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Variation in microclimate associated with dispersed-retention harvests in coniferous forests of western Washington

Troy D. Heithecker *, Charles B. Halpern

College of Forest Resources, Box 352100, University of Washington, Seattle, WA 98195-2100, USA

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Abstract

Green-tree or structural retention is becoming increasingly common as a method of regeneration harvest in the Pacific Northwest. Amelioration of microclimatic stress is assumed to be one mechanism by which overstory retention enhances the survival of forest organisms and the potential for ecosystem recovery following timber harvest. We examined patterns of transmitted light (photosynthetic photon flux density, PPFD), air and soil temperature, and soil moisture across a broad gradient of dispersed retention in mature, coniferous forests at three locations in western Washington. Treatment means and within-treatment variation (coefficients of variation among sample points within treatments) were compared for warm, sunny days in 6–7-year-old experimental harvest units representing 0, 15, 40, and 100% retention of original basal area. Multiple linear regression was used to explore relationships between microclimate and plot-scale measures of forest structure (including overstory attributes, understory vegetation, and logging slash). PPFD and mean and maximum air and soil temperatures decreased with level of retention. PPFD showed the strongest response, but did not differ between 40 and 100% retention. Mean and maximum air temperatures were significantly greater at 0 and 15% retention than at 100%. Among harvest treatments (0, 15, and 40%), mean air temperature was significantly lower at 40 than at 0%, but maximum air temperature did not differ among treatments. Mean and maximum soil temperatures differed only between 0 and 100% retention. Minimum air and soil temperatures and late-summer soil moisture did not differ among treatments. Within-treatment variability (coefficient of variation, CV) did not differ significantly with level of retention for any of the variables sampled, but CVs for soil temperature showed a consistent increase with decreasing retention. In combination, topography, residual forest structure, and understory variables were good predictors of PPFD and mean and maximum temperatures (R^2 of 0.55–0.85 in multiple regression models), but were poorer predictors of minimum temperatures and soil moisture (R^2 of 0.10–0.51). Canopy cover appeared most frequently in the models and cover of understory vegetation was a significant predictor in models of soil temperature. Trends in microclimate among experimental treatments were consistent, in large part, with the early responses of bryophyte, herbaceous, and fungal communities at these sites. Our results suggest that 15% retention, the current minimum standard on federal forests within the range of the northern spotted owl, does little to ameliorate microclimatic conditions relative to traditional clearcut logging.

Keywords: DEMO; Forest management; Forest microclimate; Light; Pacific Northwest; Structural retention; Temperature; Variable-retention harvest

1. Introduction

In the Pacific Northwest, variable-retention harvests that retain elements of old forest structure (large live trees, snags, and logs) have replaced clearcut logging on federal forests within the range of the northern spotted owl (Franklin et al., 1997; Aubry et al., 1999; Beese et al., 2003). Current federal standards require that live trees are retained across a minimum of 15% of each harvest unit (USDA and USDI, 1994) to moderate loss of biological diversity and to facilitate recovery of the regenerating forest. Although there are various mechanisms by which overstory retention can minimize species' loss and facilitate ecosystem recovery, it is generally assumed that amelioration of environmental stress (excess solar radiation, extremes in temperature, or soil moisture deficit) plays a critical role (Chen et al., 1992, 1995; Franklin et al., 1997; Barg and Edmonds, 1999). However, few studies have examined the relationships between microclimate and forest structure in the context of variable-retention systems (but see Barg and Edmonds, 1999; Chen et al., 1999; Zheng et al., 2000).

Some aspects of microclimate show strong and predictable relationships with forest structure. For example, solar radiation

* Corresponding author. Present address: USDA Forest Service, Pacific Northwest Research Station, 2770 Sherwood Lane, Suite 2A, Juneau, AK 99801, USA. Tel.: +1 907 586 8811; fax: +1 907 586 7848.

E-mail addresses: theithecker@fs.fed.us (T.D. Heithecker), chalpern@u.washington.edu (C.B. Halpern).

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at the forest floor is directly related to the amount and spatial distribution of overstory cover (Drever and Lertzman, 2003). Other elements of microclimate are less predictable from forest structure. For example, soil and ground-surface temperatures are affected by incoming (short-wave) and outgoing (long-wave) radiation, which are determined, in part, by the full vertical profile of vegetation cover (Yoshino, 1975; Aussenac, 2000; Prevost and Pothier, 2003). Removal of canopy cover increases solar radiation which should elevate daytime temperatures; however, this should also result in greater loss of long-wave radiation, thus lowering nighttime temperatures and increasing potential for frost (Groot and Carlson, 1996). Canopy removal can also facilitate growth of understory vegetation, thereby reducing heat exchange with the soil and mitigating loss of overstory cover. Effects of forest structure on soil moisture may also be difficult to predict: reductions in canopy cover may lead to more evaporation from the soil surface (Morecroft et al., 1998; Chen et al., 1999), but less transpirational loss (e.g., Breda et al., 1995).

Dispersed retention of trees should serve to moderate forest-floor microclimate and thus benefit organisms sensitive to excess solar radiation or extremes in temperature. Logically, these benefits should increase with the amount of retention. However, little research has been devoted to understanding the nature of this relationship (e.g., the existence of thresholds), or to identifying the features of residual forest structure that most influence microclimatic variation (Barg and Edmonds, 1999; Drever and Lertzman, 2003). Relative to clearcut logging, dispersed retention should also affect the spatial variability of microclimate in the forest understory. Patchy shading by residual trees, local accumulations of logging slash, and differential survival and growth of ground vegetation should increase the spatial heterogeneity of light, temperature, and soil moisture, and thus spatial variability in the survival of forest organisms that are sensitive to variation in these environmental factors (Hungerford and Babbitt, 1987; McInnis and Roberts, 1995; Gray and Spies, 1997; Grimmond et al., 2000; Martens et al., 2000). However, to date, studies of forest microclimate have emphasized the average conditions of harvest treatments, not the magnitude or sources of variation within them (but see Chen et al., 1999; Zheng et al., 2000; Drever and Lertzman, 2003).

In this study we examine patterns of microclimatic variation among harvest treatments that represent a broad gradient in overstory retention in mature, coniferous forests of western Washington. The treatments are part of the Demonstration of Ecosystem Management Options (DEMO) study, a regional experiment in variable-retention harvest that evaluates the roles of level and pattern of retention in the persistence and recovery of organisms associated with late-seral forests (Aubry et al., 1999; Halpern et al., 2005). We assess variation in light, air and soil temperature, and soil moisture among and within harvest treatments and identify the components of residual forest structure (including overstory characteristics, understory vegetation, and logging slash) that best explain this variation. We address the following questions: (1) How do treatment-scale patterns of light, air and soil temperature, and soil moisture vary with level of retention? (2) Is the spatial heterogeneity (within-treatment variation) of light, temperature, or soil moisture greater at intermediate levels of retention, reflecting the greater dispersion of trees? (3) Which elements of residual forest structure, including overstory characteristics, understory vegetation, and logging slash, explain local variation in microclimate? We conclude by examining whether microclimate trends among treatments are consistent with the biological responses that have been observed in companion studies on these sites.

2. Methods

2.1. Study areas

This study was conducted at three of the six experimental blocks that comprise the DEMO study—Butte (BU), Little White Salmon (LWS), and Paradise Hills (PH). All are located in the southern Cascade Range of Washington (Aubry et al., 1999). The climate of this region is characterized by relatively warm, dry summers and cool, wet winters with most precipitation falling between October and April (Franklin and Dyrness, 1988). However, local climatic conditions vary both among and within the experimental blocks, reflecting variation in latitude, elevation, and aspect (Table 1) (see also Halpern et al., 1999, 2005). Soils are moderately deep and well-drained loams to loamy sands derived from andesite, basalt, or breccia parent materials, or from aerial deposits of pumice (Wade et al., 1992). Three forest zones are represented, defined by the climax tree species: *Tsuga heterophylla* (BU), *Abies grandis* (LWS), and *Abies amabilis* (PH). At the time of harvest, forests were dominated by *Pseudotsuga menziesii* with no previous history of management. Forest age and structure varied greatly among blocks, and to a degree, among treatment units within blocks (Table 1). BU (70–80 years) and PH (110–140 years) were relatively dense forests (~1000 trees ha^{-1}); LWS (140–170 years) was characterized by large, widely spaced trees (~220 trees ha^{-1}) (Table 1). Understory development also varied markedly among blocks: herb and shrub cover were much higher at LWS (43 and 69%, respectively) than at BU (27 and 20%) or PH (19 and 13%) (Halpern et al., 2005).

2.2. Experimental treatments

The DEMO experimental design consists of six, 13-ha treatments randomly assigned to experimental units within each block. Treatments differ in level of retention (percentage of original basal area) and/or the spatial pattern in which trees are retained (dispersed versus aggregated) (details can be found in Aubry et al., 1999). For this study, four of these treatments were selected to represent a gradient of dispersed overstory retention (Fig. 1):

(1) 100%: control, no harvest.
(2) 40% dispersed (40%D): residual trees are dominants or co-dominants evenly dispersed through the harvest unit.
(3) 15% dispersed (15%D): residual trees are dominants or co-dominants evenly dispersed through the harvest unit.