site (Kreutzweiser et al., 2008). For example, while relatively small fluctuations in nutrient export may not be an issue in nutrient-rich eutrophic aquatic systems, they could have severe impacts in nutrient-poor systems, such as the oligotrophic landscape of the Precambrian Shield region of south-central Ontario. Both calcium (Ca) and P concentrations have declined in lakes and streams within this region (Eimers et al., 2009; Palmer et al., 2011; Watmough et al., 2003), which could have implications for aquatic biota (Yan et al., 2008; Jeziorski et al., 2008). Forest disturbance plays a large role in nutrient export in this oligotrophic landscape (Phillips and Watmough, 2012; Crossman et al., 2016), and may have contributed to long-term declines in both Ca and P (O'Brien et al., 2013; Watmough et al., 2003). Selection timber harvest regularly occurs in this part of Ontario, and understanding the biogeochemical implications of forest harvesting is clearly important for managing nutrient levels in surface waters. Selection harvesting, whereby individual trees or small groups of trees are removed at regular intervals (15–25 years), is commonly used in northern hardwood forests that are dominated by shade tolerant species such as sugar maple (*Acer saccharum* Marsh.).

The objective of this study was to investigate the impact of selection harvesting on woody debris and leaf litter inputs in oligotrophic streams on the Precambrian Shield. To accomplish this, woody debris was measured and nutrient pools were calculated and compared across six headwater streams located north of Huntsville, Ontario, including three that were recently harvested in 2013, one year prior to this study, and three which had not been harvested for at least 20 years. Leaf litter inputs were also measured to contrast nutrient influxes associated with leaf litter vs. woody debris. Finally, laboratory experiments were used to compare the water-soluble nutrient content of leaves and wood.

2. Methods

2.1. Study sites

For the purpose of this study, six headwater streams were selected in May 2014, including three 'disturbed' streams located in catchments subjected to selection harvest one year previously (2013), and three 'undisturbed' streams that had no record of timber harvest for at least 20 years (Fig. 1) All of the impacted streams (S1, S2, and S3) and two of the control streams (RR, ATV) are located in the Parry Sound District of southern Ontario, Canada, within 20 km of the town of Kearney, Ontario (45°33′N, 79°13′W). The third control stream (HP3A) is located in the Muskoka District at Harp Lake (45°22′N, 79°08′W), and is part of the Ontario Ministry of the Environment and Climate Change (OMOECC) Dorset Environmental Science Centre's (DESC) monitoring program, which has been collecting stream flow and chemistry data since the late 1970 s. All sites are located on the Precambrian Shield, which is characterized by shallow (generally < 1 m deep), acidic, and nutrient poor sandy soils; classified as podzols or brunisols (Soil Classification Working Group, 1998). Soils in the area overlie igneous and metamorphic bedrock, including biotite and hornblende gneiss, amphibolite, and schist (Dillon et al., 1991). Forest cover at all sites is largely dominated by sugar maple and yellow birch (*Betula alleghaniensis* Britt).

Disturbed sites (S1, S2, and S3) were selectively harvested (35–40% basal area removal) in the winter of 2013. An assigned riparian buffer of at least 15 m was used, with larger widths used in areas of greater slope. Sugar maple was the primary species harvested, with lesser amounts of yellow birch and American beech (*Fagus grandifolia* EhrH; Barry Davidson, Westwind Forest Stewardship Inc., pers. comm.). Disturbance along the disturbed streams was variable; some areas showed little to no impact due to poor accessibility, while other areas, such as designated stream crossings, showed large accumulations of woody debris where logging slash (logs and branches) was purposely placed in the stream for use as debris bridges. Streams RR, ATV, and HP3A are located in secondary growth stands that have not been harvested for at least 20 years. Based on harvesting records provided by Westwind Forest Stewardship Inc., selective harvest last occurred within the RR and ATV catchments in the early to mid-1980 s. It should be noted that the harvesting records show that harvesting occurred in the outer limits of the RR catchment in 2000, but based on observations during preliminary site visits, it appears that this impact was either insignificant, or non-existent. The forest surrounding HP3A was also selection harvested in the late 1970 s and early 1980 s, but these harvests are not well documented because this catchment is privately owned. The riparian forest around every sample reach was primarily

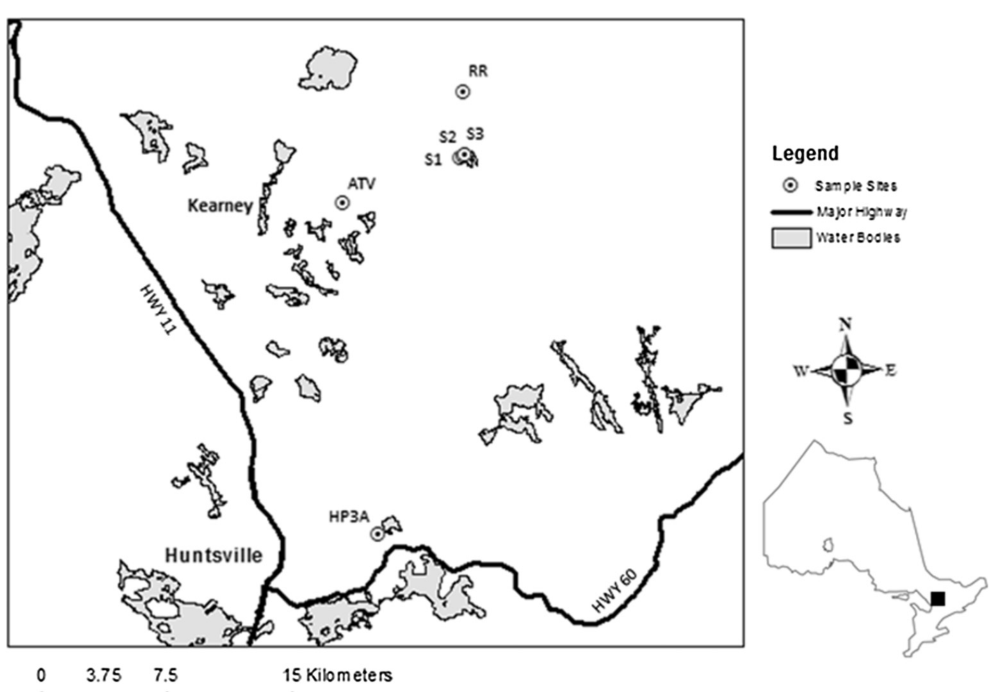

Fig. 1. Location of study sites. Select major water bodies, and the location of the towns of Kearney and Huntsville are shown for reference.