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Long-term effects of vegetation management on biomass stock of four coniferous species in the Pacific Northwest United States

Herman N. Flamenco, Carlos A. Gonzalez-Benecke*, Maxwell G. Wightman

Department of Forest Engineering, Resources and Management, 280 Peavy Hall, Oregon State University, Corvallis, OR 97331, USA

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ABSTRACT

Silvicultural treatments applied during the early stages of stand development can have long-lasting impacts on forest ecosystem structure. Forest vegetation management (VM) is an important component of many reforestation programs and although several studies have demonstrated the benefits of VM on planted conifer growth and survival, few reports have been published on the long-term effects of VM treatments on total ecosystem biomass accumulation. In this study we assessed the effects of two contrasting VM treatments on total tree and ecosystem biomass stock for Douglas-fir, western hemlock, western redcedar, and grand fir growing in Oregon's central Coast Range (CR) and Douglas-fir and western redcedar growing in Oregon's Cascade foothills (CF). The assessments were made at age 16 years, 11 years after treatment application ended. The study contained two vegetation management treatments: control (C) and vegetation management (VM). Both the C and VM plots received a pre-planting herbicide site preparation treatment. The VM plots had, additionally, sustained vegetation control using herbicides during the first 5 years after planting. At age 16 years, at the CR site, the VM treatment increased the biomass stock of crop trees by 26.5, 91.2, 44.7, and 96.1 Mg ha^{-1} for Douglas-fir, western hemlock, western redcedar, and grand fir, respectively. At the same age, at the CF site, the VM treatment increased crop tree biomass stock by 48.1 Mg ha^{-1} for Douglas-fir and 42.2 Mg ha^{-1} for western redcedar. When other ecosystem components were considered, however, total ecosystem biomass did not differ between C and VM treated plots for western hemlock, western redcedar and grand fir at the CR site largely due to the development of an abundant hardwood midstory. On the other hand, VM treatments increased the ecosystem biomass stock of Douglas-fir and western redcedar at the site with a low abundance of hardwood midstory (CF site). Midstory biomass of C plots at the CR site averaged 52.9, 64.7, and 36.0 Mg ha^{-1}, for western hemlock, western redcedar, and grand fir, respectively. At the CF site, midstory biomass of C plots averaged 1.2 and 5.9 Mg ha^{-1}, for Douglas-fir and western redcedar, respectively. The results of this study demonstrate that sustained VM treatments during the first 5 years of stand establishment increases the biomass stock of crop trees, directing site resources towards planted crop trees.

1. Introduction

Silviculturists can influence the trajectory and rate of forest development using several different management techniques. The use of artificial regeneration (planted seedlings) and forest vegetation management treatments are two important management strategies used in the United States Pacific Northwest (PNW) to successfully establish healthy and highly productive conifer plantations. When establishing a new stand, forest managers must select a crop tree species and make vegetation management decisions that may have long-term impacts on stand condition and growth. Understanding how these decisions impact forest ecosystems can help silviculturists to develop management strategies for diverse objectives such as timber production, forest restoration, or carbon sequestration.

Forest vegetation management (VM) is an integral part of reforestation in the PNW. After a harvest, site resources become readily available and early seral species quickly use these resources to occupy the site. This can create intense competition with crop trees, especially during the dry summers typical to the region (Dinger and Rose, 2009). Research has shown that controlling competing vegetation increases the growth of planted conifer species in the PNW (Newton and Preest, 1988, Rose et al., 2006; Maguire et al., 2009). The most effective VM method in the PNW, and in other parts of the world, has been herbicide use due to its low cost, high efficacy, and associated improvements in seedling growth and survival (Ketchum et al., 1999, Rose et al., 2006, Maguire et al., 2009).

* Corresponding author.
E-mail address: carlos.gonzalez@oregonstate.edu (C.A. Gonzalez-Benecke).

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VM studies in the PNW have often focused on the short-term effects of VM (Clark et al., 2009) and in other regions only a few studies have monitored long-term effects [Nilsson and Allen (2003) (SE USA), Albaugh et al. (2015) (Chile), Vargas et al. (2017) (Chile)]. Many of these studies focused on stand attributes, such as stem volume, basal area, mean diameter at breast height, and dominant height, as they are of most popular interest to forest managers. However, other stand attributes such as forest biomass stock, net primary productivity, and leaf area are equally important. These stand attributes, separate or in combination, are useful indices of productivity, light use efficiency, maturity and stability of forest ecosystems (Gholz, 1982).

Forests in the PNW are highly productive, dominated by long-lived species, and are known for their large accumulation of biomass (Waring and Franklin, 1979, Franklin et al., 2017). Common conifer species in the region include Douglas-fir (*Pseudotsuga menziesii* (Mirbel) Franco), western hemlock (*Tsuga heteophylla* (Raf.) Sarg.), western redcedar (*Thuja plicata* Donn ex D. Don), and grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl.). Of these, Douglas-fir is the most adaptable species and can thrive on a diversity of sites while western hemlock prefers mesic conditions and is most commonly found in the temperate rainforests of the northwest coast (Burns and Honkala, 1990). Western redcedar is found in many forest swamps, however, it is also more drought tolerant than western hemlock. Grand fir is most commonly found in stream bottoms, valleys, and mountain slopes. In Oregon, Douglas-fir accounted for 70% of timber volume harvest between 2013 and 2014 followed by western hemlock (11%), true firs (abies) (8%), and western redcedar (2%) (Simmons et al., 2016).

In the past, forests in the PNW have accounted for 39% of the 57.8 billion tons of carbon stored in U.S. forests (Birdsey, 1992). While mature forests have high biomass storage, young forests accumulate biomass at a higher rate (Gray et al., 2016) which has led to some debate as to whether planted forests are better suited for sequestering carbon than mature forests (Harmon, 2001). Silvicultural practices that increase stand productivity, such as VM, could also increase forest carbon sequestration and storage (Martin and Jokela, 2004; Wagner et al., 2006).

A large fraction of the carbon stored in forest ecosystems is found in overstory trees. Forest stands, however, are not only composed of planted overstory trees and other ecosystem components must also be accounted for to estimate forest biomass. These include midstory vegetation, understory vegetation, forest floor, and soil organic matter. While allometric functions exist for many tree species, other ecosystem components must be determined by direct field samplings. In this study we analyzed the long-term effects of contrasting vegetation management treatments on total and component tree biomass and total and component ecosystem biomass stock for four coniferous species at age 16 years growing on two sites in western central Oregon. The specific objectives were: (1) determine the effect of crop species, VM treatment, and site on stand biomass stock, (2) determine the effect of crop species, VM treatment, and site on understory, midstory, and forest floor biomass and soil organic matter content, and (3) determine the effect of crop species, VM treatment, and site on total ecosystem biomass. Even though the species used in this study have a long life-span, intensive forest management is reducing harvest age to 35–50 years (Briggs, 2007; Curtis et al., 2007), our estimations at age 16 years represent about 1/3 to 1/2 of the rotation length.

2. Materials and methods

2.1. Description of sites

This study contained two sites, one located in the central Coast Range (CR) near Summit, OR, and the other in the Cascade foothills (CF) near Sweet Home, OR. The CR site was planted in January of 2000 and is located approximately 40 km from the coast, 44.62°N, 123.57°W. The mean annual temperature is 11.1 °C, and the mean annual rainfall is 1,707 mm. The site is characterized by fine loamy soil. The CF site was planted in February of 2001 and is located approximately 110 km from the coast, 44.48°N, 122.73°W. The mean annual temperature is 12.4 °C and the mean annual rainfall is 1179 mm. The site is characterized by silty clay loam soil. At both sites most of the annual rainfall occurs between October to April.

A randomized complete-block experiment with eight VM treatments was implemented at both sites. All plots at both sites received a broadcast fall site preparation treatment of sulfometuron (0.15 L/ha), metsulfuron (0.04 L/ha), and glyphosate (4.68 L/ha) prior to seedling planting. The eight different VM treatments consisted of spring release applications that differed in the number and timing of herbicide treatments applied during the first 5 years after planting. For this study, only the control (C; pre-planting vegetation control) and the 5 consecutive years of spring release vegetation management treatment (VM) were used. Atrazine (4.5–4.9 kg/ha) and clopyralid (0.58–0.73 L/ha) were applied for the spring release treatments. If competing vegetation cover of treated plots exceeded a 25% threshold during the growing season, glyphosate (1.5–2.0%) was applied during the summer. Percent cover by species was visually determined in late summer of growing seasons 1 through 5 using six 1-m radius vegetation survey subplots per plot. The VM treatments created significant differences in competing vegetation cover during the first 5 years of stand establishment. During the fifth growing season, across species and sites, the summed cover of competing vegetation in VM treated plots, ranged between 4 and 11%, while in C plots it ranged between 124 and 151% (Table 1). Further details on treatment design can be found in Maguire et al. (2009).

Plots were planted with Styro-15 seedlings in eight tree by eight tree rows at 3 m (10-ft) spacing. Stand inventories were conducted on the internal 6 rows of 6 trees allowing for a one tree buffer on all sides. This resulted in a measurement plot size of about 0.06 ha. At the CR site, four coniferous species were planted: Douglas-fir (*Pseudotsuga menziesii* (Mirbel) Franco), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), western redcedar (*Thuja plicata* Donn ex D. Don), and grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl.). There are four blocks of Douglas-fir and western hemlock, and three blocks for western redcedar and grand fir. The CF site was planted with only Douglas-fir and western redcedar, each with four blocks. Prior to the start of this study, the last stand inventories were conducted at age 12 years, corresponding to 2011 for the CR site and 2012 for the CF site. At both sites, Douglas-fir VM and C plots were thinned from below to reduce stocking by 25% at this age.

Table 1
Cover of competing vegetation during the fifth growing season for Douglas-fir, western hemlock, western redcedar, and grand fir trees growing under contrasting treatments of vegetation management on sites located in the central Coast Range (CR) and the Cascade foothills (CF) of western Oregon. C: no post-planting vegetation control, VM: sustained vegetation control for first 5 years post planting. Understory cover represented the summed cover of each individual species of competing vegetation.

Site	Species	Treatment	Vegetation Cover (%)
CR	Douglas-fir	C	124
		VM	5
	Western hemlock	C	139
		VM	4
	Western redcedar	C	139
		VM	6
	Grand fir	C	130
		VM	6
CF	Douglas-fir	C	151
		VM	9
	Western redcedar	C	140
		VM	11

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