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Structure of early old-growth Douglas-fir forests in the Pacific Northwest

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ABSTRACT

Few empirical studies exist on structural transitions from mature forests dominated by Douglas-fir to structurally complex older forests. Stand structure (live tree diameter, height distributions, snag and log metrics) and composition of nine early old-growth (200–350 years old) forests were quantified and compared with those of fully developed old-growth (400–600 years old) forests. We investigated Douglas-fir and western hemlock-dominated forests of the Pacific Northwest where Douglas-fir established following a single stand-replacing disturbance. Stand-level attributes were summarized using descriptive statistics, nonlinear regression, and old-growth indices. Variability in individual structural features was large between sites but broadly consistent with models of natural Douglas-fir forest development. Compared to older (>450 years old) forests, diameter distributions exhibited similar reverse J-shapes. Tree height distributions showed that shade tolerant species occupy lower canopy positions. Coarse woody debris was abundant in early old-growth forests for both snags (42–140 m^3 ha^{-1}) and logs (172–584 m^3 ha^{-1}). Early old-growth stands scored high enough on old-growth indices to qualify as old growth but their scores were significantly lower than older forests (400–600 years-old). Early old-growth structure fits well with the natural conceptual model of development providing a basis for ecologically focused management. Furthermore, structural conditions and variability of early old-growth forests provides a closer temporal target for managers seeking to accelerate the development of structure in younger stands or retain natural elements such as spatial patterning of trees.

1. Introduction

Naturally developing forests characteristically subject to stand-replacement disturbances undergo repeated cycles of stand initiation and development. Structural development in these forests involves many processes, such as those associated with recruitment, growth and maturation of individual trees, competitive interactions (Lutz et al., 2014), and small-scale disturbances (Barnes et al., 1998; Kimmins, 2004). Development of structurally complex forests can require many centuries, particularly in forest ecosystems that include long-lived tree species, such as those found in northwestern North America (Waring and Franklin, 1979; Franklin and Dyrness, 1988). Structural attributes commonly used to assess forest structural complexity include diameter distributions, spatial variation of density, basal area, and biomass (Lutz et al., 2012, 2013), tree crown structure (Van Pelt and Sillett, 2008; Kane et al., 2010, 2011), and development and persistence of coarse woody debris (Franklin et al., 2002).

Douglas-fir (*Pseudotsuga menziesii* (Mirb) Franco.) forests in the Pacific Northwest represent an example of forests in which centuries of structural development culminate in structurally complex old-growth forests (Franklin et al., 2002; Franklin and Van Pelt, 2004; Van Pelt and Nadkarni, 2004). Although Douglas-fir forests are broadly distributed, the structural attributes and driving ecosystem process of older populations are poorly understood (Franklin, 2009). Consequently, conceptual models of the age classes documenting how forests transition structurally over time are primarily based on a limited set of developmental stages (e.g., Franklin et al., 2002 and Spies and Duncan, 2009; Table 1). Some developmental stages – such as young (<100 years) and well developed old-growth (>400 year) forests – have received extensive study (e.g. Franklin and Spies, 1984; Spies and Franklin, 1991; Tappeiner et al., 1997; Van Pelt and Nadkarni, 2004, Lutz and Halpern, 2006, Larson et al., 2008; Halpern and Lutz, 2013). The intermediate stages (100–400 years), importantly the early old-growth stage (200–350 years old), remains poorly understood,

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Table 1
Terminology for forest age classes described in this study.

Forest age class	
Young	<100 years
Mature	100–190 years
Early old-growth	190–350 years
Old growth	>400 years

even while understanding of the intermediate age classes is becoming more important to forest management in a changing climate.

The conceptual model advanced by Franklin et al. (2002) on Douglas-fir forest structural development is largely based on empirical data and analyses of young, early-mature, and well-developed old-growth forests. Structural characterizations of old-growth in the Franklin et al. (2002) model are largely based on stands that originated ca. 1500 AD (Spies and Duncan, 2009) and may represent idiosyncratic stand developmental trajectories from stands originating in following centuries. For example, many of the old-growth stands used to construct the current conceptual model may have experienced one or more additional disturbances severe enough to regenerate new cohorts of Douglas-fir (Van Pelt, 2007; Tepley et al., 2013). Stages of structural development following single high severity disturbances have been investigated using space (e.g. stands of a particular age) for time substitutions. These chronosequence approaches have limitations (e.g. Pickett, 1989) but can be very useful when sequential data on the full developmental sequence are not available (Spies and Franklin, 1991). Intermediate disturbances such as fire or wind can also influence development of structure in different types of ways by reducing densities of tree species, consuming coarse woody debris, and changing crown morphology and canopy structure. Hence, it is important to examine the conceptual framework by analyzing preceding forest stages that developed in the absence of moderate severity disturbances. Structure, composition, and process of early old-growth forest stages remain largely undocumented (but see Spies and Franklin, 1991; Huff, 1995; Zenner, 2005). However, no study has yet specifically focused on characterizing early old-growth structure despite the apparent importance of this stage for old-growth development. General descriptions of this developmental stage have been provided by Franklin et al. (2002) and includes discussion of, (1) transitions in canopy architecture from single-layered canopies in young-mature forests to vertically continuous canopies in early old-growth, and (2) the period of development when chronic small-scale disturbances create canopy gaps that diversify forest structure in the horizontal plane (Franklin et al., 2002; Tepley et al., 2013). In this study, the structural and compositional conditions in natural, early old-growth Douglas-fir-dominated forests are reported. Above-ground attributes of nine forest stands that originated ca. 1650 to 1800 AD in western Washington and Oregon are analyzed and their characteristics are compared with both younger and older Douglas-fir forests. Three general questions are addressed: (1) What are the structural dimensions of early old-growth forests, including the variability between stands; (2) How do early old-growth stands score on existing structural indices in comparison with young-mature forests and well-developed old-growth forests; and (3) Will modeled Douglas-fir stem densities in the early old-growth be similar to the densities of existing well developed old-growth Douglas-fir stands?

2. Methods

2.1. Study area

A total of nine early old-growth stands were sampled during this study. Eight of nine sampled stands are distributed along the western slope of the Cascade Range between elevations of 318–799 m. These stands occupy moist to relatively dry sites representative of the Western Hemlock Zone (Franklin and Dyrness, 1988) (Table 2). One stand (Huckleberry) is located in the eastern Olympic Mountains, Washington in the cooler, moister Pacific Silver Fir Zone (Franklin and Dyrness, 1988) (Table 2). All sites have a maritime climate characterized by cool wet winters and warm dry summers (Table 2). Annual precipitation ranges from 1974 mm to 3622 mm with the majority occurring during the months of October through April; conditions in the Pacific Silver Fir zone are somewhat cooler and moister and include a significant winter snowpack accumulation. Maximum July temperatures range from 20 to 25 °C and minimum January temperatures range from −1 to −4 °C.

Douglas-fir is an important shade-intolerant, pioneer tree species in the Western Hemlock and Pacific Silver Fir zones growing to very large dimensions, developing complex crowns (Van Pelt and Sillett, 2008), and living up to 700 to 1000+ years. Common tree associates in this region include western hemlock, western redcedar (*Thuja plicata* Donn ex D. Don), western white pine (*Pinus monticola* (Dougl.), Pacific silver-fir (*Abies amabilis* (Dougl. ex. Loud) Dougl. ex Forbes), Pacific yew (*Taxus brevifolia* Nutt.), noble fir (*Abies procera*), big-leaf maple (*Acer macrophyllum* Pursh), and Pacific dogwood (*Cornus nuttallii* Aud.). Soils range from sandy loams to clay loams and great soil groups include Haplorthods, Xerumbrepts, and Vitrandepts.

Stand-replacement wildfire is the principal agent of disturbance in this forest zone with events occurring relatively infrequently every 200–400 years (Hemstrom and Franklin, 1982; Agee, 1993), although partial stand-replacement events are also characteristic in more southerly latitudes (Tepley et al., 2013). Smaller-scale disturbances include wind, pathogens, and insects, and are important in creating structural complexity in older stages of forest development (Franklin et al., 2002).

2.2. Site selection

Sites were selected in Douglas-fir-dominated stands ~200 to 350 years of age that established after a single wildfire event. Sites were selected after extensive reconnaissance (see Freund et al., 2014), which included aging Douglas-fir trees at each candidate location and eliminating sites with evidence of post-establishment fire. Concentrations of this age class are found in only a few locations, such as the Clackamas and Breitenbush River drainages in the northern Oregon Cascade Range, in the Lewis River and Ohanapecosh River drainages of the Washington Cascade Range, and in eastern portions of Washington's Olympic Peninsula. Candidate stands were located following review of regional fire-history studies (Morrison and Swanson, 1990; Agee, 1991; Impara, 1997; Weisberg and Swanson, 2003), stand age-class maps (US Forest Service), conversations with forest ecologists familiar with the region (personal communications with Ken Bible, Rolf Gersonde, Scott Gremel, Jan Henderson, Robin Lesher, and Robert Van Pelt), and extensive reconnaissance. Due to its restricted distribution on the landscape, the nine sites we selected are broadly representative of the remaining examples of this age class.

The youngest age class of forest sampled was ~200 years in age, and stands of this age were uncommon, which made it unfeasible to replicate sampling in this age class over a broad geographic range. Four suitable stands of this age class were located in the Lewis River drainage of southwestern Washington and probably originated from a single extensive wildfire event although we did not reconstruct fire histories (Cedar Flats, Drift Creek, Osprey, and Skynard). Hence, these four stands could be viewed as "pseudo-replicates" (Hurlbert, 1984). However, site conditions and behavior of large wildfires can produce high levels of