Forest Ecology and Management 340 (2015) 114–125

Contents lists available at ScienceDirect

Forest Ecology and Management

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

Managing early succession for biodiversity and long-term productivity of conifer forests in southwestern Oregon

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ARTICLE INFO

Article history:
Received 12 September 2014
Received in revised form 12 December 2014
Accepted 17 December 2014
Available online 13 January 2015

Keywords:
Early succession
Early-seral
Biodiversity
Long-term productivity
N_2 fixation

ABSTRACT

Early-successional stages have been truncated and altered in many western U.S. forest landscapes by planting conifers, controlling competing vegetation, suppressing fire, and focusing on maintaining late-seral species and undisturbed riparian zones. Declining area of early-successional stages may be reducing resilience and sustainability on landscapes that experience elevated disturbance related to future climate changes. In this study, two post-harvest early-successional treatments were compared to each other and to two mature-forest treatments using 20 years of evidence from replicated 7-ha experimental units in a southwestern Oregon forest dominated by Douglas-fir (*Pseudotsuga menziesii* Mirb. Franco). One early-successional treatment (Douglas-fir plantation) planted Douglas-fir and was followed by a brushing to reduce hardwood competition to move quickly to the conifer stem-exclusion stage; the other (Early-seral plantation) favored natural sprouting and regeneration of hardwood shrubs and trees and planted scattered knobcone pines (*Pinus attenuata* Lemmon) and Douglas-fir. Plant diversity in the Early-seral plantation was 56% (year 2) and 26% (year 6) higher than in the Douglas-fir plantation. Both early-successional treatments far exceeded plant diversity in Unaltered and Thinned mature stands. Fifteen years of growth of shrubs and hardwood trees in the Early-seral plantation was remarkable, resulting in total aboveground biomass increment (18 Mg ha^{-1} yr^{-1}) double that of the Douglas-fir plantations. Important process effects related to primary productivity were noted: losses of soil organic matter from the B horizon in young Douglas-fir, and, after wildfire, increases in N_2-fixing plant cover in Early-seral plantation. The burl-sprouting and deep rooting of many hardwoods also created opportunities for nutrient retention and release from primary minerals as well as deep-profile water supply. Recognizing the importance of intentionally managing for shrubs and hardwood trees is particularly relevant at this site, because stand reconstruction and historical records indicate these species, along with knobcone pine, dominated the site for 40 years before the current mature Douglas-fir forest started gaining dominance. In contrast, the prolific natural regeneration of Douglas-fir after recent harvest and wildfire suggests that what comes back "naturally" in modern times will not allow this history to be repeated.

Published by Elsevier B.V.

1. Introduction

A broad debate is underway about how important early-successional stages are to a landscape, for maintaining or increasing forest sustainability and resilience to disturbance. Adequate representation of all seral stages across a forested landscape is thought to underpin resilience and sustainability by assuring that natural processes are maintained through time and space (Pickett and White, 1985). Reasoned concern about depleted late-successional stands may have overshadowed a growing scarcity of early-seral stages

Abbreviations: dbh, diameter at breast height; DSLR, digital single-lens reflex; FEMAT, forest ecosystem management assessment team (assessment that the Northwest Forest Plan was based); LTEP, long-term ecosystem productivity; NFMA, National Forest Management Act of 1976; O&C, Oregon and California Revested Lands Act of 1937; USDA, United States Department of Agriculture.

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http://dx.doi.org/10.1016/j.foreco.2014.12.016
0378-1127/Published by Elsevier B.V.

in Europe (Angelstam, 1998), New England (DeGraaf et al., 2003; King and Schlossberg, 2014), and the Pacific Northwest (Noss et al., 2006; Swanson et al., 2011; Campbell and Donato, 2014). A wide range of factors, including intensive plantation management on private lands, fire suppression and exclusion, and old-growth and riparian habitat objectives on public lands, are inadvertently leading to a scarcity of early-seral conditions in the Pacific Northwest (Kennedy and Spies, 2004). We use long-term experimental evidence from the Long-Term Ecosystem Productivity study to better understand early succession in the Pacific Northwest, and to link empirical evidence to the general but difficult-to-quantify goals of forest sustainability and resilience.

Slowly evolving scientific concepts of early succession have shaped the policy context for early-succession management. The National Forest Management Act (NFMA, 1976), responding to "cut and run" practices, required that conifers be reestablished after forest harvesting, and mandated a detailed and expensive accounting system to assure this objective was met. At that time, this concept was aligned with strong conifer production goals on public and private lands in the western states. Later, scientists concerned with disappearing late-successional stages began to study succession, but mostly in older forests. Time-series graphs showing disturbance, usually fire, followed by conifer regeneration and conifer-dominated sequence of stand structures ending with old-growth are common (e.g., Franklin and Spies, 1991). Other species were absent from studies and diagrams, and deviations from this simple sequence were in effect considered rare. As knowledge of the stochastic nature of disturbances emerged, the linear model was replaced by processes that could create many diverse pathways (Botkin, 1990; O'Hara et al., 1996). Following changes in land-management objectives catalyzed by the Northern Spotted Owl (*Strix occidentalis caurina*) injunction, however, the late-seral, conifer-centric paradigm continues on federal lands today. The Northwest Forest Plan was based on conservation biology concerns about an adequate distribution of seral stages, with a clear focus on the lack of old growth (FEMAT, 1993). Young, intensively managed Douglas-fir (*Pseudotsuga menziesii* Bong.) plantations were considered as a sufficient form of early succession. The Plan recognized "legacies" of old-growth stands that carry into early succession, by mandating minimum standards of leave trees, snags, and down wood, but not other early-seral conditions, such as biodiversity of herbs, shrubs, and hardwood species, and their function in maintaining early-seral foodchains and soil as a basis for plant productivity. The role of non-conifer vegetation in early succession started gaining attention when wildlife biologists began to realize that many species dependent on early succession were declining regardless of the abundance of young conifer plantations. This linking of early-seral stages with habitat needs has propelled the issue into policy discussions. The current debate (O & C Act, 2013) includes the need for legacies and large openings, but also suggests that the resulting vegetation should not be further managed, allowing natural processes to unfold.

Scientific knowledge about the effects of early stages of succession in managed coniferous forests in the Pacific Northwest depends largely on studies of conifer plantations with and without vegetation control (e.g., Gratkowski, 1961; Roberts et al., 2005; Rose et al., 2006; Newton and Cole, 2008; Maguire et al., 2009). After planting and tending strategies became very effective at speeding conifer canopy closure at the expense of early-seral species, concerns arose over biodiversity (Bunnell et al., 1999; Koivula et al., 1999; Hanley, 2005). The threat extends beyond plant diversity because the low stature, diversity, and reproductive strategies of many early-seral plants drive energy flows into secondary production, supporting more herbivores, granivores, nectarivores, frugivores, and omnivores than conifers. For example, Hagar (2007) identifies several reptiles and amphibians and many birds and mammals closely associated with food supply and cover provided by early-seral species in Pacific Northwest forests. One of these species, the dusky-footed wood rat (*Neotoma fuscipes*), is even critical to the survival of the threatened Northern Spotted Owl (Franklin et al., 2000a), though the owl is usually associated with late-successional conditions. Similar dependencies are seen in Europe (Enoksson et al., 1995) and the eastern U.S. (DeGraaf et al., 2003; King and Schlossberg, 2014) as well.

Primary and post-disturbance succession chronosequences and mesocosm mass-balance studies are the primary sources of information on the effects of succession on processes controlling long-term soil productivity. For example, N_2-fixers and some hardwoods increase soil organic matter and nutrient availability (e.g., Binkley, 1983; Batterman et al., 2013); pines (*P. resinosa* and *rigida*) can increase weathering release from primary minerals (Bormann et al., 1998; Balogh-Brunstad et al., 2008); and late-successional species such as mature spruce (*Picea* sp.) and hemlock (*Tsuga* sp.) are linked to declining rooting depth and nutrient immobilization in podzolic horizons (Bormann et al., 1995). More recently, management-oriented experiments have been implemented in the Pacific Northwest and SE Alaska that vary overstory conifer retention patterns and then examine effects on naturally regenerating species (e.g., Hanley, 2005; Wilson et al., 2009; Cole et al., 2010; Halpern et al., 2011; Burton et al., 2013). These studies are almost exclusively focused on biodiversity at stand scales and have not included an ecosystem analysis about effects on biomass distribution, energy flow, or soil nutrients and organic matter.

Here we seek to address gaps in knowledge about ecosystem functioning in early-successional Pacific Northwest forests. Our specific objectives are to: (i) quantify biodiversity and ecosystem properties and processes resulting from two early-successional management practices that establish and control vegetation composition differently; (ii) compare the early-successional management practices to mature stands, both thinned and unaltered; (iii) assess the consequences of interactions of these management strategies with unanticipated wildfire; and (iv) consider historical changes in early-successional pathways. To meet these objectives, we evaluate the 20-year vegetation and soil record of a large-scale forest-manipulation experiment in southwest Oregon, USA, and contrast modern managed-stand succession to historical responses demonstrated by local stand reconstruction and a review of historic documents. The two early-successional strategies, along with thinning and no-action, are four clear alternatives facing decision makers on fire-prone federal forest lands. Our study will inform both the design and choices among these alternatives to help meet management objectives at the landscape scale.

2. Materials and methods

2.1. Study site

The study has 5 distributed experimental blocks on the Rogue River – Siskiyou National Forest about 25 km southeast of Gold Beach, Oregon at 750–900 m elevation (Fig. 1). Soils in blocks B1 and Bb are derived primarily from schist-phyllite, in B2 from metamorphisized sandstone, and in B3 and Ba from mixed sandstone and schist-phyllite. Climate records (1971 to 2000) report average temperatures of 4 °C in January and 18 °C in July, and annual precipitation of 190 cm with only 10 cm during June to September (PRISM, 2012).

The pre-study forest developed following an 1881 fire (Little et al., 1995). In 1992, live-tree density ranged from 900 to 1300 trees ha^{-1}, and basal area from 40 to 80 m^2 ha^{-1} (Table 1). The forest was dominated by Douglas-fir (68–86% of the total trees ha^{-1}), but also had a diversity of mid-story hardwoods including

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