Biomass and Bioenergy 108 (2018) 236–243

Contents lists available at ScienceDirect

Biomass and Bioenergy

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

Research paper

Negligible impacts of biomass removal on Douglas-fir growth 29 years after outplanting in the northern Rocky Mountains

Woongsoon Jang[a,*], Christopher R. Keyes[a], Deborah S. Page-Dumroese[b]

[a] Department of Forest Management, University of Montana, Missoula, MT 59812, USA
[b] USDA Forest Service, Rocky Mountain Research Station, 1221 South Main, Moscow, ID 83843, USA

ARTICLE INFO

Keywords:
Western larch forest
Forest stand dynamics
Silviculture
Biomass harvesting
Estimated coefficients analysis

ABSTRACT

To investigate the long-term impacts of biomass harvesting on site productivity, we remeasured trees in the 1974 Forest Residues Utilization Research and Development Program at Coram Experimental Forest in western Montana. Three levels (high, medium, and low) of biomass removal intensity combined with broadcast burning treatment were assigned after clearcut in western larch (*Larix occidentalis* Nutt.) stands in 1974. From 1976 to 79, twenty five 2 + 0 bare root seedlings of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) were consecutively planted in rows. In 2013, tree height, dbh (diameter at breast height), foliar N and C concentrations were measured. From cross-sectional sapwood area, growth efficiency (the ratio of 5-year-basal area increment to total leaf area) was calculated. Previous measurements from 1980, 1987, 1992, and 2001 were used for dbh and height growth analyses. At this site, none of the response variables were affected by biomass removal level. Only seedling planting year contributed significantly to affect tree mean height, dbh, volume. Growth efficiency was not affected by any treatment. These results indicate no apparent effect of biomass removal on site productivity for the range of biomass harvest levels performed.

1. Introduction

Forest biomass harvesting for bioenergy, which involves extracting biomass from a site that is above the level of extraction typically associated with conventional timber harvesting, is emerging as a source of alternative energy feedstocks, due mainly to public concerns over use of fossil fuels and climate change [1]. Conventional harvesting produces a considerable amount of woody biomass residues. Those are usually left on the ground, broadcast burned, or piled and burned to reduce wildfire hazard. Intensive removal of woody biomass residues is not a wholly new concept. Whole-tree harvesting has been practiced since the 1970s in North American forests. Moreover, further intensive harvesting methods (e.g., energy-wood harvesting; [2,3]) have been investigated in the forests of northern Europe and the northeastern United States. It seems apparent that future timber harvesting in northern Rocky Mountain forests will utilize greater levels of biomass than contemporary harvests [4], but the long-term effects of such harvests on productivity in this region have been studied very little [5].

Increased biomass removal from forest ecosystems has the potential to produce a decline in site productivity. Since branches, twigs, and foliage have higher nutrient concentrations than stemwood, their removal may cause excessive nutrient loss [6,7]. Studies of whole-tree harvesting have consistently indicated significantly greater nutrient loss than conventional harvesting methods [8–11]. The simulation efforts and nutrient budget analyses have also warned of the site productivity impacts of nutrient depletion by intensive biomass removal (e.g. [12–14]). In addition, abrupt elimination of aboveground vegetation exacerbates the temporary loss of soluble nutrients through soil leaching (e.g. [15]). Thus, the concern that biomass harvesting could adversely impact site productivity is reasonable.

Biomass harvesting for bioenergy can also influence a site's nutrient flux indirectly by altering other environmental factors. Increased biomass removal can affect the understory microclimate by altering solar radiation, soil temperature, and soil moisture [16]. Moreover, soil properties can be altered by biomass harvesting. For example, Nykvist and Rosén [17] and Staaf and Olsson [18] found that increased biomass removal can exacerbate soil acidification. By modifying organic matter dynamics, these environmental alterations can affect soil biota, consequently modifying nutrient cycling and availability [19,20]. Such complex effects of increased biomass removal make it difficult to predict the protracted impacts of biomass harvesting on site productivity, emphasizing the necessity of long-term field experiments.

Several experimental efforts in recent decades have sought to determine the consequences of biomass harvesting on site productivity.

* Corresponding author.
E-mail addresses: woongsoon.jang@umontana.edu (W. Jang), christopher.keyes@umontana.edu (C.R. Keyes), ddumroese@fs.fed.us (D.S. Page-Dumroese).

https://doi.org/10.1016/j.biombioe.2017.11.012
Received 21 May 2017; Received in revised form 10 November 2017; Accepted 14 November 2017

These have focused on the growth of regenerating stands or physiological responses (e.g., growth efficiency, foliar nutrient status) following increased biomass removal as indicators of site productivity impacts. In the United Kingdom, Proe et al. [21] reported that whole-tree harvesting led to a 13% volume reduction of Sitka spruce (*Picea sitchensis* (Bong.) Carrière) plantation seedlings compared to conventional harvesting after 12 years. In another Sitka spruce stand in North Wales, whole-tree harvesting caused an approximately 10% reduction in dbh (diameter at breast height) 23 years after planting [22]. In Sweden, increased biomass removal resulted in a 17% basal area reduction for Scots pine (*Pinus sylvestris* L.) trees after 24 years [23], and negative impacts on growth of Norway spruce (*Picea abies* (L.) Karst.) trees after 15 years [20]. From a series of experimental sites across Scandinavian countries, Jacobson et al. [24] observed reduced tree volume growth in Scots pine and Norway spruce stands (5 and 6%, respectively) 10 years after thinning with whole-tree removal. They speculated that the reason for tree growth reduction could be nutrient removals and subsequent indirect effects, but the magnitude of the negative impacts is complicated by abiotic and biotic factors – such as precipitation, soil fertility, and belowground nutrient cycling [24].

Conversely, the North American Long-Term Soil Productivity (LTSP) study yielded somewhat different results from those of northern European forests. Ten years after biomass removal treatment, Powers et al. [25] and Ponder et al. [26] failed to find consistent consequences of increased biomass removal on tree responses. Thus, tree responses to biomass harvesting appear to vary depending on regional factors such as vegetation, soil properties, and disturbance/harvest regimes.

The equivocal impacts of biomass removal emphasize the necessity for experimental efforts to evaluate site-specific long-term impacts on productivity. An opportunity to evaluate the long-term impacts of biomass harvesting on site productivity in the northern Rocky Mountains exists at western Montana's Coram Experimental Forest. In 1974, timber harvesting was conducted with three levels of biomass removal in a western larch (*Larix occidentalis* Nutt.) forest (Table 1). For four consecutive years thereafter (1976–1979), Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) seedlings were planted within a reserved portion of each biomass removal treatment separate from the naturally regenerated stand that developed afterward. This experiment enables an isolation of the long-term effects of biomass harvesting on site productivity by holding constant or randomizing other factors that can affect seedling growth, such as genetic traits, microsite, spacing, time of initiation, and competition. The objective of this study was to investigate the long-term impact of biomass harvesting on individual tree growth. To achieve this objective, we compared tree responses such as height, diameter, volume growth, tree vigor, and foliar nutrient concentrations among three biomass removal levels.

Therefore, we tested the hypotheses:

1. If the increased biomass removal has a negative impact on forest productivity, then the lowest height, diameter, volume growth should be observed at the highest biomass removal level.
2. If the increased biomass removal decreases forest productivity, then the lowest leaf area, growth efficiency (GE), and foliar nutrient (C and N) concentration should be detected at the highest biomass removal level.

2. Methods

2.1. Study site

This study was conducted at Coram Experimental Forest (CEF; 48°25′N, 113°59′W) on the Flathead National Forest in northwestern Montana, USA, located about 9 km south of Glacier National Park. The elevation of the study site ranges from 1188 to 1615 m, with 30–80% slopes. Soils have approximately 40–80% rock-fragment content, are underlain with glacial till [27], and are classified as loamy-skeletal, isotic Andic Haplocryalfs [28]. The climate of CEF is classified as a modified Pacific maritime type [29]. Average annual precipitation is 1076 mm, primarily occurring in the form of snow from November to March [30]. Mean annual temperature is reported as 2 °C–7 °C [31].

The biomass harvesting experiment was implemented in mature stands of the Western Larch cover type (Society of American Foresters Cover Type 212; [32]) on the Upper Abbot Creek Basin. Major tree species of the study site are: western larch, Douglas-fir, subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.), Engelmann spruce (*Picea engelmannii* Parry ex Engelm.), and paper birch (*Betula papyrifera* Marshall). The study site is relatively moist and productive (western larch site index of 16.7 m at base age 50; [33]), and is predominantly classified as the subalpine fir/queencup beadlily (*Clintonia uniflora* (Menzies ex Schult. & Schult. f.) Kunth) (ABLA/CLUN) habitat type [34,35].

2.2. Experimental design

Experimentally controlled clearcuts were operationally installed in 1974 at two blocks: a higher elevation site (1341–1615 m) and a lower elevation site (1195–1390 m). Within each of these sites (blocks), three residue removal treatments (1.6 ha per treatment on average; Table 1) were designated that combined removal level with prescribed burning (i.e., high-unburned, low-burned, and medium-burned). The original experimental design contained one additional treatment (medium-unburn, also known as "understory protected"; [36,37]) but that treatment was not included in this follow-up planting experiment, presumably because that biomass removal treatment retained understory vegetation and advance regeneration that would have interfered with planted seedling survival. Removed woody materials for the high-unburned, low-burned, and medium-burned treatments were 72.3, 54.2, and 65.6%, respectively (based on aboveground woody material volumes; [38]). All trees were hand-felled, and harvested trees were removed via a skyline yarding system.

An area within each treatment was set aside for the present planted

Table 1
Design of the biomass removal treatments within harvesting units (details and data from Refs. [35,38,47]).

Treatment	Removed woody materials	Pre-harvest volume (m^3 ha^{-1})		Post-harvest volume (m^3 ha^{-1})		Removed woody materials (%)	Post-harvest treatment
		Block1	Block2	Block1	Block2		
High-Unburned (H_U)	All woody material (live and dead, standing and down) to 2.5 cm diameter	414	387	66	140	72.3	Unburned
Low-Burned (L_B)[a]	All sawtimber material (live and recently dead) to 17.8 cm dbh and 15.2 cm top diameter, 2.4 m in length, 1/3 sound	469	564	167	247	54.2	Broadcast burned
Medium-Burned (M_B)	All woody material (live and dead, standing and down) to 7.6 cm small end diameter, 2.4 m in length, 1/3 sound	570	617	121	170	65.6	Broadcast burned

[a] Followed the United States Forest Service standards in 1974.