Forest Ecology and Management 430 (2018) 299–311

Contents lists available at ScienceDirect

Forest Ecology and Management

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

From skid trails to landscapes: Vegetation is the dominant factor influencing erosion after forest harvest in a low relief glaciated landscape

Zachary P. McEachran[a,*], Robert A. Slesak[b], Diana L. Karwan[a]

[a] University of Minnesota, Department of Forest Resources, St. Paul, MN 55108, United States
[b] Minnesota Forest Resources Council, St. Paul, MN 55108, United States

ARTICLE INFO

Keywords:
Forestry water quality
Watershed management and planning
Forest roads
Timber harvest
Best management practices
Erosion risk areas

ABSTRACT

Water quality in working forested watersheds is generally high, but forestry activities may cause sedimentation of surface water if best management practices (BMPs) are not implemented during harvesting. As water resources are often managed at a landscape scale (such as by ecoregion or watershed), and BMPs are often implemented at the feature scale (such as forest road or skid trail), it is imperative to understand how biophysical factors influencing erosion (e.g., slope, soil properties, rainfall, and vegetation) behave across multiple scales. Our objective was to identify which biophysical factors determine whether erosion occurs after forest harvesting in a low relief glaciated region at the feature, harvest site, and landscape scales in order to aid in BMP optimization and ecological assessment of erosion dynamics in working forested watersheds. We analyzed monitoring data from forest roads, skid trails, and log landings on spatially referenced harvest sites in Minnesota, USA collected between 2004 and 2016 to identify major erosion risk factors. Post-harvest vegetative cover levels are more important than slope, soils, and climate factors at all spatial scales for explaining the occurrence of erosion. At the landscape scale, we identified a moderate inverse relationship between mean erosion and vegetative cover levels on sites located in different ecoregions ($r^2 = 0.66$) and a strong relationship for sites located on different glacial landforms ($r^2 = 0.90$). Vegetative cover is a dominant factor controlling erosion occurrence after forest harvesting in low relief glaciated regions, and glacial history is an important driver of both erosion and vegetation dynamics at the landscape scale for these regions. Revegetation BMPs and harvest practices that promote revegetation should be focused on high-erosion landscapes to reduce erosion where it is most likely to occur.

1. Introduction

Soil erosion associated with forest harvesting activities has been an area of concern for decades (Binkley and Brown, 1993; Cristan et al., 2016; Megahan, 1972). Forests generally maintain high water quality (Neary et al., 2009), but water quality can decrease if proper forest management practices are not implemented (Binkley and Brown, 1993). When implemented properly, best management practices (BMPs) are effective at mitigating negative effects of forest harvesting on water quality due to erosion and sediment delivery (Anderson and Lockaby, 2011; Aust and Blinn, 2004; Cristan et al., 2016). Questions remain, however, about the quantitative efficacy of specific BMPs, and how to optimize their use with respect to economic, operational, and environmental considerations (Anderson and Lockaby, 2011), as well as about cumulative watershed effects of forest harvesting and BMP effectiveness across spatial and temporal scales (Grace, 2005; Klein et al., 2012; Slesak et al., 2018). Part of optimizing the usage of BMPs with respect to erosion is identifying areas that have a relatively high probability of erosion occurrence so BMP efforts can be focused and made more effective on higher-risk areas (Slesak et al., 2018).

Erosion on forest harvest sites can occur in many forms, including mass slope failures, water, and wind erosion. In steep terrain, much of the erosion after forest harvesting is the result of landslides and mass failures on a small fraction of managed area (Rice and Lewis, 1991) caused by steep slopes, forest roads and their interruption of hillslope drainage, high subsurface water associated with vegetation loss, noncohesive slope materials, and loss of soil strength due to decay of roots (Durgin et al., 1988; Johnson et al., 2007; Rice and Lewis, 1991). Wind erosion can be a driver of sediment rivaling water erosion in arid and semi-arid regions (Breshears et al., 2003; Whicker et al., 2006). In wet regions with low relief, sheet and rill erosion are more common after harvest, with gully erosion also occurring depending on relief and land

* Corresponding author at: 209C Green Hall, 1530 Cleveland Avenue N., St. Paul, MN 55108, United States.
E-mail address: mceac015@umn.edu (Z.P. McEachran).

https://doi.org/10.1016/j.foreco.2018.08.021
Received 18 June 2018; Received in revised form 10 August 2018; Accepted 11 August 2018
0378-1127/

use history (Merten et al., 2010; Patric, 1976; Rivenbark and Jackson, 2004).

Factors influencing water erosion are widely studied, and include slope grade, length, and roughness; vegetative ground coverage and root structure; soil texture, compaction, and erosivity; and rainfall amount and intensity (Luce and Black, 1999; Valentin et al., 2005; Wischmeier and Smith, 1978). These factors can be used to identify areas associated with a relatively high probability of erosion occurrence, but specific identification of risk areas depends largely on the spatial scale at which the factors influencing erosion are assessed (Slesak et al., 2018). When erosion risk areas are identified on a feature scale (i.e., on individual forest roads or skid trails), this offers valuable information for on-the-ground evaluation of individual BMP effectiveness. Assessment at the site scale may offer managers a broader perspective for planning BMP usage and recommendations prior to harvest. Assessment at a landscape scale (demarcated by ecoregion, for example) could allow customized recommendations for landscapes or ecosystems of interest, and clarify the potential role erosion plays in broader ecosystem functions. An example of a landscape demarcation scheme is Minnesota's Ecological Classification System (ECS) that defines nested ecoregions throughout the state based on soils, climate, vegetation, geology, and hydrology to inform management of ecosystems (Hanson and Hargrave, 1996; Minnesota Department of Natural Resources (MN DNR), n.d.). The relative importance of erosion drivers at each of these scales is unclear.

Studies designed to identify erosion risk factors tend to focus on high timber producing regions. In the United States, these include the Southeast and Pacific Northwest/intermountain West regions (Adams et al., 2006). Studies typically focus on one scale at a time, and do not compare erosion dynamics across multiple scales in the same region of interest. In the Southeast, erosion due to forest harvesting is affected by the legacy of agricultural land use (Jefferson and Mcgee, 2013; Lang et al., 2015; Rivenbark and Jackson, 2004), geologic and hillslope factors and associated steep slopes in the Appalachians and foothills (Piedmont) (Aust et al., 2015; Rivenbark and Jackson, 2004; Vinson et al., 2017a,b), and high precipitation amount and intensity relative to the rest of the United States (Beasley and Granillo, 1988; Hershfield, 1961; Terrell et al., 2011). Intensive forest management practices (e.g., slash removal and utilization, site preparation, vegetation control (Grigal, 2000)) are reported to influence water quality (Grace, 2005; Lewis et al., 2001). In the United States, forests in the Southeast are intensively managed and some of the most productive in the world (Grace, 2005). In the Pacific Northwest and intermountain West, erosion due to forest harvesting is affected by high slope grades and related hillslope position (Litschert and MacDonald, 2009; Luce and Black, 1999; Madej, 2001; Megahan et al., 2001; Sugden and Woods, 2007), mountain and coastal driven precipitation patterns (Bywater-Reyes et al., 2017; Madej, 2001; Rashin et al., 2006), geologic history (Bywater-Reyes et al., 2017; Sugden and Woods, 2007), and slope material cohesiveness as well as subsurface water levels (Durgin et al., 1988; Rice and Lewis, 1991). Forest management tends to be intensive in the Pacific Northwest as well (Moores et al., 2007); this could also affect water resources and erosion. Implementation of contemporary BMPs, however, have substantially reduced negative water quality effects due to harvesting throughout the United States (Cristan et al., 2016; Loehle et al., 2014; National Council for Air and Stream Improvement Inc (NCASI), 2012).

The inference and applicability of findings from the landscapes of the Pacific Northwest/intermountain West and Southeast to other regions warrants investigation, especially those with landscapes exhibiting vastly different geomorphic characteristics – such as the low relief glaciated landscapes of the western Great Lakes region, which include Minnesota, Wisconsin, and Michigan in the United States (known as the western Lake States). The western Lake States generally have very low topographic relief; as a reference, a typical northern Minnesota upland-peatland small watershed has an average upland slope of about 10% and average peatland slope of less than 0.1% (Verry et al., 1983). Groundwater-surface water connection through wetlands, peatlands, and lakes are ubiquitous in the western Lake States, with vast areas of wetland soils. There are deep layers of glacial till throughout the western Lake States due to their extensive glaciation by lobes of the Laurentide Ice Sheet. This glaciation is primarily responsible for the topographic properties of the landscape, and also has large influence on soil types and vegetative communities present in different areas (Hobbs and Breckenridge, 2011; Jennings and Johnson, 2011; Larson, 2011; Syverson and Colgan, 2011). In contrast, the Southeast was never glaciated during the Quaternary, and the last glacial maximum of the Laurentide Ice Sheet had influences over only the most northern parts of the Pacific Northwest and intermountain West (Dyke et al., 2002). Forest management tends to be relatively extensive, rather than intensive, in the western Lake States (e.g., site preparation and short rotations are uncommon; D'Amato et al., 2009; Grigal, 2000). Furthermore, most forest harvesting occurs in the winter on frozen soils (Rossman et al., 2016), which limits soil compaction and promotes revegetation (Berger et al., 2004; Kolka et al., 2012). Because of these defining factors typical of a low relief glaciated landscape, and consequent differences in watershed and erosion dynamics compared to other regions, it is not clear how past work carried out in regions with large differences in characteristics applies to an extensively managed, low relief, and glaciated landscape, exemplified by the western Lake States.

To assess the drivers of erosion across spatial scales in a low relief and glaciated landscape, we conducted an analysis to determine the primary factors influencing the occurrence of surface, water-derived erosion following forest harvesting in Minnesota, USA. We aim to identify dominant biophysical erosion factors and provide managers with information enabling their identification of erosion risk areas and subsequent BMP optimization and implementation. We utilized an extensive BMP monitoring dataset in combination with other geospatial data to evaluate the factors influencing whether or not erosion occurs following forest harvesting activities. The assessment was conducted across a range of scales, spanning from the individual feature within a site to the landscape region. By analyzing data from northern Minnesota, in which nearly all of the forest harvesting in Minnesota occurs, this analysis has implications for similar low relief glaciated regions globally, and especially for the greater Great Lakes region.

2. Methods

2.1. Setting

Forests cover about 1/3 of the land area in Minnesota, with the forested regions concentrated in the north and northeastern parts of the state (Fig. 1). Common forest types include aspen/birch, northern hardwoods, pine, and wetland conifers such as black spruce and tamarack. Wetlands are extensive throughout the northern part of the state, especially in the north-central region. The climate is continental, with moist, warm summers and dry, cold winters (Sebestyen et al., 2011). The Quaternary of Minnesota was dominated by several advances of lobes of the Laurentide Ice Sheet, which shaped much of the present-day topography and deposited deep layers of glacial till that strongly influenced soil development (Fig. 2) (Jennings and Johnson, 2011). Ownership of forest land is split almost evenly between public and private entities, but forest harvesting is concentrated on publicly owned land (~65% of production, (Minnesota Department of Natural Resources (MN DNR), 2016)). Forest management is generally low intensity with practices such as site preparation, short rotations, and cultural inputs (e.g., herbicide, fertilization) uncommon (D'Amato et al., 2009; Slesak et al., 2018). Most harvesting is conducted with mechanized equipment (ranging from full tree skidding to cut-to-length systems; Blinn et al., 2015), uses the clear cut with reserves (i.e., green tree retention) silvicultural method, and occurs during winter months