Long-Term Biomass Harvesting Effects on Forest Productivity under Three Silvicultural Systems in the Northern Rocky Mountains

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Abstract

Recent rising public concerns about climate change and increasing energy costs have led to the need to re-evaluate forest biomass as an alternative energy feedstock. Biomass harvesting could potentially impact ecosystems in various ways, including site productivity and forest stand dynamics. Since these issues influence decision-making, the effects of biomass utilization are primary issues not only for silviculturists but also forest engineers. Yet our understanding of long-term effects of biomass removal remains limited. Better understanding is needed of the effects of biomass utilization on forest composition, structure, and productivity. This study revisits a 1974 forest harvest and biomass utilization research program in mixed-conifer stands at Coram Experimental Forest in northwestern Montana. Four harvest utilization standards (combined with prescribed burning treatment) were established with two replications under three harvesting systems (shelterwood, clearcut and group selection) via a running skyline yarder. This study will examine the consequences of biomass utilization and harvesting system on 1) the physiological productivity of individual trees, 2) stand productivity, 3) vegetation structure and composition, and 4) regeneration dynamics. In combination with a related study of soil responses, this study will provide a comprehensive understanding of the effects of biomass utilization and harvesting treatments on above-ground and below-ground forest condition and productivity.

Introduction

Recent rising public concerns about climate change and increasing energy costs have spurred public attention to an alternative energy feedstock – using forest biomass (Guo et al. 2007; Janowiak and Webster 2010). Estimates suggest that forest biomass has the potential to supply up to 10% of America’s current level of fossil fuel consumption (Perlack et al. 2005). For this reason, the US government seeks to boost the utilization of forest biomass (e.g. Energy Policy Act of 2005, Energy Independence and Security Act (EISA) of 2007).

According to EISA, biofuel production should be increased five times within the next 15 years, and 60% of biofuel should be derived from cellulosic feedstocks. There are many advantages to using forest biomass as an energy feedstock: 1) reduction of greenhouse gas emissions, 2) benefits for local economy, 3) reduction of energy costs, 4) promotion of sustainable forest management, and 5) promotion of rural development.

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4) reduction of emissions from burning treatments, 5) mitigation of dependency on energy feedstock imports, and 6) recycling of waste materials (Farr and Atkins 2010). With these advantages, it seems inevitable that future demands of forest biomass as a feedstock alternative will increase.

The responses of forest land management activities to meet future potential demands were summarized by Janowiak and Webster (2010) in three general ways. First, previously unmanaged, mismanaged, or underused stands (due to their low-market values) will be managed more aggressively. Second, on currently managed forest, biomass harvest intensity will be increased through increased residue removal. Lastly, more stands will be managed for the crops of short rotation. Among those alternatives, the second is most likely to be realized immediately due to its feasibility. Thus, future demands will likely lead to a more intensive utilization of forest residual materials.

Providing an alternative energy source must be balanced against maintaining ecosystem function and service. Forest residues are known to play an important role with crucial ecological functions forming structural features of forest ecosystem (Harmon et al. 2004). Many studies have addressed the importance of residues for various ecological functions, such as provision of soil organic matter, influence on nutrient cycling and hydrology, and wildlife habitat composition (Reijnders 2006; Patton-Mallory 2008). The long-term effect of intensive biomass removal on a forest ecosystem and its productivity should be a primary consideration among forest managers.

Impacts of biomass harvesting on soil/forest productivity

Biomass removal treatments affect ecosystems in various ways, with effects on microclimate, soil and forest productivity, hydrology, vegetation, biodiversity, and wildlife habitat (Reinhardt et al. 2010). Although some of these issues are beyond the scope of this study, these properties and processes are closely related and interact with each other.

Soil productivity – Timber harvesting and related management activities can enhance the soil microclimate. In Western Montana, Hungerford (1980) and Hungerford and Babbitt (1987) reported that exposed mineral soils or remnant substrates after management activities can increase the soil temperature, stimulating tree growth by enhancement of the root membranes’ permeability (Burger 2002). In addition, reduced solar radiation on the forest floor due to the generation of forest residues can adjust the water balance favorably. Since management practice can enhance the balance between water and air to improve root respiration, water uptake, and nutrient uptake (Burger 2002), biomass utilization might induce positive effects on productivity.

However, negative effects of biomass harvest on forest productivity are relatively well documented. These can include: soil compaction, depletion of organic matter and nutrients, and obstruction of microbial functions.
Most negative impacts of harvesting practice on soil physical properties are likely caused by soil compaction, especially from ground-based equipment. The greater removal of biomass requires more machinery use in general, resulting in increased soil compaction (Janowiak and Webster 2010). Compaction reduces soil porosity, hindering the movement of air, water, and nutrients needed for microbial activity (Thibodeau et al. 2000). Decrease of microbial activity in soil can consequently reduce the tree growth (Page-Dumroese et al. 2010).

In addition, intensified biomass removal may remove a larger amount of soil carbon and forest floor organic matter (Janowiak and Webster 2010). Loss of organic matter can negatively impact soil moisture retention, cation exchange capacity, and, as a result, tree growth (Ballard and Will 1981). Therefore, a reduction of soil organic matter and change in soil physical properties could have even greater consequences for site productivity than simply the removal of soil nutrients (Page-Dumroese et al. 2010).

Many studies have demonstrated the potential negative impact of intensive biomass removal on soil nutrient contents (e.g. White 1974; Kimmins 1977). Compared to conventional harvesting, intensive biomass utilization involves removal of additional materials. The problem is that these materials – such as branches and foliage – have much higher nutrient concentrations. Many scientists have argued that intensive biomass removal increases the risk of soil nutrient depletion such as N (Johnson and Curtis 2001), P, K (White 1974) and Ca (Boyle et al. 1973; Mann et al. 1988).

Stand manipulation can control microbial functions (Larsen et al. 1980). Mahmood et al. (1999) argued that there was a strong biomass removal effect on the quantity and development of ectomycorrhizae in Norway spruce forest in Sweden. They detected a significant decrease in ectomycorrhizal roots and humus layer thickness resulting from residue harvesting. Since the development of ectomycorrhizal roots is critically related to forest productivity in western forests (Harvey et al. 1980; Perry et al. 1989), the impact of biomass removal on microbial activity is an important determinant of site productivity. Larsen et al. (1980), for example, argued that decaying residues could mitigate water stress by increasing the pore volume of the woody substrate in northern Rocky Mountain forests. In contrast, biomass removal from the forest floor could lower moisture levels, leading to a decline in nitrogen fixation by soil bacteria.

**Forest productivity & vegetation dynamics** – The negative effects of biomass removal on soil productivity have the potential to be manifested in reduced tree growth. Simulation modeling approaches have shown that intensive biomass utilization is capable of depleting the nutrient budget to the extent that long-term productivity decline results (e.g. Boyle et al. 1973; Paré et al. 2002). Empirical evidence has also been found suggesting that nutrition deficiency induced by intensive biomass utilization leads to reduced tree growth. In Europe, whole-tree harvest resulted in tree growth reduction for Scots pine (Egnell and Leijon 1999; Egnell and Valinger 2003) and Sitka spruce (Walmsley et al. 2009; Proe et al. 1996).

However, increased biomass utilization does not always cause a reduction of above-ground biomass increment. There was no effect of biomass removal on Scot pine
growth in 22 yrs after whole-tree harvest in eastern Finland (Saarsalmi et al. 2010). Power et al. (2005) failed to find any significant relationship among biomass utilization treatments, soil nutrient contents, and above-ground biomass in a summary of 26 experimental sites across North America after 10 years harvest. Thus, the controversy over above ground productivity is still in progress.

Biomass utilization treatments can influence understory vegetation dynamics. In Sweden, Bråkenhielm and Liu (1998) found differences in understory vegetation species composition, dominance, species richness, and diversity when logging residues were retained versus removed. Schmidt (1980) and Fahey et al. (1991) reported differences in shrub recovery associated with combinations of biomass utilization level in the northern Rocky Mountains and in Wales, respectively.

Regeneration can be affected by the biomass utilization level as well as the harvesting system. In Washington, the height and diameter growth of 2-year-old Douglas-fir decreased with increasing biomass utilization levels, especially at low productivity sites (Bigger and Cole 1983). In the northern Rocky Mountains, Shearer and Schmidt (1999) observed the least natural regeneration at the intermediate biomass utilization level treatment (combined with no-burn treatment) 15-20 yrs following harvest. In the southern United States, 5-yr-old loblolly pine seedlings showed an 18 percent reduction in volume growth in a whole-tree harvest treatment (Scott et al. 2004).

Our understanding of the long-term effects of biomass removal remains limited. Many studies (e.g. nutrient budget analysis, modeling approach) on this topic have yielded uncertainty thus far (Mann et al. 1988; Egnell and Valinger 2003), since biotic and abiotic factors change and interact intricately after harvest. Instead, studies have demonstrated the necessity of long-term field experiments (Egnell and Leijon 1999; Egnell and Valinger 2003). Long-term assessment is critical in order to thoroughly understand complex changes in ecosystem function and structure (Likens 2004), but conducting and maintaining such experiments is often infeasible, expensive, and impractically time- and resource-consuming (Reinhardt et al. 2010). Although the subject is tangentially addressed by several long-term research networks – such as the North American Long-Term Soil Productivity (LTSP; for detail see Powers 2006; Page-Dumroese et al. 2006) and Long Term Ecological Research (LTER) – studies specifically focusing on biomass harvesting are insufficient, or are too young to draw long-term inferences.

1974 Forest Residues Utilization Research and Development Program

In the 1970s, there was plenty of interest in increasing biomass utilization from forests. This interest arose from increasing demands for wood material and from concerns over undesirable impacts on ecosystems (Benson and Schlieter, 1980). In the forest manager’s point of view, two conflicting needs emerged: 1) improvement of recovery and utilization of wood resources under the minimum residual materials, and 2)
reduction of unfavorable esthetic and environmental consequences of management activities (Barger 1980).

To address these concerns, a comprehensive and multidisciplinary research effort, the Forest Residues Utilization Research and Development Program, was established in 1974 at Coram Experimental Forest. Managed by researchers at the US Forest Service's Intermountain Forest and Range Experiment Station, the program was initiated to investigate timber harvesting alternatives and pursue the improved intensity and environmental compatibility of timber utilization.

The regeneration harvests of three silvicultural systems (shelterwood, clearcut, and group selection) were performed, and four utilization treatments ranging from conventional saw log utilization to near-complete utilization were allocated to each harvesting unit. A running skyline yader was used for harvesting to reduce understory disturbance. Prescribed broadcast burning treatment was included as part of four utilization treatments.

Today, this experimental installation provides a unique and timely opportunity to document the long-term effects of biomass utilization on productivity and regeneration dynamics. In spite of achievements of historical research program, the study’s value has not been fully exploited. The publications and reports spawned by the program contain only short-term responses or interim results, and the long-term impacts of biomass utilization level and harvest on ecosystems remain unclear. Since it has been nearly 40 years since treatments were put in place, the site now allows an opportunity to explore the long-term impacts of biomass utilization and harvest on ecosystems. Every block and treatment unit is easily accessed via a well-maintained forest road, and the integrity of treatment units remains largely intact. Coram Experimental Forest’s conditions suitably represent upland mixed conifer forests throughout the northern Rocky Mountains (Shearer and Kempf, 1999), thus the inferential value of research based at this site is great.

Research objectives and questions

The primary objective of the present study is to investigate the effects of biomass harvest levels (varying utilization standards combined with post-harvest prescribed burning treatment), when coupled with each of three common silvicultural systems (regeneration harvest methods), on northern Rocky Mountain forest vegetation and productivity. The study spans scales varying from individual tree (Objective 1) to stand (Objective 2), including understory vegetation (Objective 3). Additionally, this study will evaluate whether impacts of biomass utilization can be partially ameliorated (or exacerbated) by the use of artificial regeneration (Objective 4). Each research question and hypothesis is summarized in Table 1.
Table 1. Research questions and hypotheses.

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<th>Research Question</th>
<th>Research hypothesis</th>
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| Do biomass utilization treatments impact the physiological productivity of individual trees? | If biomass utilization treatments influence the physiological productivity of individual (regenerated) trees, then the growth efficiency of individual trees will be different by biomass utilization treatments.  
If biomass utilization treatments impact the physiological productivity of residual trees in the shelterwood harvesting units, then the growth efficiency (or radial growth) of residual trees will differ by biomass utilization treatments. |
| Do biomass utilization treatments impact the productivity of the stand?            | If there is a relation between biomass utilization treatments and stand productivity, then the total above-ground biomass of the stand following harvest differs by biomass utilization treatment treatments.  
If the impacts of biomass utilization treatments on productivity vary with stand strata (shrub, seedling, sapling and pole size-tree, and residual tree layer), then the amount of above-ground biomass for each stratum will be different by biomass utilization treatment treatments.  
If there is an interaction between biomass utilization effects and regeneration harvest method (silvicultural system), then the magnitude of effect on productivity will differ by regeneration harvest method. |
| Do biomass utilization treatments impact vegetation composition and structure?     | If the biomass utilization levels are related to the resulting vegetation composition, then species composition of tree and shrub community will vary with biomass utilization treatments.  
If biomass utilization levels affect structural complexity of the stand, then structural complexity will differ by biomass utilization treatments. |
| Can biomass utilization treatment impacts be ameliorated by artificial regeneration? | If planting seedlings can alleviate the negative effect of biomass utilization treatments on regeneration, then planted Douglas-fir trees will exhibit greater biomass accumulation than naturally-regenerated Douglas-fir trees.  
If planting seedling can alleviate the negative effect of biomass utilization treatments on regeneration, then planted Douglas-fir trees will exhibit greater growth efficiency than naturally regenerated Douglas-fir trees. |

Conclusion

Depending upon the specifics of the treatment, intensive biomass utilization appears capable of resulting in a more severe alteration of forest ecosystem function and structure than conventional timber harvesting. If so, then these alterations should be carefully assessed to clearly articulate the tradeoffs between biomass utilization and undesirable effects on forest and soil productivity. However, the current extent of our knowledge is insufficient to predict these effects and their magnitude, if any. The results of this study should provide meaningful information to fill these knowledge gaps and better inform biomass harvesting strategies.

References


