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Edge-related gradients in microclimate in forest aggregates following structural retention harvests in western Washington

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Abstract

Aggregated retention is now a common method of regeneration harvest in forest ecosystems managed for both timber and ecological objectives. If residual forest aggregates are to serve as temporary refugia for species sensitive to disturbance or environmental stress, microclimatic conditions must be sufficiently buffered to allow for their persistence. In 1-ha aggregates at three experimental sites in western Washington, we quantified spatial gradients in microclimate (light, air and soil temperature, and soil moisture), effects of aspect on these gradients, and how microclimate compared to conditions in adjacent harvest areas and larger tracts of undisturbed forest (controls). Light availability and temperature were greatest at the edge, but declined sharply inside the aggregate, with most change occurring within 20 m of the edge. Beyond this distance, light generally declined to levels observed in the controls. Soil temperatures exhibited greater spatial variation and stabilized further from the edge (10–30 m), but air temperatures were generally higher than those in controls. Soil moisture exhibited no spatial trends and was comparable among aggregates, harvest areas, and controls. Aspect exerted strong effects on light and temperature, particularly within 15 m of the edge, as did forest structure. Where tree density was low, microclimatic gradients were less steep and aspect-related differences were small. Comparisons with previous studies of ground vegetation indicate that microclimatic effects were consistent, in part, with declines among some groups of vascular and non-vascular plants; however, these declines were restricted to edge environments (5–10 m) and were unaffected by aspect. Our results suggest that 1-ha aggregates are sufficiently large to contain areas with light, temperature, and soil moisture that are comparable to those in undisturbed forest and suitable, in the short-term, for persistence of forest-dependent species.

Keywords: Aggregated retention; Edge effects; Forest microclimate; Light; Temperature; Variable-retention

1. Introduction

Increasingly, forest managers are designing silvicultural systems to meet multiple objectives (e.g., maintaining biodiversity, producing timber, and enhancing wildlife habitat). Structural retention harvests that retain elements of the original forest (live trees, snags, and logs) have been adopted as one method to achieve these objectives (Franklin et al., 1997; Deal, 2001; Drever and Lertzman, 2003). On federal lands in the Pacific Northwest, the current policy for regeneration harvests within the range of the northern spotted owl requires that live trees are retained over at least 15% of the harvest unit, with 70% of this retention as 0.2- to 1.0-ha aggregates of undisturbed forest (USDA and USDI, 1994). Among other functions, aggregates are intended to provide refugia for disturbance-sensitive species and dispersal sources for recolonization of adjacent harvest areas (Franklin et al., 1997). However, this requires that microclimatic conditions within forest aggregates are sufficiently buffered to maintain species sensitive to environmental changes. Patches that are too small or permeable may be vulnerable to microclimatic changes that diminish their ecological integrity. Thus, understanding the potential for edge effects is critical to designing variable-retention systems that employ aggregates to maintain and facilitate recovery of biological diversity after harvest.

Studies of clearcut-forest boundaries provide the empirical basis for much of our understanding of edge effects. Radiation, temperature, and other physical processes can differ substantially between forest-edge and interior environments. Steep gradients in microclimate are typical along the boundary

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between recently cut and intact forest. Most change appears to occur within 40–50 m of the edge (e.g., Chen et al., 1993, 1995), however, stabilization may occur at considerably shorter distances for variables that are less sensitive to ambient conditions (e.g., soil temperature; Williams-Linera, 1990; Young and Mitchell, 1994; Camargo and Kapos, 1995; Davies-Colley et al., 2000). In contrast, some microclimatic variables (e.g., humidity, wind speed) are highly sensitive to forest edges and effects can be detected at distances >200 m (e.g., Chen et al., 1995). Topography and latitude can diminish or amplify the depth and magnitude of these effects through changes in solar angle or heat load (e.g., Camargo and Kapos, 1995; Chen et al., 1995; Turton and Freiburger, 1997). Forest structure can also affect these gradients. Edge contrast, the difference in canopy height between cleared and intact forest, and edge closure, the density and vertical distribution of foliage along the edge, can affect light penetration and air movement and thus gradients in temperature and humidity (Canham et al., 1990; Matlack, 1993; Chen et al., 1995). Moreover, both can change over time with growth of the regenerating forest and in-filling along the edge (e.g., Denyer et al., 2006).

In this study, we explore edge-related gradients in microclimate (light, temperature, and soil moisture) within residual forest patches resulting from aggregated-retention harvest of mature, coniferous forests in the southern Cascade Range of western Washington. To our knowledge, this is the first such study of forest aggregates and one of the few studies that have explored the microclimatic effects of structural retention (e.g., Barg and Edmonds, 1999; Chen et al., 1999; Zheng et al., 2000; Heithecker and Halpern, 2006). We utilize a subset of the aggregated retention and control treatments, from the Demonstration of Ecosystem Management Options (DEMO) Study, a large-scale experiment that examines ecological responses to variable-retention harvest (Aubry et al., 1999). We address the following questions: (1) do forest aggregates show consistently greater light availability, greater summer temperature, and lower soil moisture than larger blocks of undisturbed forest? Conversely, do they support microclimatic conditions that differ significantly from those in adjacent harvest areas? (2) How do light, temperature, and soil moisture vary with distance from forest edge? (3) How do these gradients vary with aspect? These characteristics represent important mechanistic links between the manipulation of forest structure and the responses of forest organisms to resulting changes in microclimate. We conclude by discussing the relevance of microclimatic patterns for biological responses at these sites using data on the edge-related responses of vascular and non-vascular plants (Nelson and Halpern, 2005a,b).

2. Methods

2.1. Study sites

Studies were conducted at three sites in the southern Cascade Range, Washington, within the framework of the DEMO study (Aubry et al., 1999; Halpern et al., 1999, 2005). The sites – Butte (BU), Paradise Hills (PH), and Little White Salmon (LWS) – occur at elevations between ~800 and 1158 m and vary in slope and aspect (Table 1). 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). The climate is characterized by warm, dry summers and cool, wet winters. Most precipitation falls between October and April resulting in a long period of summer drought (Franklin and Dyrness, 1988). Additional details on the physical environments of these sites are contained in Halpern et al. (2005).

All forests were dominated by Douglas-fir (*Pseudotsuga menziesii*), but stand age, structure, and species composition varied markedly (Table 2; see also Halpern et al., 1999, 2005; Maguire et al., 2007). Forests at BU were relatively young (70–80 years) and dense (830–1000 stems ha^{-1}) with a significant component of western hemlock (*Tsuga heterophylla*) and western redcedar (*Thuja plicata*) in the subcanopy; canopy height averaged 28–33 m. Forests at PH were mature (110–140 years), moderately dense (590–1000 stems ha^{-1}), and structurally and compositionally more diverse than at BU or LWS. *T. heterophylla* comprised a significant proportion of canopy stems and Pacific silver fir (*Abies amabilis*) was common in the understory; canopy height averaged 27–32 m. Forests at LWS were the oldest (140–170 years) and very open (230–300 stems ha^{-1}), comprised of large *P. menziesii* with a well-developed shrub layer of vine maple (*Acer circinatum*) (~70% cover); canopy height averaged 49 m. Additional information on understory composition is contained in Halpern et al. (1999, 2005).

Table 1
Environmental attributes of forest aggregates and reference environments at each site

Site	Latitude, longitude (°)	Environment	Elevation (m)	Slope (°)	Aspect (°)
Butte (BU)	46.37N, 122.20W	Harvest area	988–1134	30	138
		Forest aggregates	988–1134	31	145
		Control	963–1158	28	146
Paradise Hills (PH)	46.01N, 121.99W	Harvest area	985–1027	6	157
		Forest aggregates	985–1027	6	155
		Control	853–902	6	133
Little White Salmon (LWS)	45.86N, 121.59W	Harvest area	792–939	29	74
		Forest aggregates	792–939	28	74
		Control	841–1000	23	316