Forest Ecology and Management 404 (2017) 344–353

Contents lists available at ScienceDirect

Forest Ecology and Management

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

Soil properties in site prepared loblolly pine (*Pinus taeda* L.) stands 25 years after wet weather harvesting in the lower Atlantic coastal plain

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ARTICLE INFO

Keywords:
Forest operations
Harvesting
Site preparation
Loblolly pine
Bedding
Soil properties

ABSTRACT

Harvesting traffic may alter soil properties and reduce forest productivity if soil disturbances are not mitigated. Logging operations were conducted during high soil moisture conditions on the South Carolina, USA coast to salvage timber and reduce wildfire potential following Hurricane Hugo in 1989. Long term study sites were established on wet pine flats to evaluate effects of primary skid trails and site preparation on soil properties and loblolly pine productivity. The experiment was analyzed as a split-plot within an unbalanced randomized complete block design having 12 blocks, two levels of traffic (primary skid trail (On), no obvious traffic (Off)) and four levels of site preparation (bedding (Bed), disking with bedding (D/B), disking (Disk), no site preparation (None)). Remeasurement of the study was conducted in 2015 at 25 years after salvage logging (stand age 23 years). Bed and D/B treatments had greater saturated hydraulic conductivity ($p = 0.0567$) and macroporosity ($p = 0.0071$) and lower bulk density ($p = 0.0226$) values than Disk and None treatments. Macroporosity benefits were evident two years after site preparation installation, but bulk density and saturated hydraulic conductivity were not, suggesting these two measurements were affected over time by differences in rooting activity influenced by initial aeration benefits. Depth to iron depletion ($p = 0.0055$) was significantly greater and soil carbon ($p < 0.0001$) was significantly lower in Bed and D/B treatments due to bed elevation above the water table and improved drainage. This implies greater aeration for roots, but trade-offs in aboveground biomass and soil carbon storage. However, above and below ground carbon differences balanced one another between treatments so that combined carbon storage in soil and above ground loblolly pine biomass was not significantly different by site preparation treatment ($p = 0.1127$). Bed and D/B resulted in approximately double the stand biomass ($p < 0.0001$) and stand density ($p < 0.0001$) than Disk and None. Bed and D/B generally created more favorable soil properties and enhanced long term loblolly pine stand productivity. Differences in soil properties and stand productivity between traffic levels, with and without site preparation, were negligible suggesting natural soil recovery mechanisms were mitigated effects of wet site harvesting over 25 years.

1. Introduction

1.1. Background

Society benefits from numerous ecosystem services provided by forests. Demands for these services are expected to increase concomitantly with global declines in forested land area due to human population growth (Burger, 2009; FAO, 2015; Fox, 2000). To capitalize on timber resources, forests are often harvested with heavy machinery which has potential to alter soil properties, thereby reducing forest productivity and quality of ecosystem services (Cambi et al., 2015; Miwa et al., 2004). The effects of heavy equipment traffic on soil properties and forest productivity have been investigated around the world (Horn et al., 2004; Makineci et al., 2007; Murphy et al., 2004; Naghdi et al., 2016; Pinard et al., 2000; Powers et al., 2005; Rab, 2004). Forest harvest related soil disturbances that have been associated with decreased forest productivity include compaction (Greacen and Sands, 1980; Moehring and Rawls, 1970), decreased saturated hydraulic

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http://dx.doi.org/10.1016/j.foreco.2017.08.015
Received 7 July 2017; Received in revised form 4 August 2017; Accepted 9 August 2017
Available online 14 September 2017
0378-1127/

Fig. 1. Approximate location of study area within the Francis Marion National Forest, Berkeley County, S.C., United States.

conductivity (Gent et al., 1984, 1983), poor aeration (Aust et al., 1998a, 1995, 1993; Xu et al., 2002), reduced nutrient availability (Powers et al., 2005; Tan et al., 2005), increased mechanical resistance to root penetration (Carter et al., 2007; Hatchell et al., 1970; Lockaby and Vidrine, 1984), and organic matter displacement (Powers et al., 2005; Rab, 2004).

In the Southeastern U.S. coastal plain, intensively managed pine plantations are commonly implemented to enhance timber production and the quality of ecosystem services on a per hectare basis (Fox, 2000; Stanturf et al., 2003). Pine plantations may occur on "wet pine flats," "wet flats," or "wet flatwoods," and some satisfy criteria of jurisdictional wetlands (Harms et al., 1998). In addition to those provided by upland forests, forested wetlands provide a suite of ecosystem services that may be jeopardized by traditional forestry practices (Richardson, 1994). The frequent high soil moisture conditions characteristic of wetlands may exacerbate degradation of soil properties caused by equipment traffic (Akram and Kemper, 1979; Cambi et al., 2015; Greacen and Sands, 1980; Miwa et al., 2004; Moehring and Rawls, 1970). Forestry best management practices recommend avoidance of equipment operation during periods of high soil moisture, but this is often not logistically or economically feasible (Miwa et al., 2004). The resulting changes in soil properties must be mitigated to a condition capable of supporting desired species, either naturally or artificially, to ensure forestry is sustainable (Burger, 2009; Fox, 2000). Some forests apparently have adequate natural soil and productivity recovery mechanisms such as sediment deposition (McKee et al., 2012), shrink-swell activity (Lang et al., 2016, McKee et al., 2012), weather patterns (Eisenbies et al., 2007; Passauer et al., 2013), and resilience to compaction (Powers et al., 2005).

Site preparation can enhance forest productivity by manipulating soil properties (Fox, 2000; Morris and Lowery, 1988). Researchers have also suggested that site preparation is essential to ameliorate properties and productivity of soils disturbed by logging (Lof et al., 2012; Miwa et al., 2004; Reisinger et al., 1988). Bedding and disking have traditionally been prescribed in the Southeastern U.S. to augment or mitigate soil properties and site productivity, and short term benefits of bedding and variable results of disking have been reported (Aust et al., 1998b; Gent et al., 1984, 1983; Hatchell, 1981; Mann and Derr, 1970; McKee and Shoulders, 1974; Pritchett, 1979; Xu et al., 2002). Long term effects of bedding on forest productivity are also widely reported (Gent et al., 1986; McKee and Hatchell, 1986; McKee and Wilhite, 1986; Passauer et al., 2013; Tiarks and Haywood, 1996; Wilhite and Jones, 1981); however; few studies report the long term effects of mechanical site preparation on soil properties (Kyle et al., 2005; Lang et al., 2016). Evaluating how soil properties change over time allows for understanding of factors controlling forest productivity such that management prescriptions can be made precisely, efficiently, and sustainably to fulfill the growing demand for forest ecosystem services (Burger, 2009).

1.2. Objectives

The objectives of this study are to evaluate the effects of site preparation and wet weather primary skid trails on selected soil properties and stand productivity at stand age 23 years (25 years after salvage logging). The study also seeks to determine if soil properties and stand productivity in non-site prepared primary skid trails have naturally recovered to the state of an undisturbed soil at stand age 23 years. The effects of these treatments on loblolly pine productivity are presented in Neaves et al. (2017).

2. Methods

2.1. Study site description

Six experimental sites were established within the Francis Marion National Forest in Berkeley County, South Carolina, United States (Fig. 1). Berkeley County is in the lower Atlantic coastal plain physiographic region. Average annual precipitation is 129 cm (NOAA, 2016), and average daily high temperatures are near or above 32 °C during the summer and 15.5 °C in the winter (Long, 1980). The sites were established in 1989 to study the long term effects of site preparation and wet weather primary skid trails on soil properties and loblolly pine productivity. The study was implemented following the salvage logging of timber damaged by Hurricane Hugo. Five to twelve loblolly or longleaf pine trees per hectare remained standing after the hurricane (Scheerer, 1994; Tippett, 1992).

The sites are characterized as wet pine flats, distinguished by minimal lateral relief, dense argillic horizons, and longleaf pine (*Pinus palustris* Mill.) and loblolly pine (*Pinus taeda* L.) dominated canopies. Dominant soil series within the study sites include somewhat poorly drained Lynchburg (fine-loamy, siliceous, semiactive, thermic Aeric