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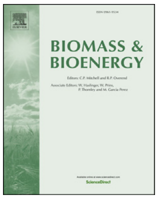

Research paper

Recovery and diversity of the forest shrub community 38 years after biomass harvesting in the northern Rocky Mountains

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ABSTRACT

We investigated the long-term impact of biomass utilization on shrub recovery, species composition, and biodiversity 38 years after harvesting at Coram Experimental Forest in northwestern Montana. Three levels of biomass removal intensity (high, medium, and low) treatments combined with prescribed burning treatment were nested within three regeneration harvest treatments (shelterwood, group selection, and clearcut). Four shrub biomass surveys (pre-treatment, 2, 10, and 38 years after treatment) were conducted. Shrub biomass for all treatment units 38 years after treatment exceeded the pre-treatment level, and biomass utilization intensity did not affect shrub recovery (ratio of dry biomass at time t to pre-treatment biomass). Species composition changed immediately after harvesting (2 years); however, the species composition of treated units did not differ from the untreated control 38 years after harvesting. Biodiversity indices (Shannon's and Pielou's indices) also decreased immediately following harvesting, but recovered 10 years after harvesting. The responses of diversity indices over time differed among biomass utilization levels with the high-utilization level and unburned treatment producing the most even and diverse species assemblages 38 years after harvesting. Our results indicate the shrub community is quite resilient to biomass harvesting in this forest type.

1. Introduction

Forest understory vegetation (e.g., herbs, shrubs, tree seedlings, and saplings) plays an important role in temperate forest ecosystems, providing wildlife habitat and food resources, sustaining site productivity, and underlying biodiversity [1–4]. For example, huckleberries are well known as the most important food source of grizzly bear (*Arctos ursus)* in Montana [5]. In addition, shrubs and understory herbs serve critical functions in nutrient cycling [1,6,7]. Abundance of understory vegetation is a critical factor in determining tree growth, especially in early stand development stages [8]. From a biodiversity perspective, understory vegetation comprises a large portion of plant diversity in forest ecosystems [9–11]. Thus, considerable efforts have been devoted to understanding impacts of forest management on understory vegetation structure and composition [4].

Increasing volatile fossil fuel costs and concerns about climate change have raised public interest in utilizing forest biomass as a renewable alternative energy feedstock. As a result, more intensified biomass harvesting trials beyond whole-tree harvesting are being conducted in North America (e.g., [12–14]). However, logging activity for increased woody biomass utilization inevitably involves a greater magnitude of soil disturbance and nutrient export [15]. Furthermore, logging activity may result in understory vegetation mortality and an altered microclimate [16]. Therefore, increased woody biomass utilization can also impact understory vegetation dynamics and consequently alter forest ecosystem functions.

However, knowledge gaps exist regarding the long-term impacts of biomass utilization on understory vegetation. The majority of such studies have focused on overstory vegetation or belowground layers, and several on-going studies are not mature enough to yield long-term assessments of increased biomass harvesting in North America (e.g., Long-Term Soil Productivity research network [17]). Long-term studies — spanning decades rather than years — acquire an exceptional importance in evaluating the biomass harvesting impacts, because long-term assessment provides a critical asset for understanding complex changes in forest ecosystem function and structure. Knowledge gaps in the northern Rocky Mountain forest are especially great; mill closures in the pulp and

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panel sectors has degraded the industrial infrastructure for intensive biomass harvesting, and has thereby limited opportunities to evaluate harvested sites and compare them to other forms of forest management (including prescribed fire).

In 1974, an interdisciplinary research project was conducted at the USDA Forest Service, Rocky Mountain Research Station's Coram Experimental Forest in Montana to evaluate the ecological consequences of intensified biomass harvesting [18]. About four decades later, this historical research project can now provide clues to the long-term impact of biomass harvesting on understory vegetation. The objective of this study was to identify whether biomass utilization intensity alters understory shrub dynamics. For this, we investigated the temporal changes of shrub recovery (ratio of dry biomass at time t to pre-treatment biomass), species composition, and diversity over time (pre-harvest, 2, 10, and 38 years after harvest) at four different levels of biomass utilization intensity.

2. Methods

2.1. Study site

The study was conducted at Coram Experimental Forest (CEF), on the Flathead National Forest in northwestern Montana. The experimental units were established on an east-facing slope in Upper Abbot Creek Basin (48°25′ N, 113°59′ W), ranging in elevation from 1195 to 1615 m asl, and from 30% to 80% slope. Soils originated from impure limestone, containing approximately 40–80% rock-fragment [19], and classified as loamy-skeletal, isotic Andic Haplocryalfs [20]. Average annual temperature ranges from 2 °C to 7 °C [21], and average annual precipitation is 1076 mm, mainly in the form of snow from late fall to early spring [22]. The climate of CEF is a modified Pacific maritime type [23].

The study was implemented in mature stands (>200 years without any harvesting history) of the Western Larch cover type (Society of American Foresters Cover Type 212 [24]). The pre-harvest overstory consisted of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), western larch (*Larix occidentalis* Nutt.), subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.), Engelmann spruce (*Picea engelmannii* Parry ex Engelm.), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), western redcedar (*Thuja plicata* Donn.), lodgepole pine (*Pinus contorta* Dougl. ex Loud.), and western white pine (*Pinus monticola* Dougl.) [25,26].

The understory vegetation of the study site is typified by queencup beadlily (*Clintonia uniflora* (Menzies ex Schult. & Schult. f.) Kunth), wild sarsaparilla (*Aralia nudicaulis* L.), and bunchberry dogwood (*Cornus canadensis* L.) [27], including prostrate shrubs such as twinflower (*Linnaea borealis* L.) and Oregon boxleaf (*Paxistima myrsinites* (Pursh) Raf.) [27,28]. Heartleaf arnica (*Arnica cordifolia* Hook.) and beargrass (*Xerophyllum tenax* (Pursh) Nutt.) are the characteristic perennial herbs. The forest is subject to various disturbances including fire, insect, and wind-throw [27]. The fire regime of the study site can be classified as mixed-severity with 90–130 years of (stand-replacing) fire-free interval [29], indicating that structurally and compositionally complex forests have been constructed by fires of various severities [27].

2.2. Experimental design

The experiment was conducted with a split-plot design, in which sub-plot treatments were nested within a whole-plot (Fig. 1). Three kinds of regeneration harvest treatment (shelterwood, group selection, and clearcut) plus an uncut control were implemented at the whole-plot level. The treatments were replicated twice, one per elevation block (lower block at 1195 m to 1390 m, and upper block at 1341 m to 1615 m). The average pre-harvest volume of aboveground woody material was 512 m^3 ha^{-1}.

Thus, the regeneration harvest units consisted of:

1. Two shelterwood units (14.2 and 8.9 ha in size): Based on merchantable volume, approximately half of the standing timber was harvested. The retained trees were primarily old-growth larch or Douglas-fir, and those overstory trees were left uncut. Thirty six percent of total woody biomass was removed.
2. Two clearcut units (5.7 and 6.9 ha): All standing timber was cut, 84% of total woody materials were removed.
3. Two group selection units, each unit contains eight cutting gaps (0.1–0.6 ha, 0.3 ha on average): All standing timber was cut within gap, 70% of total woody materials were removed.

At the sub-plot (hereafter, "biomass utilization treatment") levels, three levels of biomass utilization intensity (high, medium, and low) combined with post-harvest burning treatment (burn and unburned) were randomly assigned. The original experimental design was not able to adopt a full-factorial design, because the low biomass utilization level resulted in too large fuel load for the unburned treatment, whereas the high biomass utilization left too little fuels for burning. As a result, M_U (medium/unburned), H_U (high/unburned), L_B (low/burned), and M_B (medium/burned) were implemented as the biomass utilization treatments (see Table 1 for experimental design details).

In 1974, trees were hand-felled and removed via a running skyline yarder to minimize soil disturbance. Subsequent broadcast burning was applied in the fall of 1975. However, due to cool and wet weather condition, the burning treatment was not implemented in lower shelterwood unit [30,31]. Thus, an additional biomass utilization treatment (i.e., low/unburned) occurred in the lower shelterwood unit, but was excluded from this study's data analysis to remain consistent and avoid analytical problems during model construction.

There was no subsequent entry or disturbance, thus the study sites have been conserved intact. Thirty years after harvesting, the regeneration biomass reached 56.1, 34.5, and 19.7 Mg ha^{-1} for the clearcut, group selection, and shelterwood, respectively [32]. The biomass of residual trees in the shelterwood was 116.5 Mg ha^{-1}, and in the control was 194.6 Mg ha^{-1} [33].

2.3. Data collection and analysis

In the shelterwood, clearcut, and control units, ten permanent sample points were systematically located in 5 × 2 (row × column) grids within each sub-plot (i.e., biomass utilization treatment sub-plots), at 30.5 m spacing. In the group selection units, five permanent points were installed in each cutting gap (8 gaps per replicate) at various distances, depending on the size of gaps. Therefore, a total of 40 permanent points were assigned in each of the 3 regeneration harvest units per replicate, for a total of 280 points.

Measured crown volumes or root-collar diameters were used to compute shrub biomass. In 1973, 1976, and 1984, shrub crowns were measured for each species using a nested quadrat system. Shrub volume was assumed as a cylindroid; thus, two diameters of the ellipse (projected area of crown) and height were measured. In 2012, a nested circular sampling system was utilized. Instead of measuring shrub crown volume, root-collar diameter for every stem was measured via digital caliper because the diameter often shows better prediction for shrub biomass [34,35]. Data were collected from four permanent points (3rd, 4th, 7th, and 8th) out of ten points. Plot sizes and measured shrub size classes are described in Table 2. This methodological choice and its potential effects on the interpretation of results are discussed in the next section.