Forest Ecology and Management 266 (2012) 239–245

Contents lists available at SciVerse ScienceDirect

Forest Ecology and Management

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

Downed wood associated with roundwood harvest, whole-tree harvest, and unharvested stands of aspen in Wisconsin

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ARTICLE INFO

Article history:
Received 20 August 2011
Received in revised form 1 November 2011
Accepted 17 November 2011
Available online 15 December 2011

Keywords:
Aspen
Coarse woody debris
Fine woody debris
Forest residues
Timber harvest
Woody biomass harvest

ABSTRACT

Public demand for alternative energy sources, including bioenergy and biofuels, is resulting in increased demand for woody biomass from forest ecosystems. Forest management practices may change to meet the increased demand for woody biomass through the intensification of timber harvest, which includes shortened rotation times and increased removal of woody material. Our goals were to provide empirical data on residual wood retained on site following operational harvest of aspen stands, including quantification of woody debris of all size classes and the development of quantitative models to express the relationship between coarse and fine woody debris. Aspens stands with roundwood harvest (125.71 ± 20.79 m^3/ha) contained more total downed wood than stands with whole-tree harvest (75.54 ± 23.70 m^3/ha), and both harvest types contained more downed wood than unharvested, mature aspen stands (40.90 ± 11.60 m^3/ha). Notably, harvested stands contained on average more fine woody debris (58.31 ± 15.86 m^3/ha) than coarse woody debris (39.89 ± 20.48 m^3/ha). We found strong support for the model predicting volume of fine woody debris from volume of coarse woody debris, harvest type, and county. This tool will enable managers to estimate volumes of fine woody debris when field measurements of fine woody debris are too labor intensive. Our results indicate that recently harvested stands of aspen contain downed wood that could lend itself to intensification of timber harvest as markets for woody biomass increase. However, these estimates also highlight that substantial amounts of woody material have historically remained on site as wildlife habitat and nutrient inputs into regenerating stands, and thus this woody material may be necessary for long-term forest sustainability.

Published by Elsevier B.V.

1. Introduction

Increasing energy costs along with efforts to reduce carbon emissions are motivating public interest in alternative energy sources and subsequent passage of legislation, such as the Energy Policy Act of 2005 and the Energy Independence and Security Act of 2007. These Acts aim to increase use of alternative energy sources through the development of biofuels and mandate a five-fold increase in biofuel production over the next 15 years, with 60% derived from cellulosic biomass (Benjamin et al., 2010). These policy goals have created greatly increased markets for woody biomass.

Increased demand for woody biomass affects forest management through: (1) additional timber harvests of stands previously deemed too low in quality for timber production, (2) expansion of short-rotation woody crops such as fast growing hybrid willow, and (3) intensification of timber harvests in managed forests through shortened rotation times and increased removal of woody material (hereafter referred to as intensification; Janowiak and Webster, 2010). Increased removal of woody material could result from the removal of tree tops, limbs, stumps, roots, or dead standing and downed wood present before harvest. Intensification has the potential to be a rapid change to forest management since this change is a modification of current practices as opposed to the addition of a practice, such as planting hybrid willow stands. Timber sale documents often do not require or include information regarding small size classes of woody material which provides potential for logging operators to intensify woody debris removal without further authorization from forest managers. For example, the sale documents for an aspen whole tree chip harvest may not change, but markets for woody biomass now provide logging operations with an increased incentive to ensure all tree tops are chipped.

Meeting human needs for resources require that forest management remain sustainable as defined as "the practice of meeting

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0378-1127/$ - see front matter Published by Elsevier B.V.
doi:10.1016/j.foreco.2011.11.029

forest resources needs and values of the present without compromising the similar capabilities of future generations (Janowiak and Webster, 2010)". Hence, many states are developing management guidelines for harvest of woody biomass to advise threshold levels of woody material needed to support key ecological functions. For example, the Wisconsin's Forestland Woody Biomass Harvesting Guidelines state that logging operations should retain all coarse woody debris present prior to harvest and 10% of the tree tops on site following timber harvest (Herrick et al., 2009). Similarly, Michigan advises that 1/6–1/3 of harvested tree residues (i.e., tree tops, limbs <10 cm diameter) be retained and Missouri recommends that 1/3 of tree tops be retained on site (Evans and Perschel, 2009).

Downed wood on recently harvested stands serves a critical role in nutrient retention (reviewed by Johnson and Curtis, 2001) and serves as wildlife habitat (reviewed by Riffell et al., 2011). Key ecological functions of retaining coarse woody debris include maintaining soil C and N, preventing run-off, and providing foraging substrates for a variety of wildlife species (e.g., perches for foraging predators or cover while foraging for prey). The definition of coarse woody debris is varied in the literature and in practice. A global review found 10 cm in diameter to be the most common among countries and 7.6 cm to be a close second (Woodall et al., 2009). Wildlife biologists tend to use the 10 cm in diameter definition (Riffell et al., 2011). The 7.6 cm definition is used by the Forest Inventory and Analysis (FIA) program and this definition originated from a classification of burn times for fuel management (Brown, 1974; Deeming et al., 1977; Harmon and Sexton, 1996). Notably, the size class of wood needed to produce end products also corresponds to these definitions. Sawmills historically required saw or veneer logs from tree trunks at least 25 cm in diameter and pulp mills supporting paper production prefer high-quality woodchips that are the byproduct of sawmills or tree trunks at least 10 cm in diameter. The remaining woody material in a forest, including branches, unmarketable timber (e.g., crooked or damaged tree trucks, undesirable tree species), roots, and shrubs has historically been left on site following harvest. Biofuel and energy production now provides a market for these materials. The ecological importance of fine woody debris is poorly understood (Riffell et al., 2011; but see Manning and Edge, 2008). Therefore the ability to write effective biomass harvest guidelines is hindered by the lack of information.

New harvest methods developed to support emerging woody biofuel and energy markets may alter levels of residual wood through removal of formerly unmarketable size classes; these changes are poorly understood and unquantified. The ecological impacts of increased woody debris removal cannot be understood fully without quantification of woody debris volumes following different harvest methods. Estimates of forest biomass that include live and dead wood have been calculated within the context of carbon cycling and sequestration (Perry and Brand, 2007; Brown et al., 2008) or regional quantification of biomass (Becker et al., 2009); however, much less effort has been put into direct measurements of downed wood left on the ground following harvest, especially of size classes ⩽10 cm in diameter (Riffell et al., 2011). Further, most quantifications of downed wood have been completed in stands experimentally harvested for scientific purposes, and thus quantification of residual wood is lacking on operationally harvested stands and is also rarely reported in the Great Lakes Region (Riffell et al., 2011).

Our goal was to provide empirical data on downed wood retained on site following operational harvest of aspen stands. Our first objective was to quantify the volume of both coarse and fine woody debris retained on site following harvest. We compared two harvest types, roundwood harvest (i.e., boles >10 cm in diameter) and whole tree chip harvest, to mature stands. In roundwood harvest, the bole of the tree is removed from the stand and all remaining woody material is left on site. In whole-tree harvest, the entire tree including branches is removed from stands as wood chips. Our second objective was to quantify the relationship between fine woody debris and coarse woody debris and to develop predictive models for estimating fine woody debris from coarse woody debris.

2. Methods

2.1. Selection of aspen stands

We sampled replicate aspen (*Populus tremuloides*) stands of three harvest types ($N_{\text{Roundwood}} = 14$, $N_{\text{Whole-tree}} = 17$, $N_{\text{Control}} = 10$) in four counties ($N_{\text{Burnett}} = 14$, $N_{\text{Douglas}} = 7$, $N_{\text{Oneida}} = 14$, $N_{\text{Marinette}} = 6$) for a total of 41 stands in northern Wisconsin. Harvest type was defined as roundwood harvest (i.e., traditional 4 inch bole harvest, where the boles are removed and limbs left on site), whole-tree harvest (i.e., trees are cut at the base, brought to a staging area, and the entire tree including limbs is fed through a chipper or grinder on site) or control (i.e., unharvested, mature aspen stand between 40 and 50 years). Burnett, Oneida, and Marinette Counties are the three counties with the sandiest soils in the state and are dispersed among the western, central, and eastern parts of the state (Fig. 1A). Sandy soils were selected based on their greater susceptibility to nutrient depletion (Paré et al., 2002). We added Douglas County as a comparison to Burnett County after discovery of unusually low levels of residual wood in Burnett County while collecting data. There is replication of all treatment combinations of harvest type and county, except that only one stand was classified as whole-tree harvest in Marinette County. This stand was described by the county forester as an intensive traditional bole harvest where chipping was conducted, and our results suggest that this stand could have been classified as roundwood harvest. Finally, we ensured that the three harvest types were spatially interspersed within each county.

We selected stands from the Wisconsin Forest Inventory & Reporting System (WisFIRS), a database designed to track timber sales on public and private lands throughout Wisconsin. We focused on county forest land due to the completeness of data entry by county foresters, but also included a few stands on state-owned property. We selected stands meeting the following criteria: (1) aspen listed a primary species, (2) 35–100 acres in size, (3) approximately circular in shape with minimal edge (i.e., linear or torus shaped stands were not sampled to reduce edge effects), (4) harvested between 2007 and 2010 or between 1960 and 1970. We then contacted county or state foresters to confirm date and season of harvest and we asked the local forester to classify the harvest type. Since aspen is generally managed through even-aged management, harvest of aspen generally leaves no standing trees. However, a common practice for Wisconsin foresters is to indicate in sale prescriptions that red oak (*Quercus rubra*), white oak (*Quercus alba*), white spruce (*Picea glauca*), and white pine (*Pinus strobus*) should be left standing. We did not sample stands found to have an abundance of standing non-aspen species. Sampling occurred between September 2009 and July 2010.

2.2. Residual downed wood measurements

We placed 10 points randomly within each stand, subject to the requirement that points were >40 m from the stand edge and >80 m from each other. We sampled residual downed woody material at each point using line intersect sampling (Bate et al., 2004; Woodall and Monleon, 2008). Five transects 40 m in length radiated out from the point at 0, 72, 144, 216, 288 degrees to