Microclimate Patterns Associated with Density Management and Riparian Buffers

An Interim Report on the Riparian Buffer Component of the Density Management Studies

Prepared for the USDI Bureau of Land Management

by

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Disclaimer: ***This report is based on preliminary analyses. The data, analyses, and inferences contained herein have not been subject to peer review. The intent of this report is to provide the funding agency with documentation of progress made, and planned additional effort, in partial fulfillment of the interagency funding agreement. The information and inferences herein do not represent policies or recommendations of either the US Forest Service or the US Bureau of Land Management.***

Executive Summary

Introduction

Over the past 10 to 15 years a fundamental change in forest management has occurred throughout federal lands of the Pacific Northwest. An ecosystem management paradigm has been adopted. Among the many facets of this strategic shift, two in particular are relevant to the research encompassed by this report. First, the intent to manage substantial portions of federal lands for development of late-seral forest features of structural complexity and diverse biota. Secondly, the administrative use of riparian reserves and buffers to protect critical ecological functions associated with streams and their adjacent habitats.

Microclimate is an important element of ecosystem function as it influences biological processes such as primary production and decomposition, and the physical environment determining habitat suitability for many organisms. Basic knowledge of spatial and temporal variation in microclimate of riparian and adjacent upland forests of western Oregon is lacking. Further, the influence of forest management practices, particularly overstory thinning and riparian buffer delineation, on microclimate conditions of riparian zones is generally unknown. Given that much of the active management on federal lands occurs in headwater forests, it is important that relationships between silvicultural treatments and microclimate be characterized for riparian and adjacent upslope forests.

The Bureau of Land Management initiated the Density Management Studies (DMS) in the mid-1990's to evaluate a range silvicultural treatments, principally variations on intensity and spatial configuration of commercial thinning, to enhance structural complexity and biodiversity in 40- to 60-year-old Douglas-fir forests of western Oregon. In conjunction with the basic DMS, a set of component studies were undertaken to investigate the influence of various buffer delineations on stream habitats and fauna in the context of upland forest thinning. This report addresses the microclimate component of the Density Management and Riparian Buffer Studies.

The microclimate study component included the following objectives: 1) describe microclimate gradients associated with riparian and adjacent upland forests in both thinned and unthinned stands; and 2) evaluate potential differences in microclimate gradients among alternative buffer widths.

Methods

The DMS implemented a range of upland thinning treatments designed explicitly to increase structural heterogeneity of forest stands. These treatments consisted of creating gaps and uncut "leave islands" of various sizes, within a matrix of forest stands thinned to 80 or 120 trees per acre (tpa); or within a variable density matrix consisting of equal-area portions of 40, 80, and 120 tpa. The Riparian Buffer component study additionally introduced four treatments to evaluate standards and guidelines establishing riparian buffer widths. Four buffer delineations were included: 1) streamside retention maintaining trees within a crown-width of the stream bank; 2) variable width as determined by channel geomorphology, streamside vegetation or other identified features of interest for maintenance (eg. wetland); 3) one site-potential-tree width; and 4) two site-potential-tree width. Additional unthinned stands served as control treatments. These combinations of upland thinning and riparian buffer treatments were established in part or in total at seven BLM sites dispersed across the Oregon Coast Range and the west-side of the Oregon Cascades range between 1997 and 2001.

For each site and treatment combination, canopy cover, understory light, air and soil temperature, and relative humidity were measured or monitored prior to, and following implementation of the commercial thinning treatments. Spatial variation in cover, light and microclimate was characterized by repeated sampling along transects originating at stream center and extending perpendicular to the channel through the riparian zone and into the adjacent upland forest. While most transects extended about 200 ft upslope, a few extended in excess of 700 ft depending on buffer width and topography. Observations of canopy cover and light transmittance were made at 3.3 ft (1 m) above ground. Air temperature and relative humidity were measured at heights of 0.7 ft (0.2 m, near ground) and 3.3 ft (understory) above ground. Light and microclimate were sampled at six of the seven BLM sites, five in the Coast Range and one in the Cascade Range. Although sampling was conducted both in winter and summer seasons, we focus this report on observations made during the summer when treatment effects are expected to be most pronounced.

Results

Commercial thinning substantially increased understory light when stand density was decreased to a basal area (BA) less than 120 ft^2, or in other terms, below a relative density (RD) of 30. At higher residual densities light transmittance values were very similar to those of unthinned stands, being about 10 percent of light in the open. Increased thinning intensity to a moderate level of 80 tpa (ca. BA of 100 ft^2 or RD 20) resulted in average light levels of 25 percent of open conditions. The heaviest thinning to 40 tpa (ca. BA of 60 ft^2 or RD 15) resulted in light levels averaging about 30 percent of that in the open; only a five percent increase for a doubling of thinning intensity over the 80 tpa treatment. Light conditions within 1-ac patch openings averaged about 57 percent of open conditions as a result of light interception by the surrounding trees. With respect to riparian buffers, increased light transmittance resulting from thinning adjacent stands was generally limited to 60 ft from the buffer-upland forest edge.

Microclimate gradients at 4 pm, the warmest and driest part of the day, indicated a significant influence of the stream extending about 75 ft outward from stream center. The strongest influence of the stream on microclimate, as indicated by steepness in temperature and relative humidity gradients, occurred within 15 ft of the stream.

Microclimates differed significantly among upslope treatment areas during the peak stress period at 4 pm. Patch openings tended to be warmer and drier than thinned stands, which in turn were warmer and drier than unthinned stands. However, among stands thinned to various densities, microclimates on average were not significantly different. There was considerable overlap in observed temperatures and humidities between thinned and unthinned stands suggesting that these stands provide a wide-range of microclimates. Microclimate differences associated with buffer width or density management were not evident during the evening and night period extending between 6 pm and 6 am.

At the stream we were unable to detect significant effects of either buffer width or upland density management on streambed water temperature, or air temperature and relative humidity within the first 15' of the stream center.

Ongoing Work

This interim report, focused on the microclimate component of the Riparian Buffer Studies, is a first step in preparation of a comprehensive final report incorporating additional information on microsite responses to density management and riparian buffers. The final report, to be delivered in draft form to the BLM on September 30, 2004, will include a tabular guide to assist managers in predicting light, shade, and overstory cover from stand metrics of basal area or relative density. The final report will also provide additional analyses of density management and riparian buffer effects on:

1) Understory vegetation composition and abundance responses;
2) Stand structure dynamics along the riparian to upland transects;
3) Canopy development based on time series hemispherical images.

I. Introduction and Background

Scope and Format of this report

This report summarizes observations and preliminary analyses of microlimate and understory light conditions in riparian and adjacent upland forests in relation to density management (thinning) and stream-side buffer delineation.

A question and answer format is used throughout this report. The questions reflect those asked of the investigators over the last several years by federal forest lands managers. The questions and answers provide details of the study including the context, objectives, approach, preliminary results, and preliminary interpretation of findings.

The results and discussion addresses three major themes: spatial variation and treatment effects on microclimate; spatial variation and treatment effects on understory light conditions; and relationships between common stand density metrics and understory light conditions. The latter topic was specifically raised by BLM managers. Definition of the relationships between basal area or relative density and understory light availability will potentially assist managers in understanding the influences of thinning on light availability, and associated impacts on riparian habitats and stream conditions.

It should be noted that all analyses and interpretations are preliminary and have not been subject to peer review. The intent of this report is to document for the BLM progress to date and to outline further analyses that will occur prior to submission of a final, peer-reviewed report later this year.

What are the intended functions of Riparian Reserves?

In the context of the Northwest Forest Plan, Riparian Reserves serve as transition zones between upslope and aquatic areas, and dispersal corridors for many terrestrial animals and plants, and connectivity corridors within a watershed (USDA and USDI 1994). The Riparian Reserve network is intended to maintain and restore hydrologic, water quality and riparian processes. The maximum reserve interim width equal to twice the height of site potential trees was partially driven by the goal to maintain typical riparian humidity and temperature conditions near the stream. However, there existed little definitive information on riparian microclimate when Riparian Reserve guidelines were formulated under the NWFP. Therefore, scientists and managers established interim Riparian Reserve widths based on available microclimate research in upland forests. The NWFP provided for adjustment of these buffers contingent upon completion of watershed analyses. The Riparian Reserve module of Watershed Analysis provided framework for this adjustment process (USDA and USDI 1996a), including an evaluation of aquatic and terrestrial species information (USDA and UDI 1996b).

Although Riparian Reserves were established to protect aquatic and riparian values, it was quickly recognized that such corridors also offered incidental benefits to a host of terrestrial species. Riparian Reserves contribute to foraging, reproductive and dispersal habitat for forest-dependent taxa. This additional role of Riparian Reserves also needed to be evaluated before interim Riparian Reserves could be altered. Understanding functional relationships of riparian vegetation and its management on hydrology, water quality, and stream productivity is of primary importance.

Why are managers treating vegetation in Riparian Reserves?

Exclusion of timber harvest from Riparian Reserves has been assumed to maintain species diversity, ecosystem integrity and protection of ecosystem functions. The "hands-off" assumption may have been valid in an ecological context when humans had little impact on disturbance regimes and ecological processes in forests. However, many of the forests designated as Riparian Reserves under the NWFP were previously managed for timber production and are characterized by relatively dense, uniform, 30-70-year-old even-aged stands of Douglas-fir (*Pseudotsuga menziesii* Franco) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.). These young stands are typically lacking in structural and biological diversity. Lack of complexity makes these stands poorly suited for supporting many riparian-dependent species, the northern spotted owl (*Strix occidentalis cuarina*), and many other wildlife species (Carey 1995; Lindermayer and Franklin 2002).

A passive management option is to assume that over time young stands within riparian reserves will naturally develop desired characteristics and functions while forgoing timber harvest for commodity production. However, these stands typically remain in the stem-exclusion stage (Oliver and Larson 1996), and therefore depauperate of desired structural characteristics, for extended periods of time (potentially exceeding 100 years).

Alternatively, an active approach to reserve management might include thinning to achieve compatible production of ecological services and timber. Thinning of young Douglas-fir stands may be a means to create more heterogeneous forest structure conducive to development of understory vegetation (DeBell et.al.1997, Bailey and Tappeiner 1998) and more rapid development of large trees (McComb et al. 1993, Carey et al. 1999a, Carey et al. 1999b) than would occur without intervention. Such active management within Riparian Reserves is permitted only after an assessment of watershed conditions concludes that proposed management activities will not pose increased risks for degradation of ecosystem integrity.

Why is knowledge on microclimate relevant for forest density and riparian buffer management?

Riparian Reserve delineation in the federal Northwest Forest Plan (NWFP) based on distance from stream channel was initially intended to maintain or protect riparian functions and processes by retaining forest vegetation that provides shade, favorable microclimate, water quality, large-wood input and delivery, rooting strength for soil stability, and leaf and organic input (FEMAT 1993). The abundance, temporal and seasonal patterns of vegetation, coarse wood, forest floor and abiotic conditions as topography, macroclimate and biota contribute to the microhabitat. Microclimate (fine scale temperature, humidity, wind, solar radiation) is a critical component of microhabitat. Microclimatic conditions are important in the distribution, establishment, survival, growth, reproduction, behavior or persistence of a wide range of organisms and in forest processes (Chen et al. 1999). However, the response of organisms to microclimate is mediated by other abiotic factors, biotic interactions, and biotic influences on microclimate (Gehlhausen et al. 2000, Freiberg 2001). Furthermore, the response of mobile organisms to microclimate is mediated by their ability to seek favorable microclimatic conditions by finding sheltered conditions when they are too warm and dry and locating exposed conditions for thermal warming and water.

Well-developed understories (herbs, forbs, shrubs and understory trees) have been hypothesized to promote a variety of ameliorated microclimates and, thus, habitats for a diverse array of species. Density management treatments have recently been devised to create spatial heterogeneity in composition and structure within young, closed canopy forest stands, previously managed intensively for commercial wood production. These treatments, designed to promote structural and functional characteristics of late seral forests, may include variable density thinning, creation of patch openings, and retention of reserve islands and riparian buffers. This type of forest manipulation is designed not simply to increase structural heterogeneity, but also to manipulate forest microclimate in ways favorable to habitat and stream conditions.

Heterogeneity in microclimate is thought to be an important determinant in maintaining diversity of vascular plants, fungi, aquatic dependent vertebrates and invertebrates. Because of the lack of understory vegetation in many second-growth stands, short-term effects of thinning on forest microclimates may be quite different from microclimate responses that would occur if there were pre-exisiting, well-developed understory vegetation.

What is currently known about microclimate and the effects of forest microclimates in the Pacific Northwest?

Chen (1991) studied microclimate gradients between an upland old-growth forest and an adjacent upland clearcut in the Wind River area of western Washington. Chen (1991) found that the adjacent clearcut influenced microclimate of the uncut stand up to three site-tree-heights from the clearcut edge (Figure 1). The extent to which microclimate of the uncut stand was influenced depended on the variable of interest; the influence of the clearcut on soil moisture and radiation was localized to the edge of the uncut forest. In contrast, alterations in wind speed and relative humidity were apparent well into the interior of the uncut stand (Figure 1).

Based on microclimate observations in riparian buffers, uncut managed forests and adjacent clearcuts, Brosofske et al. (1997) suggested that riparian buffers of a 45 m minimum width were sufficient for maintaining typical relative humidity conditions in the riparian zone. Their recommendation was based on the assumptions that gradients in microclimate stabilize within 30 m of the stream and that upslope edge effects extend no more than 15 m into the buffer.

The relationships derived by Chen (1991) from upland forests were extrapolated to riparian systems in interim guidelines defining Riparian Reserves under FEMAT (1993). However, it is worth noting that both the Chen (1991) and Brosofske et al. (1997) studies compared microclimates of intact forests and clearcuts. The relationships they describe may not hold when comparing microclimates of riparian forests and adjacent thinned forests such as exist in the DMS.

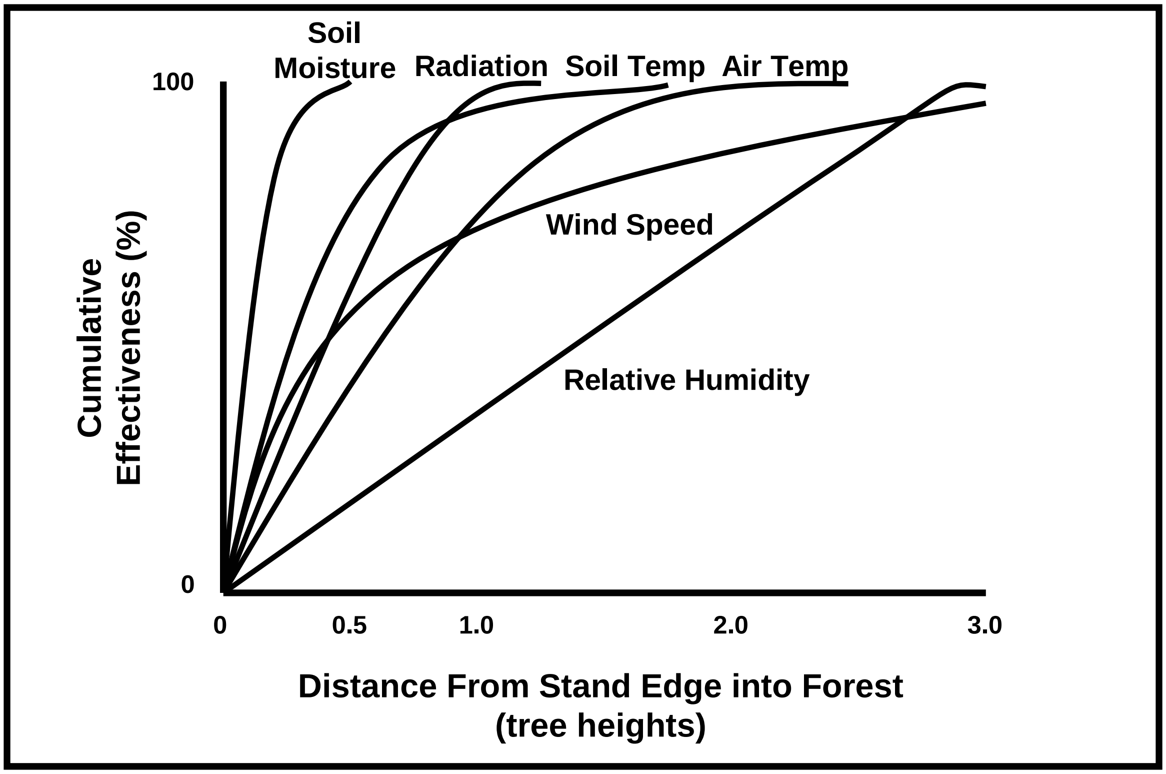


Figure 1. Cumulative effectiveness of an old-growth stand in mitigating microclimatic changes associated with clearcutting. Adapted from FEMAT (1993).

What is the influence of riparian vegetation in providing streamside cover and shade?

The effect of riparian vegetation on stream shading decreases with increasing distance from the stream-bank and is further influenced by the channel width, channel morphology, aspect and topography. Vegetation structure, including height, density, vertical and horizontal canopy connectivity, and canopy coverage will determine the effectiveness of vegetation for providing shade. Although the width of riparian areas necessary to shade streams can vary, the effectiveness of riparian vegetation for providing stream shading as described in FEMAT (1993) is substantially diminished as distance from the stream channel exceeds half the site potential tree height.

II. Study Objectives and Approach

What are the objectives of the light and microclimate components of the Riparian Buffer Studies?

This study was initiated to examine the effects of commercial thinning and riparian buffer widths on microclimate and light environments in headwaters forests.

Specifically, our objectives were to:

1) Characterize spatial variation in microclimate associated with stream channels, riparian zones and adjacent upland forests;
2) Determine if different buffer width delineations or upland thinning treatments influence microclimate of stream channels, riparian zones or upland forests;
3) Quantify the effect of upland thinning treatments on canopy cover and understory light conditions;
4) Characterize dynamics of tree canopy responses to thinning;
5) Determine the influence of overstory thinning and riparian buffer width on dynamics of understory vegetation abundance and composition in riparian and adjacent upland forests.

Objectives 1-3, above, relate directly to microclimate and light responses to riparian buffer and thinning treatments in DMS. The three objectives are the focus of this interim report. Objectives 4 and 5 are also relevant as they relate to vegetation structure which in turn is thought to be strongly related to light and microclimate. We will address objectives 4 and 5 in the final report.

What approach have we taken to improve our knowledge of microclimate associated with density management and riparian buffers?

The BLM Density Management Studies (DMS) were designed to examine the efficacy of a wide range of thinning densities and riparian buffer width delineations in enhancing structural diversity for late-seral and aquatic conservation objectives and for protecting riparian dependent organisms from sharp and sustained microclimatic changes. Thinning densities included unthinned, 120, 80 and 40 trees per acre (tpa) with a variety of intermixed patch openings and leave islands (0.25, 0.5 and 1.0 acre). Four riparian buffer widths were evaluated including 2 site-potential-tree-height (2SPTH), 1SPTH, variable width buffer (VB) based on topographic breaks and vegetation changes, and streamside retention (SR) where all trees with a canopy drip line influence over the stream were retained.

Buffer treatments delineated by the one and two site-potential-tree-height correspond to standards and guidelines established in the NWFP (USDA and USDI 1994). The variable width buffer delineation corresponds more closely to rules established for non-federal forest lands in the state of Oregon. The streamside retention buffer delineation provides a treatment that potentially accelerates the development of large trees near the stream while providing some of the physical functions of bank stability and stream shading, but perhaps less moderation of microclimate changes on and along the stream.

Periodic monitoring of sub-canopy light, microclimate, and vegetation were undertaken along transects extending from steam center into the adjacent upland forest to assess spatial and temporal responses to the treatments. At a given site, the assessment is focused at the reach scale. Sampling of multiple sites across a broad portion of the Coast and wet-side Cascade Ranges provides for a larger geographic inference scope useful to federal land managers.

Why were BLM density management sites selected for this study?

Managers in the BLM expressed strong interest in management opportunities and constraints related to Riparian Reserves and buffers. We chose to implement the riparian buffer study as a component of the Density Management Studies because the DMS sites were representative of the thousands of acres of 40-to-70-year-old Douglas-fir forests in western Oregon being considered for variable density thinning to increase structural and biotic diversity. With the operational layout in place for implementation of the upland thinning treatments, it was relatively quick to add a riparian buffer study component that was relevant to interests of lands managers. Thus, implementation of the riparian buffer study was completed within a 4-yr period. However, a drawback to overlaying the Riparian Buffer study onto the DMS framework was that sites were pre-selected and there were constraints to the random selection of streams and reaches, and constraints on randomization of various buffer treatments in relation to upland thinning treatments. As a result inferences from the study may be limited to the broader landscape (Olson et al. 2002).

III. Study Methods

In this section we address questions of methodology believed to be of direct concern to interested stakeholders. Additional methodological details are described in the comprehensive study plan on file with the BLM Research Coordinator.

What are the upland and riparian buffer treatments addressed in this report?

Four upland management treatments are included in DMS. Three of the upland treatments consist of patch openings of 0.25, 0.5, and 1.0 ac and uncut "leave islands" 0.25, 0.5 and 1.0 ac imbedded within a forest matrix thinned to: 1) 120 tpa (high density); 2) 80 tpa (moderate density); or variable densities of 40, 80, and 120 tpa (approximately equal area per density). The fourth upland treatment is an unthinned stand (approximately 220 tpa).

Four riparian buffer treatments are included in the Riparain Buffer Studies of DMS. The buffer treatments include: 1) streamside retention; variable width; 3) one site-potential-tree-height width (1SPTH, *ca.* 240 ft); and two site-potential-tree-height width (2SPTH, *ca.* 480 ft).

What environmental and microclimate variables were measured?

Microclimate variables measured included air temperature, relative humidity, and soil temperature. Estimates of canopy cover and effective shade were derived from analysis of hemispherical photographs. Streambed temperature, an indirect measure of stream temperature, was also measured.

In addition to microclimate parameters, several microsite characteristics were also recorded. These included herbaceous, forb and shrub vegetation cover and composition, overstory composition and basal area, downed woody debris, and litter. Topographical features such as aspect and height above channel were also measured. This report does not address microsite effects or responses; those analyses will be presented in the final report.

How are percent cover and effective shade defined in this study?

Percent cover is the degree that the vegetative canopy and other abiotic components obscure the sky at a given point (Ringold et al. 2003). Effective stream shade is the total solar radiation blocked from reaching the stream. Adjacent side slope steepness, vegetation species composition, tree height, vegetation density, tree distance from the stream bank, and stream width all affect effective stream shade. Thus, although riparian vegetation provides a physical barrier between the stream and incoming solar radiation, only a portion of the riparian canopy contributes to effective stream shade. In this study percent cover was derived from estimates of percent skylight (indirect light). Effective shade was derived from estimates of percent direct light (radiation). Hemispherical photographs were the basis for estimates of both percent cover and effective shade.

What sampling scheme was used to characterize environmental and microclimate variables?

Microclimate and corresponding microsite variables were sampled along transects extending perpendicular from the stream center. Measurement plots were located on the transects at distances of 0 (stream center),15 ft, 45 ft, 75 ft, 135 ft, and at 60 ft intervals beyond, up to a maximum of 735'. The length of transects varied depending on the buffer width treatment and extended approximately 240 ft from the edge of the buffer into the upland treatment (Figure 2). Occasionally some transects did not extend 240 ft into the upland treatment due to their intersection with a road or extension into another drainage or treatment.

Air temperature, relative humidity, and soil temperature (stream bed temperature at the 0 ft sampling point) were sampled hourly at each measurement point along each transect for a two-week period in both summer and winter. Data reduction resulted in calculation of hourly and periodic means for each two-week sampling period. In this report we focus on mean values for 4 pm (presumably the warmest and driest time of day during summer), 6AM to 6PM (the daily average), and 6PM to 6AM (the nightly average).

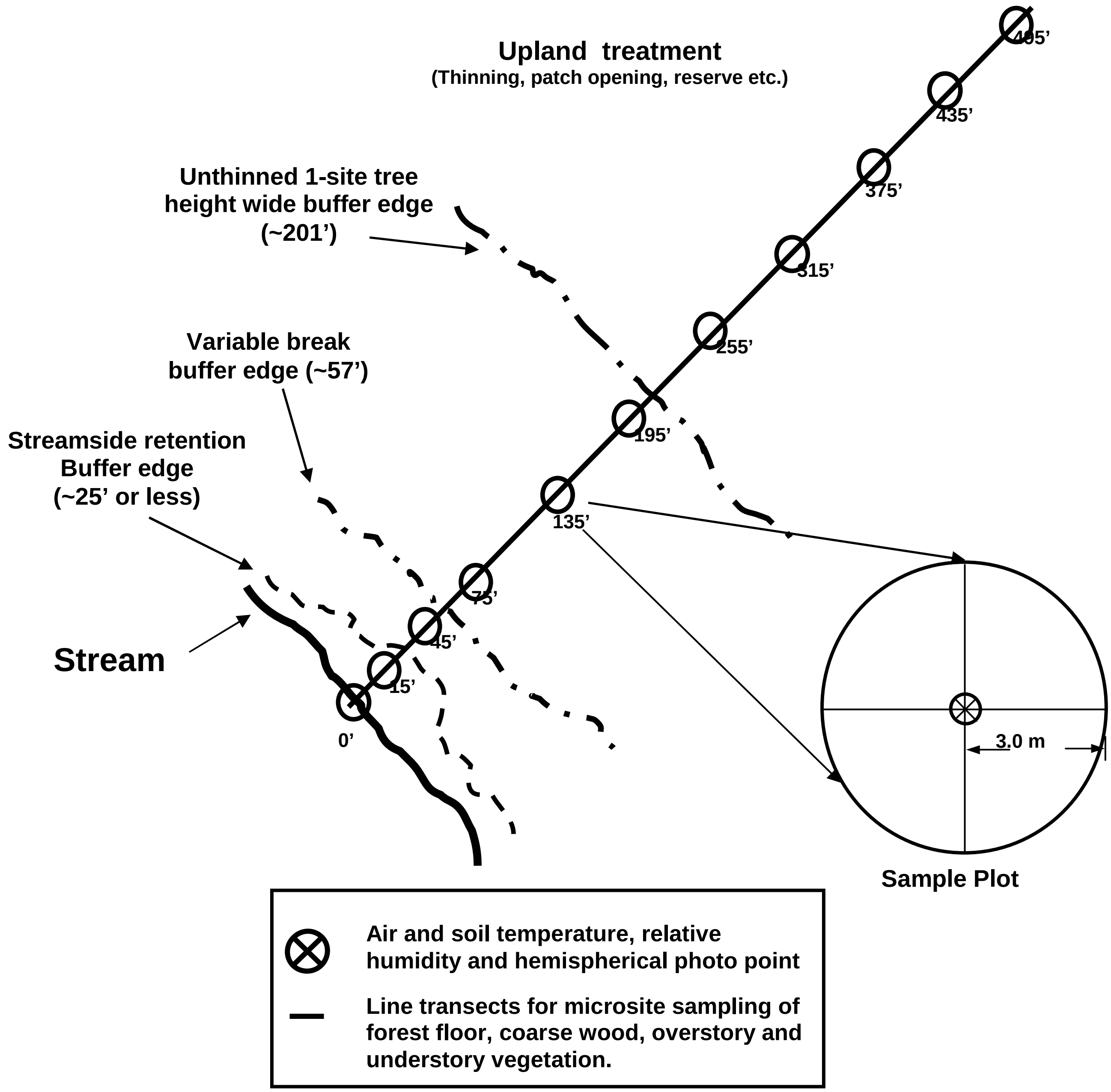


Figure 2. Transect and sub-plot layout for microclimate and microsite sampling in the riparian buffer component of the Density Management Studies.

Based on the transects, how wide are the one site potential tree height, variable break and streamside retention buffers?

The average width of a 1SPTH buffer was 225 ft with a range of 175 to 305 ft. The width of VB buffers averaged 73 ft with a range of 40 to 70 ft. Streamside retention buffers averaged 19 ft with a range of 0 to 55 ft (Table 1). These estimates are lower than what would be expected for a 1SPTH buffer at these sites. The main reason for variation in buffer width was the stream sinuosity. Transects from stream center are within the center two-thirds of the buffered reach. It would be an operational challenge to locate the same buffer width along an entire stream. Transect distances were measured with a tape along the slope.

Table 1. Width of buffers by type. Values are total number, average, minimum, and maximum for all transects across all sites in the study.

Buffer Type	# of Transects	Mean Buffer Width (ft)	Minimum Buffer Width (ft)	Maximum Buffer Width (ft)
1-Site-Potential-Tree-Height (1SPTH)	12	225	175	305
Variable Break (VB)	27	73	40	170
Streamside Retention (SR)	9	19	0	55

Why do the transect lengths vary?

The length of a microclimate transect is a function of the width of the riparian buffer plus an additional 240 ft into the upland silviculture treatment. The length is also influenced by where the upland treatment terminates and transitions into another treatment or crosses a ridgeline into another stream channel.

Our original study plan called for sample transects to extend a minimum of twice the width of the buffer. For example, for a reach having a 1SPTH buffer of 240 ft, the planned transect lengths were 240 ft, providing equal lengths of transect in the buffer and in the adjacent upland treatment.

What treatment comparisions were made in the analysis?

Three modular statistical analyses were used to analyze the effects of buffer width and upland thinning treatments (Table 2). The first test compares different buffer widths (1SPTH, VB, SR) while holding the upland treatment constant at 80 tpa. The second test compares the upland treatments of 40 tpa, 80 tpa and 1-ac circular patch opening for VB buffers. The third test compares 80 tpa and 1-ac patch openings for 1SPTH buffers. All three tests included an unthinned stand for comparison. Although the three tests may have treatments, sites, or transects in common, the same treatment in two tests may be based on different data subsets and therefore may have different mean values.

In addition to testing for buffer type and thinning treatment effects, distance from stream center was also incorporated into the analysis as an experimental factor. Analyses conducted to date have focused on treatment and distance effects and have not explicitly examined the influence of site.

Table 2. Summary of analytical comparisons. Treatment effects were analyzed in a modular fashion in three tests. See text for description of treatments.

Model	Objective	Treatments Compared	Transect Length (ft)
1	Test of buffer type holding thinning treatment constant	Streamside retention into 80 tpa Variable break into 80 tpa Unthinned	195
2	Test of thinning treatment holding buffer type constant	Variable break into 40 tpa Variable break into 80 tpa Variable break into 1-ac patch Unthinned	195
3	Test of thinning treatment holding buffer type constant	1-tree-height into 80 tpa 1-tree-height into 1-ac patch Unthinned	450

Did the plot/treatment layout impact the types of models we are testing?

Due to variation in the landscape and the physical layout of buffers and upland treatment units models 1 and 2 incorporate data from 195 ft of transects while model 3 uses data from 450 ft of transects. For comparisons being made, when transect lengths varied among replicates, the shortest transect determined the number of sample points per transect to be analyzed. This approach was used to avoid confounding treatment comparisons with imbalanced weighting of transect influence in the statistical analysis.

There were also logistical problems associated with the plot and treatment layout. Because of the large number of sites, treatments, and transects it was not possible to simultaneously collect microclimate data for all sites and treatments. As a result, data was collected at different sites between June and September, and in different years. Further confounding of sampling arose at some sites of sufficient complexity and size where it was impossible to collect microclimate data at the same time throughout the site. These logistical issues have resulted in increased variance about estimated means of temperature and relative humidity. The net effect is a decreased power for detecting treatment effects on microclimate.

What statistical methods were used and how were differences between means tested?

We used two-way repeated measures analysis of variance (ANOVA) to evaluate effects of treatments, distance from stream center, and their interaction on microclimate response variables. Because transects were repeatedly measured (multiple sampling points per transect were spatially autocorrelated), we used a repeated measures model with an autoregressive covariance matrix to account for autocorrelation in the data.

If treatment or distance main effects were significant, we tested for differences between main effects means (pair-wise differences between treatments or between distances from stream center) using adjusted pair-wise Tukey comparisons. If the treatment x transect interaction was significant, comparisons were made between treatments for the same distance from stream center.

What level of significance is being reported as statistically significant*?*

In this study we consider $p \leq 0.1$ to be statistically significant. A threshold of α=0.1 will decrease the probability of committing type II errors. Type II errors occur when one declares no effect when, in fact, there is. Results are reported as means and the 90% confidence intervals (90% CI) about the means.

What software was used in the statistical analysis?

The ANOVA models were fitted using SAS Proc Mixed incorporating the Repeated and AR(1) options statements.

IV. Results and Discussion

What period of time is represented in the results you are reporting?

We are reporting results for the second post-treatment sampling (3-5 years following completion of harvests at the six DMS sites). The data were collected across sites from 2002 to 2004.

A. Air temperature, relative humidity and soil/water temperature associated with unthinned stands, riparian buffers, upland thinnings and 1-ac patch openings

How did microclimate vary along transects in seven different buffer-upland treatments?

The general patterns of microclimate variation along transects for all treatments and the unthinned stands across all sites. The patterns are described below in a series of plots. Least squares means (LSMANES) of air temperature and relative humidity are plotted against distance from stream center. In general, our presentation is focused on air temperature measurements at 4 pm (Figures 3a, 3c and 3e). There were few treatment effects when temperatures are averaged over longer time periods representing day or night conditions (Figures 3b, 3d, and 3f). Soil temperatures in general showed little variation with distance from stream center or in response to treatments at either 4 pm or for the 6 pm to 6 am period (Figures 3a- 3f).

<u>SR buffer into 80 tpa upland</u> showed little variation in 4 pm air temperature along the entire transect. Mean temperatures ranged from 17 to 19º C over 195 ft. There was no significant difference in air temperature between transect points. Streamside retention appeared to have little buffering effect as air temperatures in the SR buffer-80 tpa treatment were consistently 3 to 5˚ C greater than those in unthinned stands at all transect distances (Figure 3a).

<u>VB buffer into 80 tpa upland</u> showed little temperature difference along the transect. Mean 4 pm air temperatures ranged from 16.5–20º C over 315 ft. There was a

significant difference in air temperature between the stream center and 15 ft. The trend in this figure indicates that air temperatures for the 80 tpa thinning did not differ greatly from those of unthinned buffers, but were approximately 1.5 to 3º C higher than those of unthinned stands (Figures 3a, 3c).

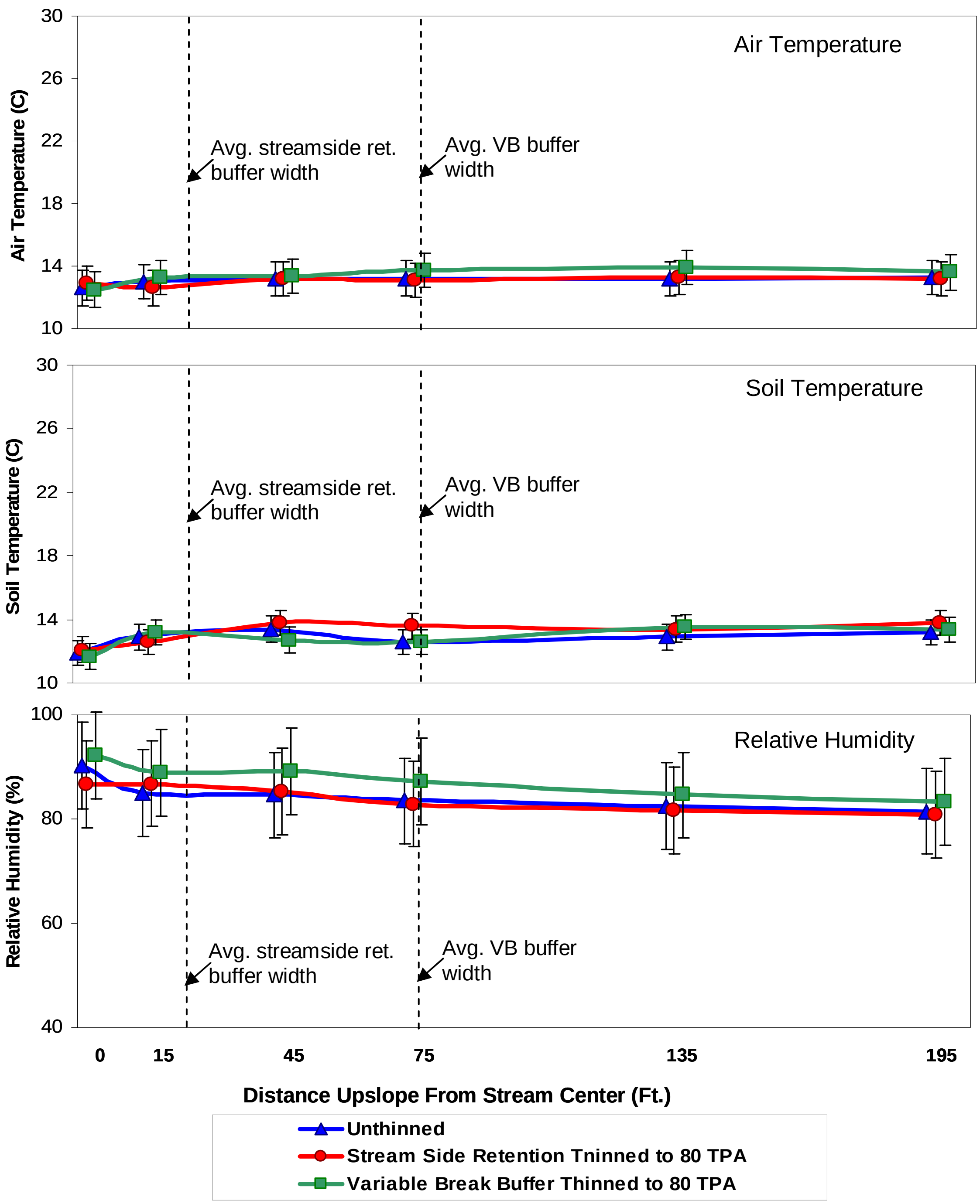


Figure 3a. Spatial variation in microclimate at 4 pm; variable break (ca. 73 ft) and streamside retention (ca. 19 ft) buffers into 80 tpa thinned stand; and an unthinned stand (Test 1).

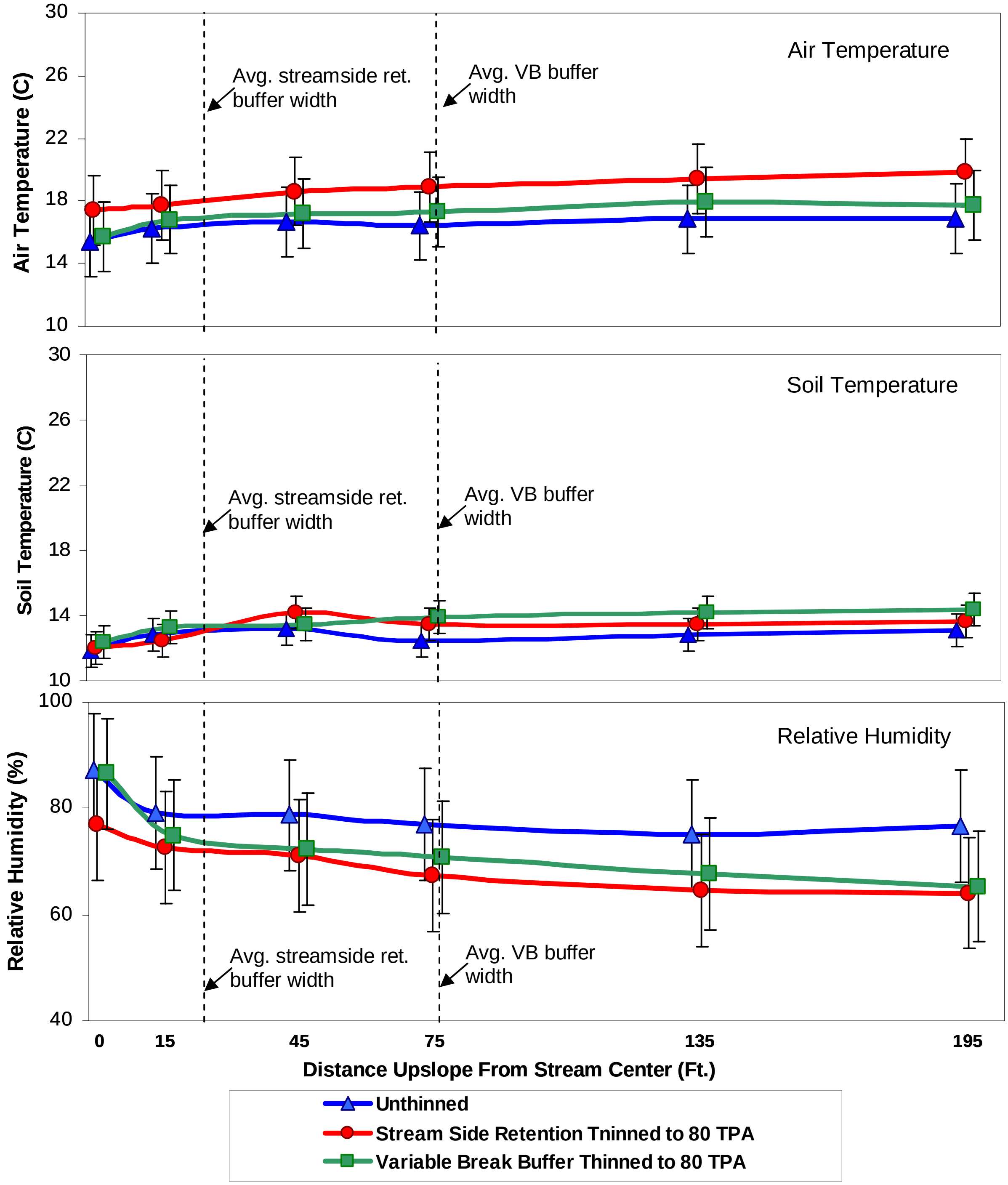


Figure 3b. Spatial variation in microclimate averaged over the 6 pm to 6 am period; variable break (ca.73 ft) and streamside retention (ca. 19 ft) buffers into 80 tpa thinned stand; and an unthinned stand (Test 1).

VB buffer into 40 tpa upland had higher 4 pm air temperatures in the 40 tpa thinning than in the variable length buffer (Figure 3c). Mean temperatures ranged from 16 to 21º C over 255 ft (Figure 3c). Air temperatures at stream center were significantly lower than those at points further than 45 ft upslope.

VB buffer into a 1-ac patch opening had increasing 4 pm air temperatures from stream center over the entire transect length (Figure 3c). Mean temperatures ranged from 19 to 25º C over 315'. Air temeprtures at stream center were significantly less than those of 1-ac patch openings (135-315 ft) along transect. One-acre patches appeared to increase temperatures along the entire transect. However, the variable break buffer decreased temperatures approximately 6º C between the buffer edge and the 15 ft distance (Figure 3c).

1SPTH buffer into 80 tpa upland treatment had relatively stable air temperatures between transect points at 4 pm. Mean temperatures ranged from 15.5–20˚ C over 375 ft (Figure 3e). Similar to unthinned stands, there was a significant distance effect on air temperature (Table 3a) with values at stream center being less than those anywhere else along the transects. Also noticeable is the slight rise in temperature at the buffer-upland interface (approximately 200 ft from stream center). Temperature gradients from this edge to the interior of the buffer become negligible at 135 ft indicating an approximate 60 ft intrusion of upslope thinning effect into the buffer (Figure 3e).

1SPTH buffer into 1-ac patch opening had mean temperatures at 4 pm increase from 17.5˚ C at stream center to 28.5˚ C over the 435 ft transect length (Figure 3e). Air temperatures were significantly lower at stream center than in the patch opening. Relative to patterns for unthinned stands, 1-ac patches appeared to result in increased temperatures along the entire transect, including within the 1SPTH buffer. However, within the 1SPTH buffer temperatures were at least 10˚ C less than the extremes measured in 1-ac patch openings.

Unthinned stands showed little variation in mean air temperature among transect points 15 ft or greater distance from stream center at either 4 pm or when averaged over the 6 pm to 6 am period (Figures 3e and 3f). At 4 pm, mean air temperatures ranged from 15-17º C over 315 ft. Regardless of time period, within unthinned stands air temperatures at stream center were lower than those elsewhere along the transects (Figures 3e and 3f).

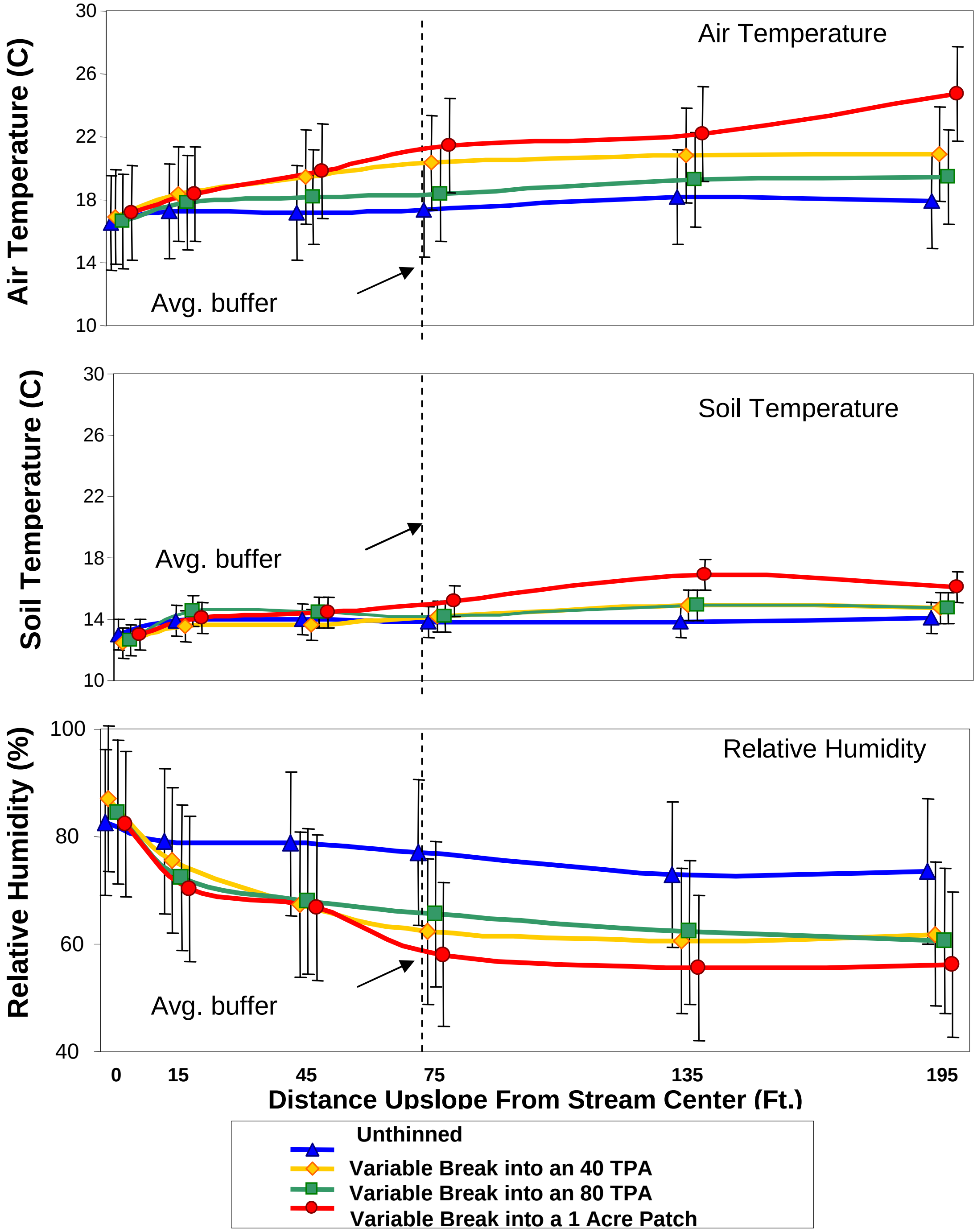


Figure 3c. Spatial variation in microclimate at 4 pm; variable break (ca. 73 ft) buffers into 80 tpa thinned stand, 40 tpa thinned stand, and 1-ac patch opening; and an unthinned stand (Test 2).

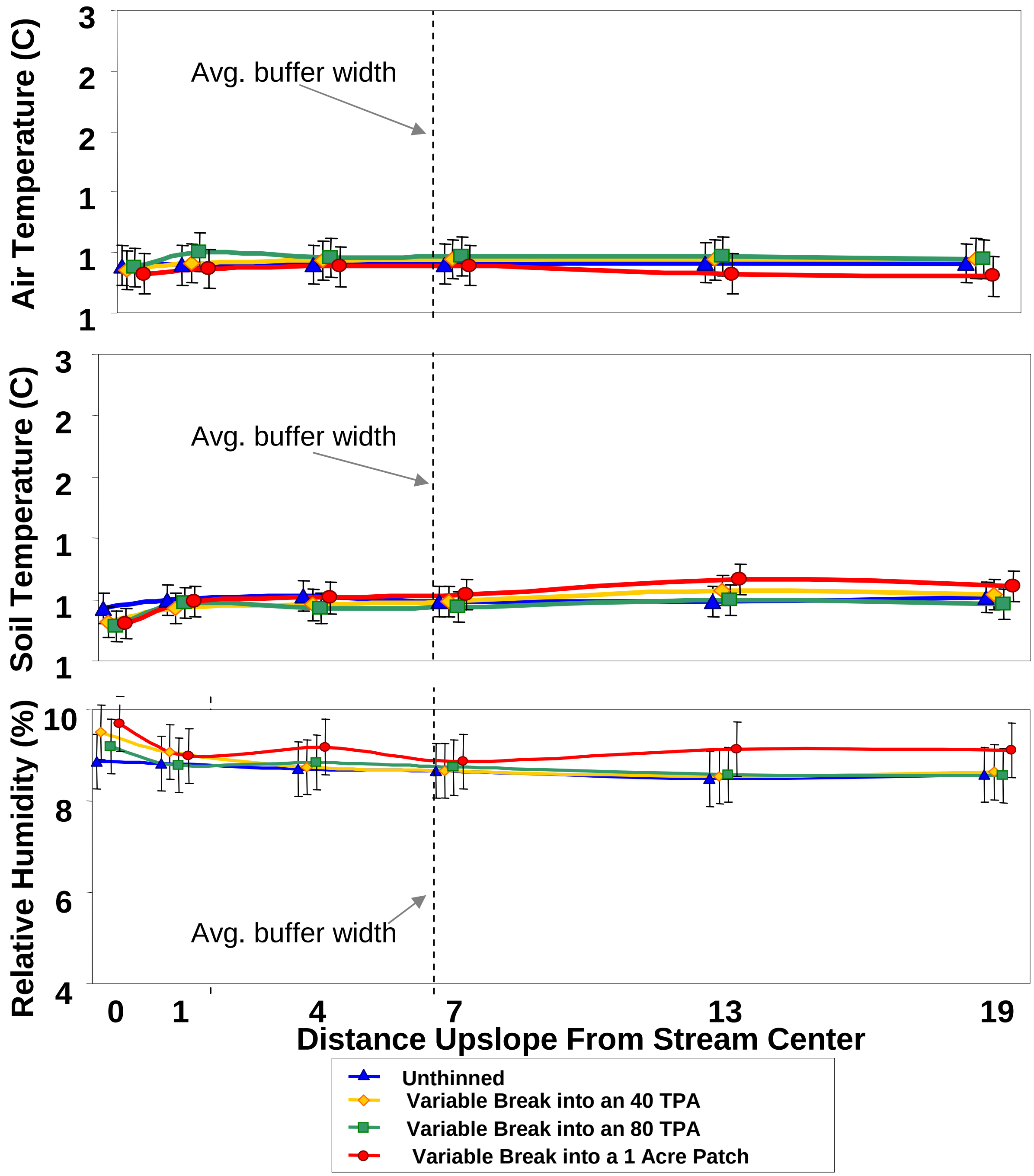


Figure 3d. Spatial variation in average microclimate over the 6 pm to 6 am period; variable break (ca. 73ft) buffer into 80 tpa thinned stand, 40 tpa thinned stand, and a 1-ac patch opening; and an unthinned stand (Test 2).

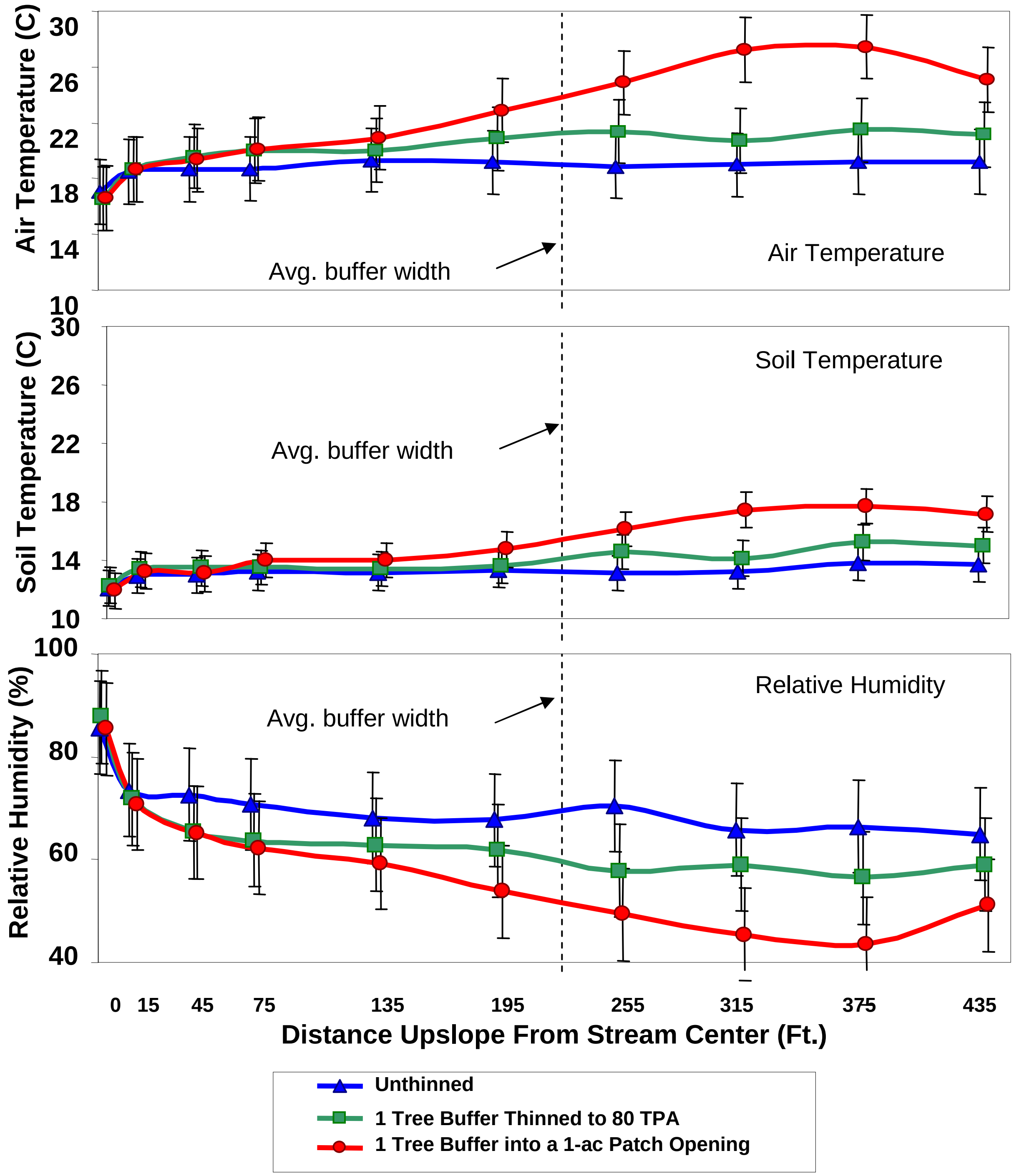


Figure 3e. Spatial variation in microclimate at 4 pm; 1SPTH Buffer (ca. 225 ft) into 80 tpa thinned stand and 1-ac patch opening; and an unthinned stand (Test 3).

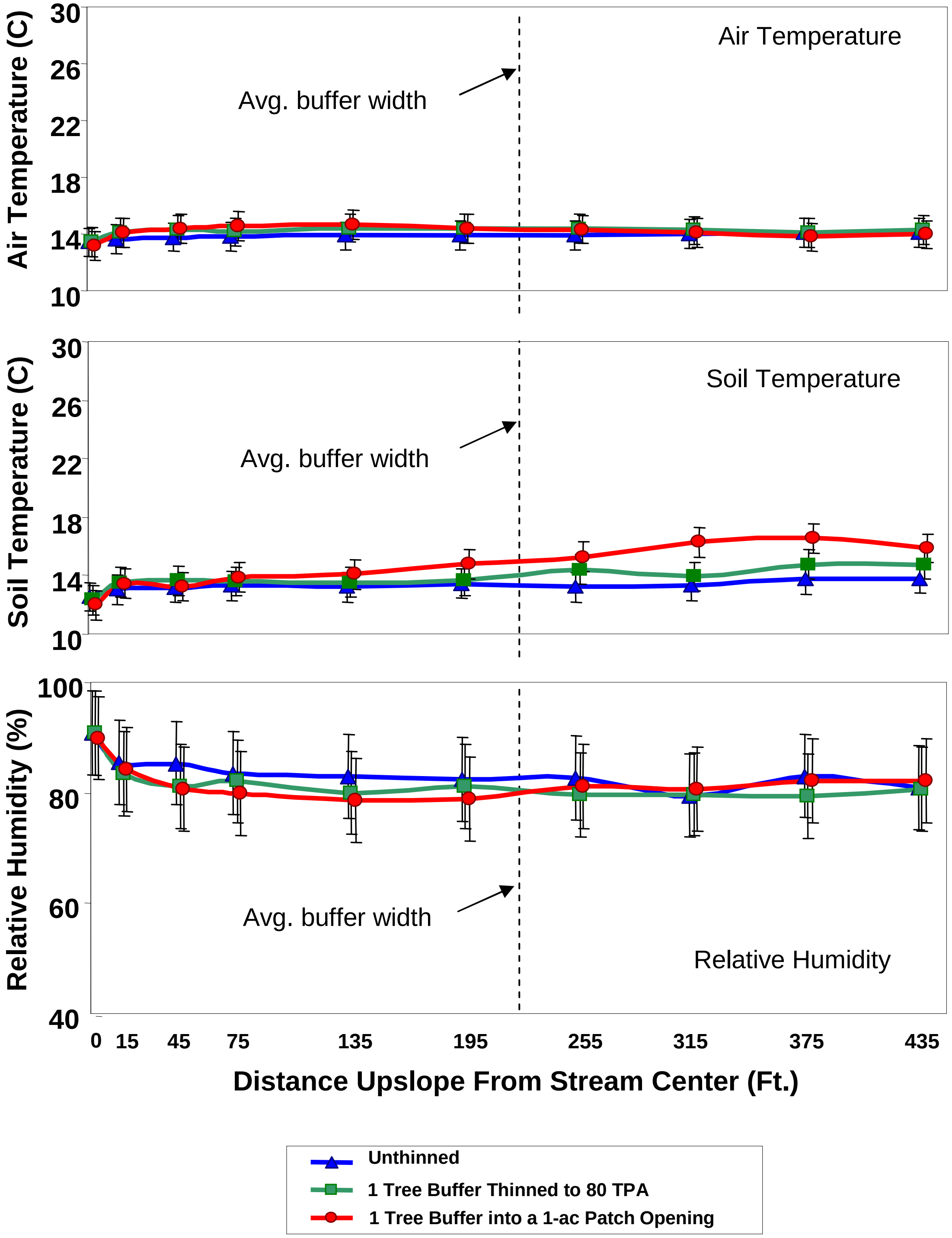


Figure 3f. Spatial variation in average microclimate over the 6 pm to 6 am period; 1SPTH Buffer (ca. 225 ft) into 80 tpa thinned stand and a 1-ac patch opening; and an unthinned stand (Test 3).

Is there evidence to indicate that apparent differences in spatial patterns of microclimate were statistically significant?

Statisitcal significance of buffer and thinning treatments, distance from stream center, and their interaction were evaluated using three test comparisons as outlined above.

For all analyses, the effect of transect distance was significant as all transects demonstrated a gradient in microclimate from stream center to the upland (Table 3). Along transects, the greatest change in microclimate occurred from stream center to 15 ft from the stream (Figures 3a-3e). With the exception of buffers adjacent to a 1-ac patch, there were few differences between adjacent transect points after 15 ft. This indicates that buffers of any length are having a moderating effect on microclimate and that thinning to 40 or 80 tpa may not significantly raise air or soil temperatures, or decrease relative humidity.

Test 1: Variable break and streamside retention buffers with 80 tpa thinning

There were significant treatment effects for relative humidity at 4PM (p=0.07, Table 3) and air temperatures for the 6 am to 6 pm period (p=0.07). Air temperatures at 4 pm were lower and relative humidity was greater for unthinned stands than for the SR into 80 tpa treatment. The streamside retention buffer was unable to moderate air temperature and relative humidity these variables at stream center. Relative to unthinned stands, air temperature and relative humidity at stream center were approximately 3° C higher and 10% lower, respectively, in the streamside retention buffer. Differences in microclimate between unthinned stands and variable break buffers were not significant; air temperature and relative humidity at stream center were similar between the two treatments. (Figures 3a – 3d).

Test 2: 80 tpa thinning, 40 tpa thinning, 1-ac patch openings with variable break buffers

There were differences among treatments in air temperature (p=0.05) and relative humidity (p=0.08) at 4 pm between unthinned stands and 1-ac patch openings (PA) with VB buffer. Air temperatures were greater and relative humidities were lower in the patch opening treatment.

For the 12-hour day (6 am to 6 pm), there was a significant treatment x distance interactive effect on air temperature (p<0.01). Microclimate conditions in thinned stands diverged from that of unthinned stands with increasing distance from stream center. Air temperature of thinned stands was greater than that of the unthinned stand at distances of 45 ft and greater from stream center. Air temperature in 1-ac patch opening and 40 tpa thinning treatments exceeded those of unthinned stands and 80 tpa thinning treatments at 45 ft and beyond stream center. For this time period, only VB into PA intruded into the buffer, but only for 10-to-30 ft. Thinned stands were not different from unthinned stands until well out of the variable break buffer (see Figures 3a – 3c).

Air temperatures in 40 tpa thinning did not differ greatly from those of the 80 tpa thinning; and air temperature at stream center was not different from that of an 80 tpa thinning with a variable length buffer.

Test 3: 80 tpa thinning and 1-ac patch openings with 1 site-potential-tree-height buffers.

In this test, soil temperature was the microclimate variable most affected by these treatments. In all cases, differences were apparent outside of the buffer, and differences were mainly between unthinned stands and 1-ac patches (Table 3). This was true also for nighttime soil temperatures. This is probably due to the fact that soil in openings heats up during the day and is slower to cool down during the evening due to the buffering effects of soil temperatures. Air temperatures at 4 pm were different between unthinned stands and 1SPTH into PA at 195 ft indicating that the influence of 1-ac patches extends into the buffer up to approximately 60 ft. However, trends in mean differences show that thinning and patch opening influence on relative humidity and air temperature may extend further into the buffer. In this test, 4 pm humidities and air temperatures in the 1SPTH into PA treatment did not converge with those of unthinned stands until 15 ft from the stream. Humidities in unthinned stands and 1SPTH into 80 treatments converge at 75 ft. However, we were not able to statistically detect these differences in this test (Figures10e and 10f).

It is important to note that in all tests, there were significant differences between transect distances. This is due almost exclusively to differences between stream center and transect points of 45' or greater distance from stream center. Regardless of microclimate variable, buffer size, or upland treatment, the greatest change in microclimate occurs between stream center and 15'. This may indicate that there is a strong local effect of a stream on microclimate, but this influence extends a relatively short distance from the stream in these small headwater streams.

How did microclimate differ among variable width buffers associated with different upland treatments? How did microclimate vary among different upland treatments?

We stratified transect data points into two groups; those within variable break buffers (transect points 0 ft, 15 ft, 45 ft) and those within the upland treatments (transect points 75 ft, 135 ft, 195 ft). We then fitted a statistical model to test differences in 4 pm air temperature among treatments by either buffer or upland treatment. Mean air temperature at 4 pm did not differ significantly ($p > 0.05$) among the upland treatments associated with VB buffers, indicating that variable break buffers appear to moderate temperature regardless of upslope treatment. Mean temperature at 4 pm was significantly different ($p < 0.01$) among upland treatments. Air temperature in unthinned stands was less than that for 40 tpa stands and 1-ac patches, but did not differ from that of 80 tpa stands. Air temperature was also greater for 1-ac patch openings than for 80 tpa treatments.

Table 3. Table of p-values indicating significance of main and interaction effects on air temperature soil temperature and relative humidity for three diurnal time periods; 4 pm (afternoon peak temperature); 6 am to 6 pm (daily mean); and 6 pm to 6 am (nightly mean). Three modular tests were used to evaluate subsets of buffer width

and upland tinning treatments as outlined in the text. *P*-values represent probabilities that differences among means are negligible.

Model	Treatments	Effect	Parameter	4pm	6am- 6pm	6pm - 6am
					Prob: H_o=0	
1	VB into 80 tpa	Treatment	Air	.12	.07	.77
	SR into 80 tpa	Distance		<0.01	<0.01	<0.01
	Unthinned	Treatment*distance		.78	.38	.01
		Treatment	Soil	.45	.65	.46
		Distance		<0.01	<0.01	<0.01
		Treatment*distance		.26	.33	.42
		Treatment	Rh	.07	.23	.48
		Distance		<0.01	<0.01	<0.01
		Treatment*distance		.87	.81	.48
2	VB into 80 tpa	Treatment	Air	.05	.01	.78
	VB into 40 tpa	Distance		<0.01	<0.01	.03
	VB into 1-ac patch	Treatment*distance		.24	<0.01	.52
	Unthinned	Treatment	Soil	.21	.45	.50
		Distance		<0.01	<0.01	<0.01
		Treatment*distance		.08	.53	.47
		Treatment	Rh	.08	.36	.47
		Distance		<0.01	<0.01	<0.01
		Treatment*distance		.32	.16	.12
3	1SPTH into 80 tpa	Treatment	Air	<0.01	.09	.40
	1SPTH into 1-ac patch	Distance		<0.01	<0.01	<0.01
	Unthinned	Treatment*distance		.03	.16	.47
		Treatment	soil	.02	.02	.03
		Distance		<0.01	<0.01	<0.01
		Treatment*distance		.16	.10	.19
		Treatment	Rh	.01	.04	.31
		Distance		<0.01	<0.01	<0.01
		Treatment*distance		.47	.43	.64

Did upland thinning influence riparian buffer microclimate?

We only tested differences in thinning intensity with variable break buffers. Results show that thinning moderates microclimate, and moderation is related to thinning intensity. We did not find any instances where transects in unthinned stands were significantly different from transects in treatments with 80tpa upland thinning. However, thinned stands always exhibited greater temperatures (lower humidity) than unthinned stands. Average 12-hour temperatures for either day or night show little differences in microclimate between 40 and 80 tpa thinning.

Did different upland treatments impact the microclimates of adjacent riparian buffers?

Yes, compared to the thinned treatments, the one acre patch opening resulted in lower relative humidity and higher temperatures within the edge of the riparian buffers. We could not detect significant differences on microclimate within the riparian buffers between the thin to 40 or 80 tpa treatments.

How far did microclimate differences associated with upland treatments extend into buffers?

It appears that variable-width buffers are capable of moderating microclimate, even during the warmest part of the day. Although unthinned stands consistently have lower temperature and higher humidity, microclimate conditions within variable–break buffers are indistinguishable from unthinned stands through at least 15 ft from stream center. Upslope thinning treatments influence buffer microclimate approximately 40 ft into the buffer from the edge. This effect of VB buffers is most noticeable in Figures 10c-10f where relative humidity is similar among 40 tpa, 80 tpa, and 1-ac patch treatments approximately 10-15 from the buffer edge.

One SPTH buffers also moderate temperature and humidity. Comparing microclimates of 1SPTH buffers adjacent to either 80 tpa thinnings or 1-ac patch openings, air temperature and humidity converge 75 ft from stream center and coincide with that of unthinned stands from 0 to 15 ft from stream center. The 1SPTH buffers appear to moderate microclimate within 125 ft of the buffer edge whereas VB buffers may moderate microclimate within 10-15 ft from the buffer edge. The reasons for this may be the strong upslope influence of stream temperatures and associated riparian vegetation on buffer microclimate. For the narrower VB buffers, the stream influence extends through a greater proportion of the buffer width than it does for the wider 1SPTH buffers.

Streamside retention buffers did not appear to have substantial moderating effects on air temperature or humidity. Our test (comparison 1) only looked at treatment differences among SR and VB buffers adjacent to 80 tpa upland thinning. It is probable that SR buffers associated with 40 tpa thinning or 1-ac patch openings would have different microlimatic effects both within and upslope of the buffers.

Why was microclimate impacted more in the 1SPTH treatment than in the VB treatment?

Our data suggest 1SPTH buffers moderate microclimate within 125 ft of a buffer-upland edge whereas VB buffers moderate microclimate within 10-to-15 ft of the buffer-upland edge. This may result from the strong moderating effect of stream temperatures and associated riparian vegetation extending outward from the stream channel into the buffer, which in the case of narrow VB buffers, extends nearly throughout the buffer.

What effects of 1-ac patch openings on stream and riparian buffer microclimates were observed?

Microclimates of both 1SPTH and VB buffers appear to be influenced by adjacency to 1-ac patch openings. Although, not statistically significant, air temperature at stream center was consistently higher in these treatments than in treatments with 40 or 80 tpa upland thinning treatments. However, these differences were small and only apparent during the warmest time of day. Average temperatures over 12-h periods did not appear to differ.

Buffers appeared to moderate temperatures both internally as well as externally. Along a buffer-upland edge, higher temperatures penetrated into the buffer while cooler temperatures extended into the upland treatment.

Were microclimate differences detected at or near the stream simply the consequence of buffer and upland treatments?

Our analysis of spatial and temporal variation in microclimate has focused to date on buffer and upslope thinning treatment effects. It is clear from these analyses that there are complex relationships between treatments and microclimate responses that are bi-directional; the stream potentially has substantial influence on microclimate within the channel, the buffer and upslope, while upland thinning can potentially influence the downslope buffer and streamside microclimates. Microclimatic gradients along stream-to-upland transects will most likely be influenced by the channel morphology, local basin physiography, and composition and structure of overstory and understory vegetation. Our final report will consider the additional influence of these physiographic and vegetation “microsite” parameters in the analysis of microclimate.

B. Light associated with unthinned stands, riparian buffers, thinnings and 1 acre patch openings.

How did light conditions vary along transects in the various treatments?

Hemispherical images (fisheye photographs) taken at points from stream center through a riparian buffer and into the upland treatment are presented in 4a – 4e.

Typically, upland thinning and patch openings resulted in increased light levels in the upland and also within the buffer near the buffer-upland edge. However this edge effect was generally limited to 30 to 60 ft from the edge and did not affect light levels near the stream within VB or 1SPTH buffers (Figures 4a, 4c-4e).

0 ft - Stream Center
13% skylight

75 ft – Buffer
5% skylight

195 ft – Buffer
6% skylight

255 ft – Edge of
buffer/thin to 80 TPA
8% skylight

315 ft – Thin to 80 TPA
15% skylight

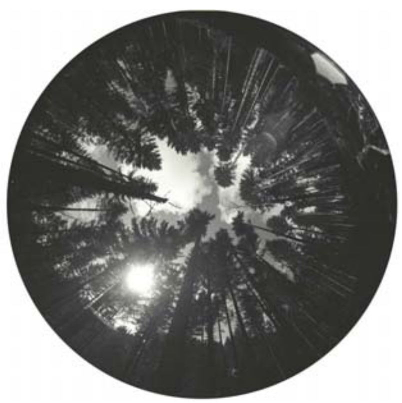
375 ft – Thin to 80 TPA
12% skylight

Figure 4a. Canopy images and skylight values for a typical 1SPTH (avg. 240 ft)" riparian buffer from stream center, upslope into an 80 tpa thin; Keel Mountain, transect 5B.

0 ft - Stream Center –
14% skylight

15 ft – Buffer edge
10% skylight

45 ft –Thin to 80 tpa
10% skylight



195 ft – Thin to 80 tpa
16% skylight

255 ft – Thin to 80 tpa
14% skylight

315 ft – Thin to 80 tpa
13% skylight

Figure 4b. Canopy images and skylight values for a transect running from stream center, through a streamside retention and upslope into an 80 tpa thinning; Green Peak, transect 4B.

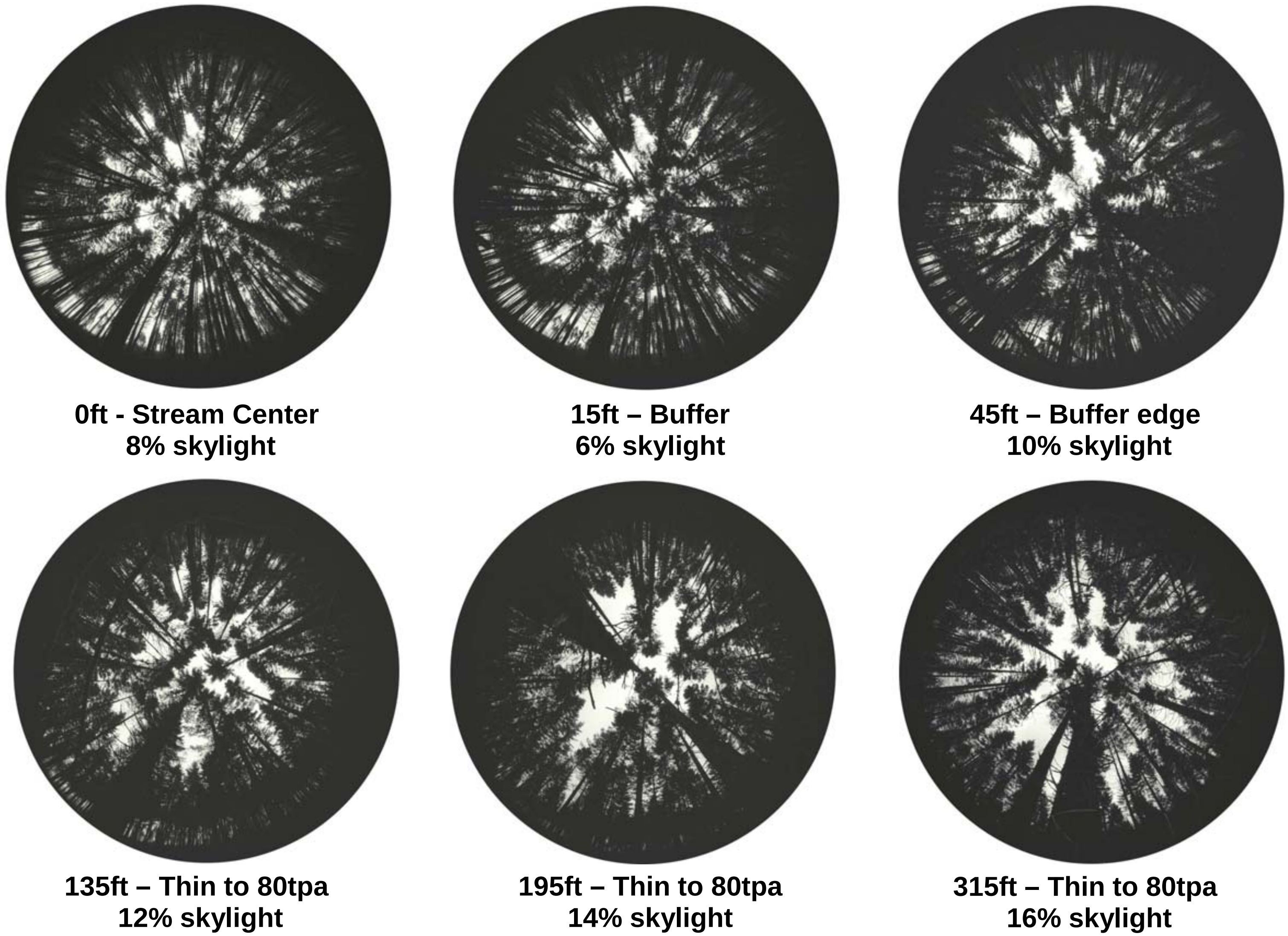


Figure 4c. Canopy images and skylight values for transect running from stream center, through a variable break (avg.73 ft) riparian buffer, upslope into an 80 tpa thinning; Green Peak, transect 7B.

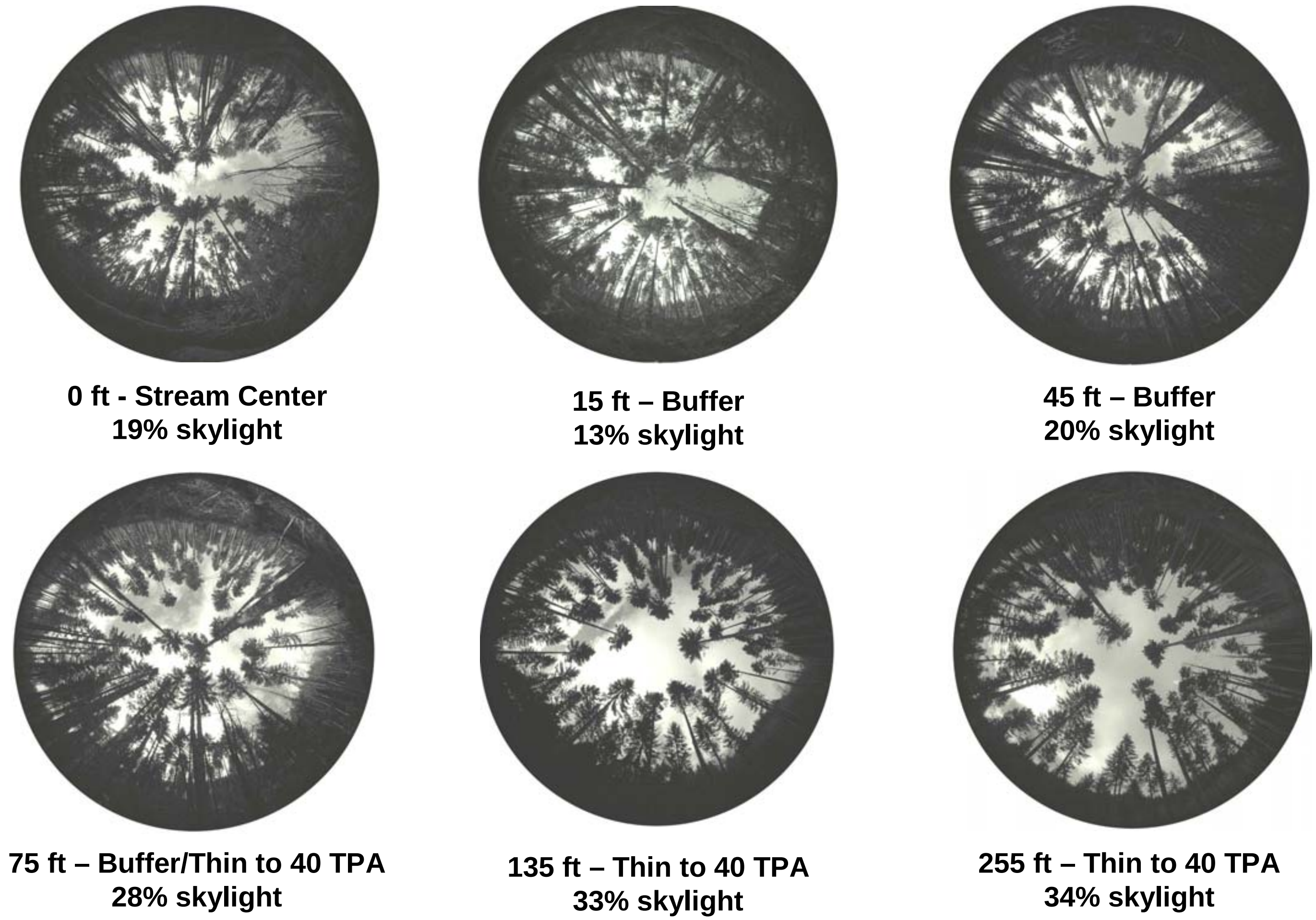


Figure 4d. Canopy images and skylight values for a typical transect running from stream center, through a variable break (avg. 57 ft) riparian buffer, upslope into a 40 tpa thin; Greenpeak, transect 3B.

0 ft – Stream Center
16% skylight

20 ft – Buffer
16% skylight

50 ft – Buffer edge
21% skylight

110 ft – 1acre patch
39% skylight

170 ft – 1 acre patch
54% skylight

Figure 4e. Canopy images and skylight values for a transect running from stream center, through a variable break (avg.73 ft) riparian buffer, upslope into a 1-ac patch opening; Bottomline, transect 1A.

What are the light values associated with the riparian buffer, upland and unthinned treatments?

Light values for the four upland treatments analyzed are shown in Figures 5 and 6. Percent available light was statistically different among upland treatments in this analysis ($p < 0.04$).

Relative to full-light conditions, light values averaged over all sites in winter, 2003 were 30% for 40 tpa thinning, 15% for 80 tpa thinning, 6% for unthinned stands, and 54% for 1-ac patch openings (Figures 4e, 5 and 6). Since the DMS treatments involved manipulation of the conifer component only, winter values were used to minimize the influence of deciduous cover, which varied among sites and treatments.

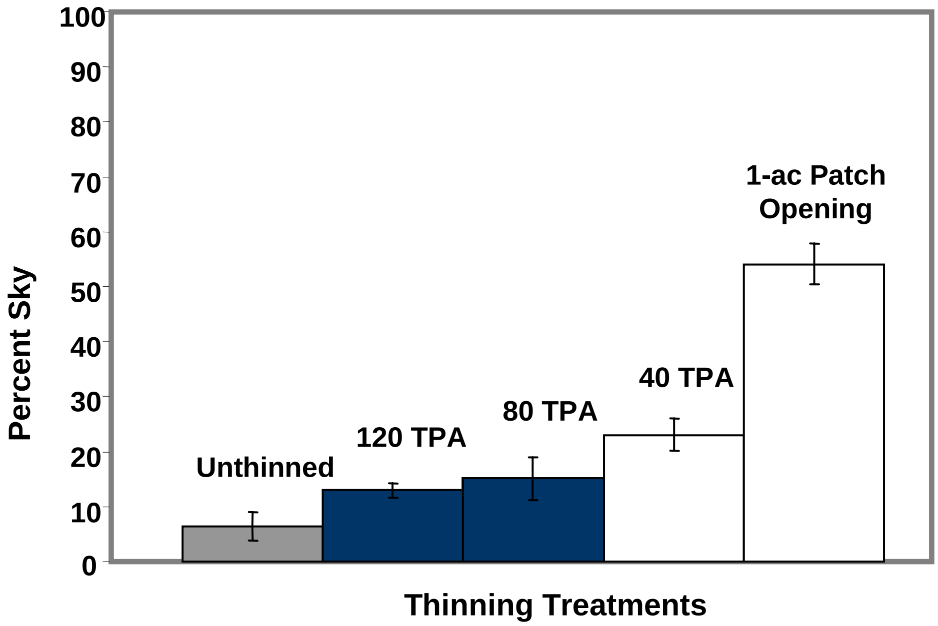


Figure 5. Average percent skylight for DMS silviculture prescriptions across all DMS sites, winter 2003. Values are means ± 95% confidence interval. Bars having different shading indicate mean values that differ significantly.

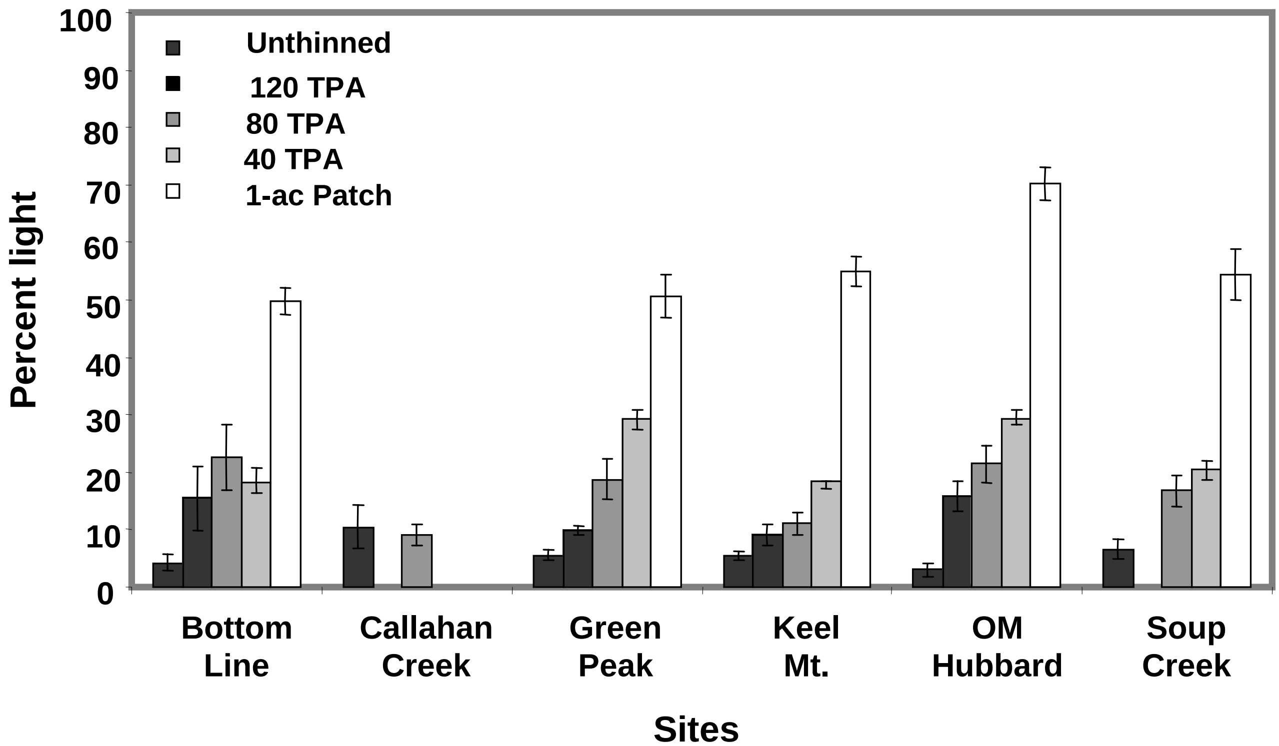


Figure 6. Average percent light through the canopy for five DMS silviculture prescriptions on individual sites. Percent light is derived from fisheye photographs taken in winter, 2003. Values are means ± 95% confidence interval. Bars having different shading indicate mean values that differ significantly.

C. Stand Density Relationships to Light

Stand basal area and RD are metrics commonly used to describe the degree of site occupancy by trees. Stand cover (% skylight) and shade (% direct light) are important metrics describing sub-overstory light availability. Given that regulation of light availability is either an explicit or implicit objective of overstory thinning, it is important that relationships between standard metrics describing overstory density and sub-overstory light availability be defined.

What is the relationship between basal area, stand density and light?

Relationships derived from data representing six DMS sites suggest that density management results in increased light availability only when stand densities are decreased to less than 120 ft^2 BA or RD 30 (Figures 7a and 7b). At higher densities, light levels average about 10% of open of conditions, similar to those of unthinned stands. In general, the heaviest thinning to 40 tpa (approximately 60 ft^2 BA or RD 15) resulted in average light levels of 30% of open conditions. Thinning to 80 TPA (approximately 100 ft^2 BA or RD 20) resulted in average light levels of 25% of open conditions. Light levels in 1-ac patch openings averaged about 54% (range 30-80%) of open conditions. This is due to edge effects of trees surrounding the gaps (Figure 4e). Increased light penetration within buffers resulting from adjacent thinning treatments was typically limited to the first 60 ft from the buffer-upland edge.

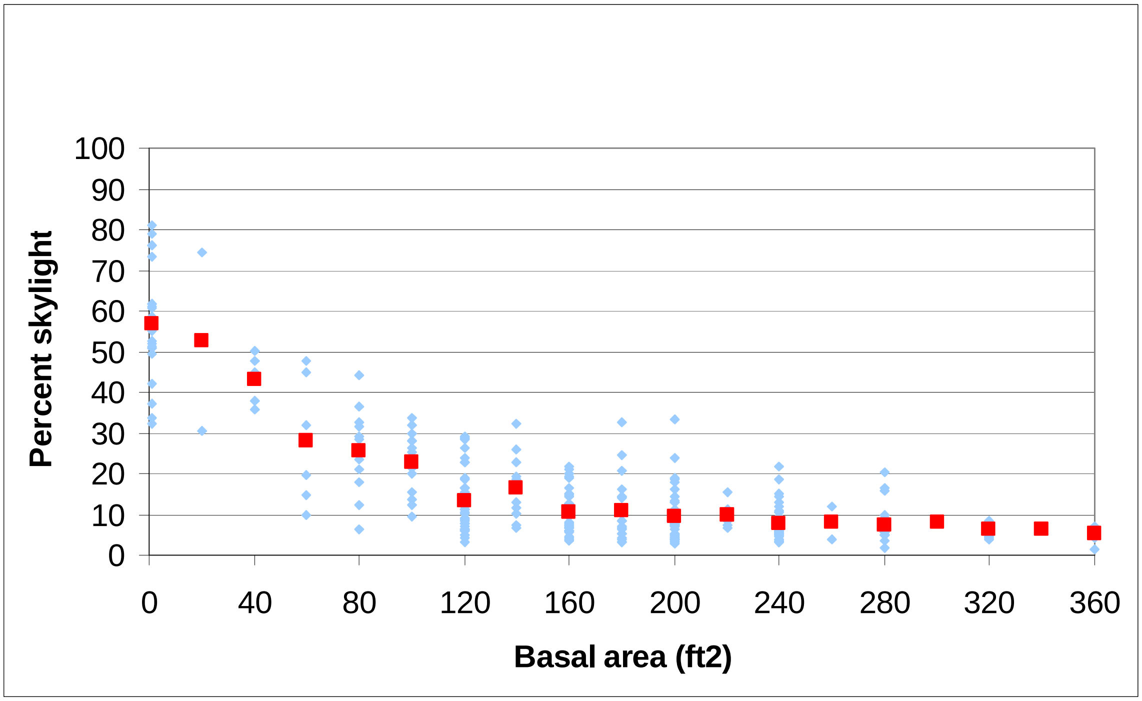


Figure 7a. Basal area and corresponding percent skylight derived from 6 Density Management Study sites during summer conditions. Scatter points represent individual plot values while squares represent means.

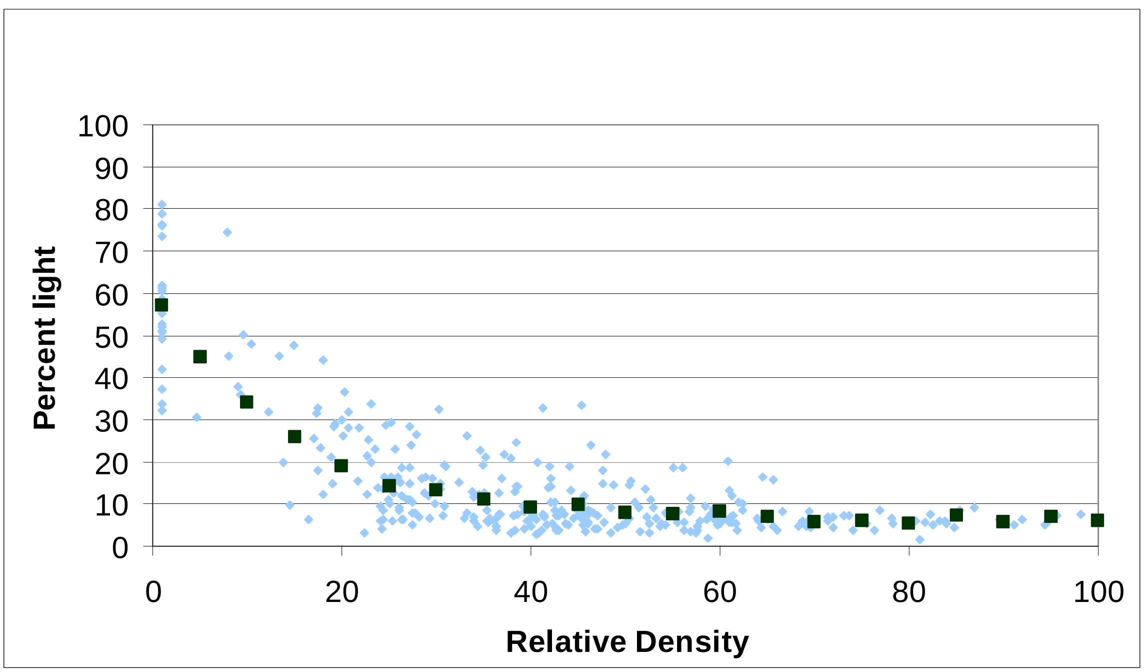


Figure 7b. Percent skylight in relation to Curtis' Relative Density. Derived from six Density Management Study sites during summer conditions. Scatter points represent individual plot values while squares represent means.

Light availability as functions of BA for six individual sites are presented in Figures 8a and 8b for summer and winter, respectively. Data from the Callahan site indicated a nearly flat relationship between light availability and stand density because the overstory canopy had closed since it was thinned nearly 5 years prior to sampling. While relationships for the other five sites indicated steep declines in skylight with increasing BA from 0 to 100 ft^2, the number of data points representing this BA range was small and therefore the relationships over this BA range should be interpreted with caution. Over the 100 – 400 ft^2 range of BA for which the data set is more robust, the relationship between percent skylight and BA is nearly linear and relatively consistent among sites.

Will you develop models that managers can use to predict sub-overstory light levels based on overstory basal area and relative density?

Yes, we will develop regression models and look up tables for relationships individual DMS sites and over all DMS sites. These will be presented in the final report.

D. General Inference

Is there a zone that we can describe as "riparian" based on microclimate?

In all cases where a buffer was retained between the stream and upslope thinning, the microclimate at stream center did not differ substantially from the microclimate of unthinned stands. For small headwaters streams such as those in this study, the region between stream center and 15 ft lateral distance is uniquely riparian with respect to microclimate. This 15 ft zone is remarkably resistant to microclimate perturbations by upland thinning treatments.

Were light and microclimate responses to upland treatments correlated?

There are several points to be made about the relationship of light and microclimate in this study.

Although percent light is different in each upland treatment, mean air and soil temperatures and relative humidity were never significantly different between unthinned stands and stands thinned to 80 tpa. This may indicate that retention of 80 tpa is sufficient to maintain near-stream microclimates similar to those of unthinned stands.

Our ability to resolve statistically significant differences in microclimate and light among treatments was determined by the statistical power of the study design. Power analysis indicated that we should be able to detect differences in mean light among upland treatments that are greater than 2.3 percent. Differences in mean light availability among treatments were frequently greater than this detection threshold. However, similar power analyses for air temperature indicated a minimum threshold difference of 3.4° C. Air temperature treatment means observed in this study ranged from 1.2° C to 4.5° C, suggesting our ability to detect statistical differences was less than for light availability. Variability resulting from sample design and potential differences in abiotic site conditions such as slope, aspect and elevation may make it more difficult to detect temperature differences.

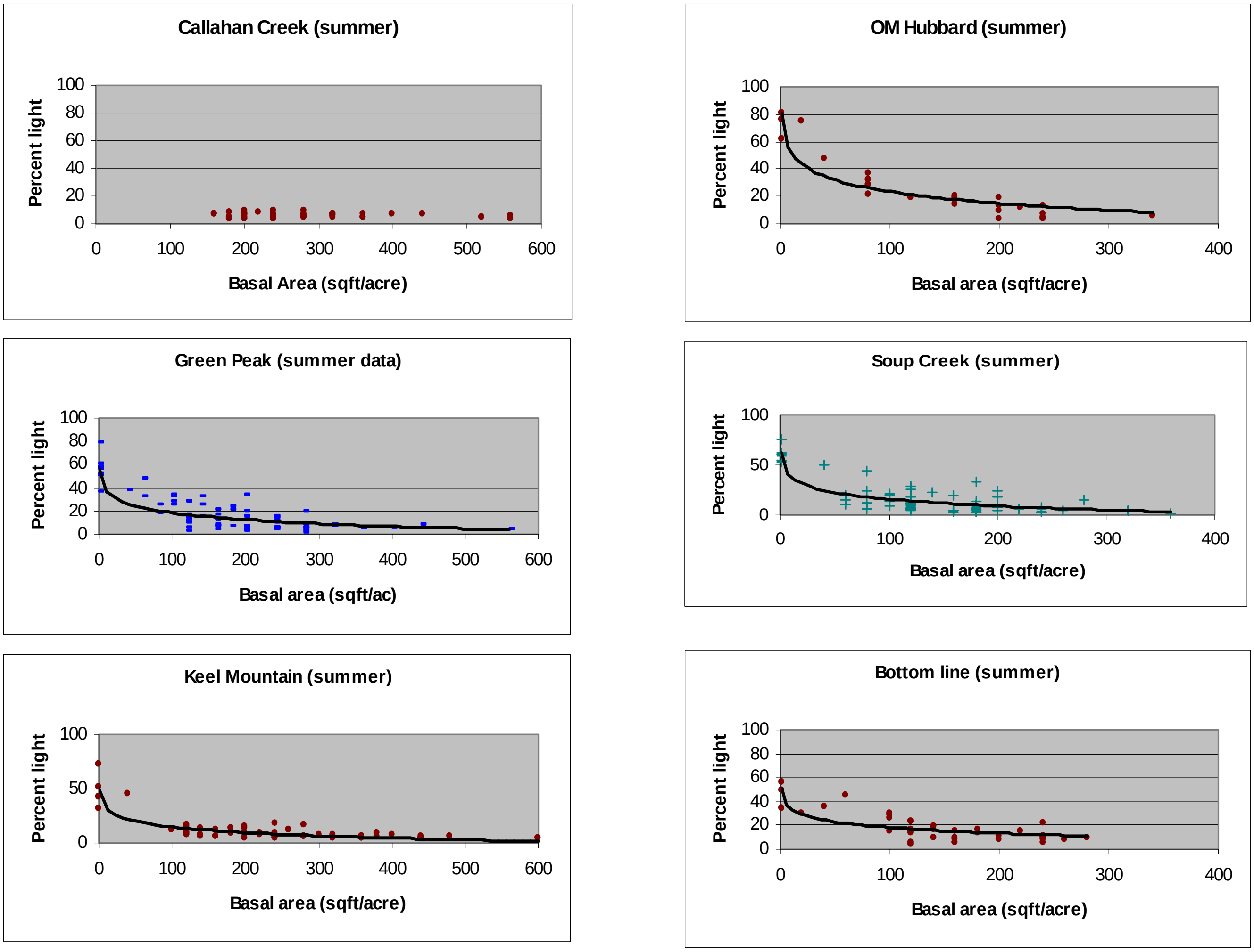


Figure 8a. Percent skylight in relation to total stand basal area (conifer and hardwood) by site. Data points are values measured at stream center on all transects per site in summer 2002-2003.

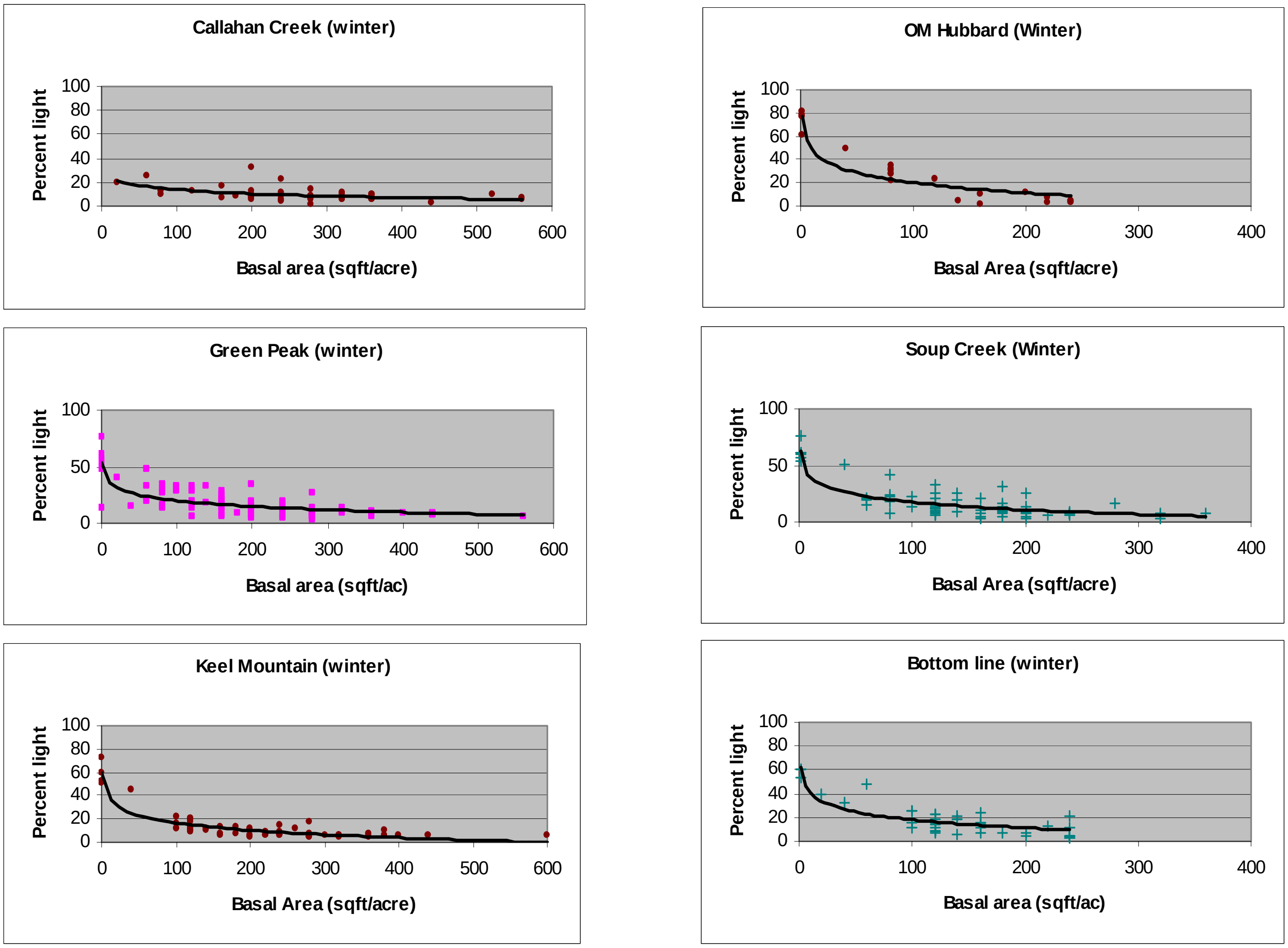


Figure 8b. Percent skylight in relation to total stand basal area (conifer + hardwood) by site. Data points are values measured at stream center on all transects per site in winter, 2002-2003.

We are still looking at ways to reduce variability and results may differ for the final report. Emphasizing small differences in temperature at the warmest part of the day may or may not be biologically significant. Also, variation in microclimate is significantly reduced when averaged over 12-hour periods of day or night.

What linkages to aquatic dependent organisms might our findings on density management and microclimate have?

Early results from the DMS suggest that upland density management coupled with riparian buffers of various configuration results in relatively small changes in the riparian environment. In turn, companion studies indicate that these relatively small changes in environment are generally not associated with detectable decreases in riparian-dependent organisms. Macro-invertebrate and amphibian monitoring suggests the existence of spatial variation in abundance and composition based on distance from the stream; the most suitable habitat for many species of riparian-dependent fauna is within 15 ft of the stream. Our observations of microclimate gradients coupled with early findings from surveys of macro-invertebrates and amphibians supports our interest in developing silvicultural systems that explicitly account for the unique features associated with riparian zones within headwaters forest ecosystems.

Why are results from the high density (120 tpa) treatment not reported?

We do not report results associated with the high density (120 tpa) thinning treatment for two reasons: 1) there were few sites in which the 120 tpa upland treatment occurred in conjunction with the array of buffer treatments; and 2) we did not detect significant differences in response variables between treatments associated with the 80 tpa upland thinning and those associated with the unthinned upland. We feel that given the lack of 80 tpa effects and the low statistical power associated with the lack of 120 tpa replication, it is unlikely we would demonstrate significant differences between the high density and unthinned treatments.

With respect to the riparian buffer treatments in the DMS, why are results from the two-site tree height wide not included in this report?

The focus of this report is on treatments with the greatest number of replications. Thus, only results from the 1SPTH, VB, and SR buffers, their respective upland thinning treatments, and the unthinned stands are presented.
There were few sites where 2SPTH buffers could be implemented in the highly dissected headwaters forest landscapes. The width of a 2SPTH buffer often extended over ridge-tops into an adjacent drainage. Thus, for the entire study consisting of 75 sampling transects, only five occurred in 2SPTH buffers.

E. Statistical Inference

What is the power of the analyses to explain minimum differences among treatment means at alpha levels of 0.10?

Statistical power is a measure of the limits to detection of differences in microclimate variable means among treatments or distances in this study. Power is determined by sample size, variance, and the desired significance level, α (Type I error: the probability of concluding that two treatment means differ when in fact they do not). Low power as a result of high α, small sample size, and large variance, can make it difficult to detect a difference when, in fact, there is. Although a study like the Density Management Study covers large tracts of forested stands and involves a massive data collection effort, statistical power to detect differences among treatments is relatively low due to the inherent variability and low degree of replication.

A power analysis for this study, indicating the ability to detect treatment differences at similar transect distances, is summarized in Table 4. The minimum differences needed to detect a significant difference at $p < 0.1$ at the 4 pm, 6 am – 6 pm, and 6pm – 6 am time periods was relatively consistent among air temperature, soil temperature, and relative humidity. Minimum differences needed were greatest at 4 pm but were less when averaged over a 12-hour period. However, differences are relative to the total range of measurements. For example, soil temperatures are much less prone to large swings in temperature and, as a result, minimum differences leading to statistical significance were small. However, the maximum differences in soil temperature between transect distances were often only 6-8°C, making it difficult to detect significant differences among treatments or transect distances.

Minimum significant differences in percent available light were consistent among the three tests (Table 4). However, the range of light was between 5 and 50%. Therefore, in contrast to temperature or relative humidity, finding significant differences among treatments with low light levels (unthinned vs. 80tpa), similar light levels (80 tpa vs. 40 tpa) or relatively high light values (1-ac patch vs. 40 tpa) may not be consistent.

Table 4. Summary of power analysis. Values indicate the minimum difference among treatment means that is statistically significant at the α=0.1 level for air temperature, soil temperature, and relative humidity at peak diurnal stress, averaged over the day or averaged over the night periods.

		Minimum Detectable Significant Difference		
		Test 1	Test 2	Test 3
Parameter	Time Period	VB – 80 tpa SR – 80 tpa Unthinned	VB – 80 tpa VB – 40 tpa VB – Patch Unthinned	1SPTH – 80 tpa 1SPTH – Patch Unthinned
Air Temp. (°C)	4 pm 6 am – 6 pm 6 pm – 6 am	2.98 1.52 1.69	3.39 1.26 2.28	3.97 2.42 1.05
Soil Temp. (°C)	4 pm 6 am – 6 pm 6 pm – 6 am	2.25 1.52 1.87	2.07 1.43 2.04	2.37 1.58 1.84
Rel. Humidity (%)	4 pm 6 am – 6 pm 6 pm – 6 am	12.5 9.7 10.2	15.8 9.8 9.4	14.2 9.1 6.6
Skylight (%)	N/A	0.76	0.85	0.82

Does the sampling design permit statistical inferences about edges and the effects of upland microclimate influence into the buffer?

In many of the analyses significant treatment or treatment x distance interaction effects were not indicated (Table 3). For these cases we were unable to make inferences about the influence of the treatments on spatial variability in microclimate. For those cases where treatment effects were significant but treatment x distance interaction effects were not, we limited our inferences to comparisons among treatments.

When ANOVA indicated a significant treatment x distance interaction, our inferences were based on comparisons among treatment means for a common distance from stream center. This allowed us to examine the effects of upland treatments on spatial variation in microclimate; particularly to determine differences among treatments or buffers on distance of influence associated with the stream or the buffer-upland edge. Our analyses indicated that when significant treatment x distance interaction occurred, typically the differences among treatments in microclimate patterns were associated with buffer-upland edges. As mentioned earlier, the influence of an edge was bi-directional as indicated by altered microclimates within and external to the buffer in the vicinity of the edge. Of the microclimate parameters considered, significant interactions were observed most frequently for soil temperature.

When testing for differences in percent available light, there was significant interaction between treatment and transect distance in all three tests (Table 3; Figures 5 and 6). As expected, transmission of light into buffers varied by upland treatment. There was no significant difference in percent available light between 40 and 80 tpa upland treatments (avg. 15% for 40 tpa, 20% for 80tpa) along the transect. Light appears to penetrate 30-60 ft into the buffer (Figures 7a –7c) in association with adjacent thinning and 1-ac patch openings. The upland harvests allow for more sidelight to enter the buffer at low angles. The distance within the buffer that sidelight will influence is likely determined by the abundance and structure of vegetation within the buffer.

How could data collection and data management procedures been improved?

Early in the study the number of microclimate sensors available for use was very limited. Thus, it was impossible to collect data at all points on all sites simultaneously. This resulted in some potential confounding of site and sampling period in the early data as spatial variation in microclimate may differ between hot summer days and cool summer days.

Variation in transect lengths due to topography and variation in the spatial layout of treatments among replicates also pose analytical problems. In the analytical approach used, it was necessary to have balanced sampling of stream, buffer, and upland conditions among transects. In many cases, data from some transects did not exist at all distances and therefore analyses were based on data subsets to include only data for distances common to all transects in the experimental units under consideration.

Understory vegetation data and summer canopy image data should be collected within a narrow time-frame during peak expression of vegetative cover. Depending on summer conditions, vegetation cover may change quickly and long sampling windows may obscure some of the vegetation patterns or responses of interest.

Data collected over a period of years should have a rigid protocol for data entry, storage, and proofing. Data collected and stored for analysis at a later date becomes increasingly difficult to validate and use if detailed metadata protocols are not closely followed. Data inspection should occur within a timeframe that allows missed or erroneous data to be recollected. The analyses developed in this will help increase the efficiency of future data collection in the DMS and other related studies.

What other limitations should be considered when using these results?

These results are from a limited number (only 6) of 50-80 year old stands located on BLM managed stands in western Oregon. Five are located in the Oregon Coast range and only one site is currently reported from the Cascades Range. The stands are dynamic. We expect significant changes in stand structure over the next three to five years as we approach a possible re-measurement. Microclimatic conditions and patterns observed during the first 3-4 years following thinning are unlikely to remain unchanged after 5-8 years post-thinning.

V. Continuing Efforts

This is an interim draft report highlighting the patterns of microclimate observed from the riparian buffer component of the BLM Density Management Study. A comprehensive draft final report will be submitted by September 30, 2004 that incorporates: 1) revisions and/or refinements to the microclimate and light analysis; 2) analyses of understory vegetation, forest floor, and topography; 3) early findings on changes in stand structure along the riparian to upland transects; 4) rates of canopy development derived from time series analysis of hemispherical images; 5) a “look up” table for managers to predict light, shade and cover based on basal area and relative density; and 6) a statement of future research needs and direction. A final report incorporating review comments from the draft will be submitted to the BLM by December 31, 2004.

What additional analyses related to this data will be performed for the final report?

We will examine the influence of height above stream, transect aspect, and understory vegetation cover as covariates in refined analyses of microclimate data. This microsite data may further illucidate differences among treatments. Overstory characteristics such as tree height, crown height, mean DBH and tree spacing will also be evaluated as possible predictors of microclimate and light variation among upland treatments and buffer types.

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