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Relative Humidity Gradients Across Riparian Areas in Eastern Oregon and Washington Forests

Abstract

Riparian relative humidity gradients were examined at twelve sites east of the Cascade Mountains in Oregon and Washington in 1997. Relative humidity was monitored at increasing distances from stream edge to 30 m in the adjacent forested stands. Within 10 m of stream edge relative humidity was similar to upland conditions with little change beyond 10 m. In 9 of the 12 sites differences in mean minimum relative humidity were significant ($P < 0.05$) between 0 and 5 m. The length of time that relative humidity was less than 50% between 0 and 5 m was significant at 11 of the 12 sites. Diurnal fluctuations ranges of more than 75% RH with maximums close to 100% occurred at night at all sites. The diurnal pattern of temperature is the dominant process in air moisture regime in these eastside forests. The small daytime increases in relative humidity close to the stream, which can be maintained over short distances by steep local topography, are apparently due to evaporation from wetted stream width and transpiration from vegetation immediately adjacent to the stream.

Introduction

Aquatic communities and adjacent riparian communities are ecologically interwoven. Riparian sources of nutrients are the starting block for many aquatic food chains and emerging insects and fish are food sources for terrestrial fauna (Meehan, 1996). Nutrients from stream sources, such as salmon carcasses, have been demonstrated to move through both aquatic and riparian pathways (Bilby et al. 1998, and Wipfli 1997). Some animals (insects and amphibians) have both aquatic and terrestrial life history stages. These habitats in and around streams are unique in forested landscapes, and support diverse and specialized flora and fauna. Many of these riparian specialists are dependent on the higher amounts of moisture that are available close to streams. These include vascular plants that are moisture obligates, amphibians whose skin needs to be moist, and non-vascular plants that acquire moisture from the atmosphere. The higher moisture levels found in riparian areas are prerequisite for the survival of these organisms.

The water in the stream channel, beneath the channel in the hyporheos, and en route to the channel through various groundwater pathways, all contribute to the available moisture in riparian zone. These sources of soil moisture are utilized by vegetation, and indirectly enter the atmosphere via transpiration and directly by surface evaporation. Evaporation from the stream surface is a source of local air moisture. Perhaps it is only an important contributor when dry conditions prevail within the surrounding riparian areas, since both evaporation from terrestrial surfaces and transpiration by upland vegetation will be reduced during periods of high temperature and infrequent precipitation that are common during summer in eastern Oregon and Washington.

Prior to the early 1990's, the investigation of microclimate characteristics in forested landscapes was rare. Plant physiology work was done to examine moisture levels with respect to its impact on limiting growth (Hoffman 1973) in mostly agricultural settings. Others (McCaughey et al. 1997) examined microclimate influence within different forest types with those results being applied to tree growth. Chen et al. (1995) completed a study on the westside of the Cascades in the Puget Sound area focusing on the microclimate gradients from the edge of recent clear-cuts into "old-growth" timber stands. While none of the research focused on riparian areas, others have recently begun investigating riparian microclimate gradients. In western Washington (Brosofske et al. 1996) and northern California (Ledwith 1996) studies were conducted of riparian forests dominated by stands of Douglas fir with annual rainfall of 150 cm. or more and adjacent to clear-cuts. While these studies did examine microclimate gradients in riparian areas, those forest stands are unlike the forests dominated by Ponderosa pine of the eastside of the cascades. East of Cascades in OR and WA there are much lower amounts of annual precipitation (< 50 cm) and the timber harvest approaches usually do not include clearcutting.

The purpose of this investigation was to analyze relative humidity gradients within riparian areas and adjacent uplands across a variety of eastern Oregon and Washington conditions. All sites were on commercial timber lands, with selective harvest (partial harvest) as the silvicultural prescription. This information is necessary to prescribe effective buffers for riparian dependant flora and fauna of eastside forests. The gradients of relative humidity were studied during the dry and hot conditions that prevail in eastern Oregon and Washington during mid-summer.

Two metrics of relative humidity (RH) calculated daily were used to examine the potential biological effects of relative humidity gradients in eastside forests: minimum relative humidity and length of time (hrs) less than 50% RH. Minimum relative humidity reflects the extreme conditions, since maximum RH approaches saturation (100%) every night. The second metric, the length of time relative humidity was less than fifty percent, was chosen as a measure of length of potential exposure of moisture obligate flora and fauna to low RH levels. The gradients of these metrics from streamside to the adjacent upland forest were examined.

Methods

Relative humidity gradients were examined at 12 sites in Washington and Oregon. The twelve sites were distributed in the Teanaway (WA), Klickitat (WA), and Grande Ronde (OR) watersheds (Figure 1). At these sites there was no measurable

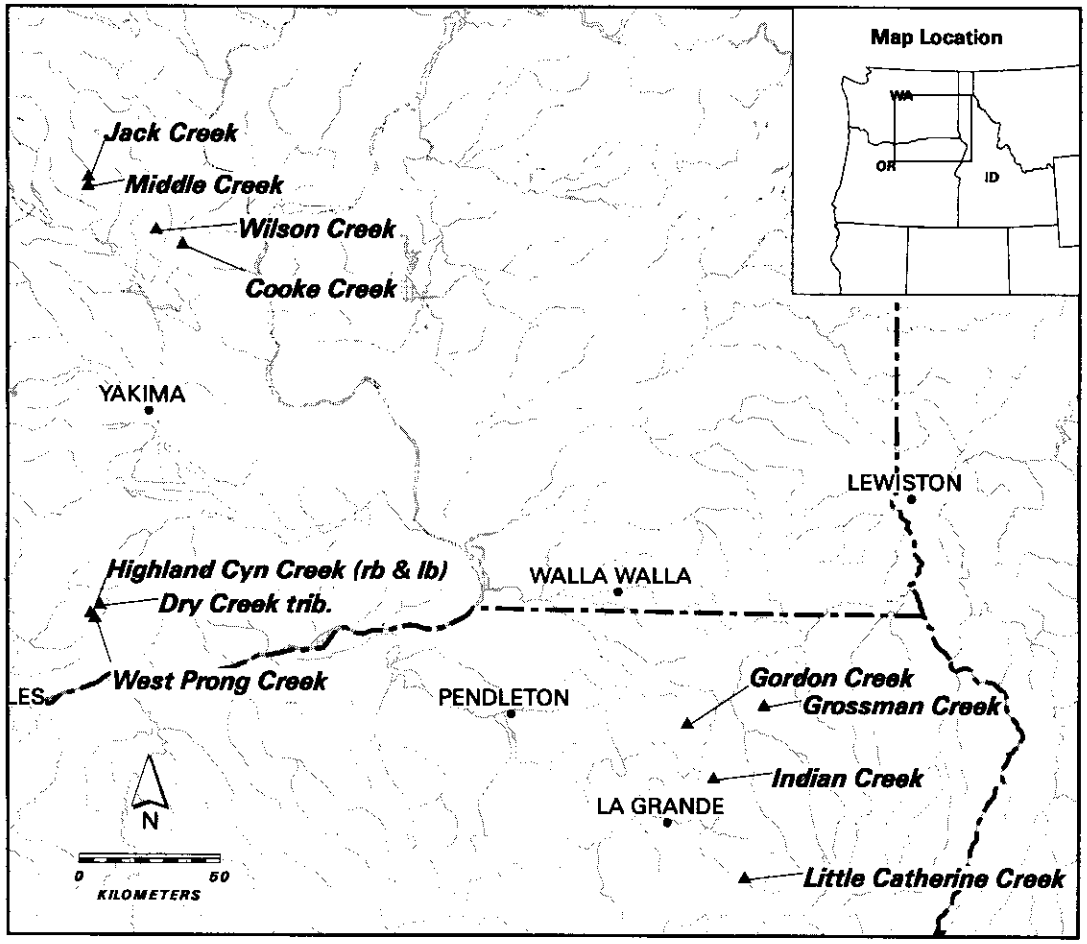

Figure 1. Twelve microclimate study sites east of the Cascade Range in Washington and Oregon.

precipitation for two days prior to or during the study. At each site an array of relative humidity data recorders (Onset Computer Corp. Hobo-RH) were set up for five to nine days between 17 July and 12 August 1997. This time frame was selected because of the expected dry and hot climate. Each array consisted of 12 transect points (Figure 2), with three each at streamside, 5 m and 10 m from stream edge. Single transect points were placed at 20 and 30 m as well as a control in a nearby opening. The array was placed randomly within a reach, after the reach had been examined for potential confounding factors such as roads, trails or landings. The transect points at 20 and 30 m followed a straight line with the middle points from the other distances. The instrument set in the opening served as control, being beyond any direct stream influence or shade. All instruments were 0.5 m above the ground surface and shielded from direct sunlight, without impedance of airflow. Pilot work had found the daily maxima and minima values to occur over a short time interval. Therefore all monitors recorded RH at ten minute intervals; with this interval the absolutes could only be missed by five minutes. Estimates of air temperature maximums were from local meteorological stations in La Grande, OR for Grande Ronde sites, Ellensburg, WA for Teanaway sites, and Goldendale, WA for Klickitat sites.

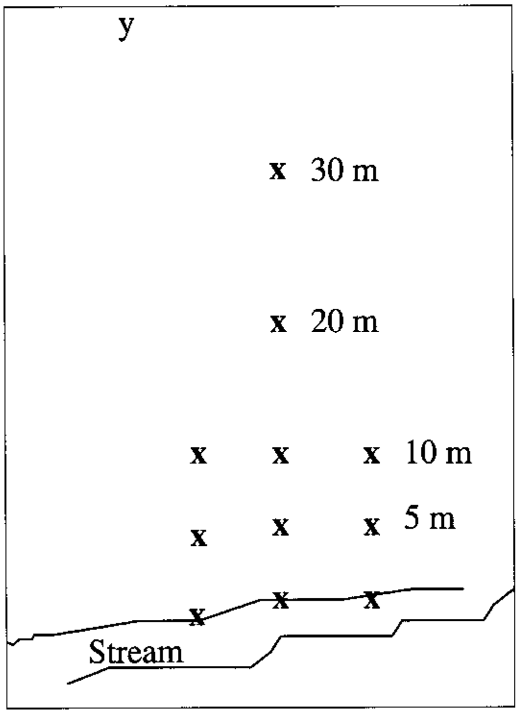

Figure 2. Instrument layout of transects with three replicates at 0, 5, 10 m and transect points at 20 and 30 m. Transect lines are 5 m apart. Y (control) is a site in an opening with minimal shade and more than 30 m from the stream.

At each site, reach and transect data were collected. Stream channel grade was measured with a hand-held clinometer and a mean stream wet width was calculated from 3 measurements. At each transect point percent shade and basal area were measured. Percent shade was calculated from the mean of four shade measurements, one in each compass direction, made with a hand-held concave densiometer. Basal area was measured with a 10 x prism 360^0 at each transect point. Tree size distribution was divided into five classes: 0–10, 10–20, 20–40 and >40 cm dbh. The understory coverage in three categories (% grass cover, shrub volume and tree branch volume) was estimated with a 1 m by 0.5 m cylinder at each transect point. The percent of each category found within the cylinder was estimated as the volume of vegetation found in each quadrant and summing the quadrants to estimate percent occupance by volume. Site characteristics, percent shade and basal area (ft^2/ac), were regressed against mean minimum relative humidity at each site for all transect points. Local topography was measured between transect points with a hand-held clinometer.

Quality assurance and control protocols of the instruments included before and after QC checks and a single set of duplicates at each site. Quality control checks of relative humidity instruments were placed within an enclosed space of water saturated air above a sodium chloride solution. Duplicate relative humidity daily minima were compared with t-tests (alpha = 0.05).

Since low humidity is considered a problem for some riparian dependant flora and fauna, data analysis focused on daily minima and number of hours per day relative humidity was less than 50%. For each day the lowest relative humidity reading observed for each transect point was used. Daily minima for each row (3 replicates) were pooled and compared to successive distances from the stream. The same procedures were conducted with the daily length of time (hrs) relative humidity was less than 50%. The 50% point was arbitrarily selected after reviewing the 1996 pilot data, because in dry conditions the value was typically between daily maxima and minima and changes in relative humidity occurred rapidly through that value.

Mean minimum relative humidity (mmRH) and mean length of time less than 50% relative humidity were compared at successive distances from the stream with analysis of variance (ANOVA). An ANOVA first tested if there were differences across the 30 m transect. Four a priori orthogonal contrasts were employed to evaluate successive distances from stream edge: 0 m vs. 5 m, 5 m vs. 10 m, 10 m vs. 20 m and 20 m vs. 30 m. Each daily RH minimum and length of time < 50% was an observation. Sample size (number of days) for the Teanaway sites was seven, Klickitat was nine, and Grande Ronde was five with each day treated as a replicate observation. Multiple linear regression was employed to determine if the site characteristics (percent shade and basal area) could explain the differences in mmRH within each site.

Results

The 12 eastside locations were located within three watersheds: Teanaway River, Klickitat River, and Grande Ronde River watersheds (Figure 1). Site characteristics of these second to third order streams are presented in Table 1. Stream gradients ranged from 2 to 9 percent with widths at the time of measurement ranging from 1.3 to 5 m. Percentage of tree diameter size distribution at each site varied with 10-20 cm dbh and 20-40 cm dbh size categories predominant at all sites (Table 1). Understory vegetation was highly variable (Table 2). Shrubs were usually the dominant understory, but no trend with distance from stream was observed. Within the sites of the three watersheds the tree basal area and resultant shade varied, with the Teanaway watershed having the lowest percent shade and basal area and Grande Ronde watershed with the most. There was no general trend with respect to shade and basal area at distance from the stream. In some cases it was highest at stream edge; while at others it could be at any transect point (Table 1).

During the period of the study the maximum air temperatures were 32°C in La Grande, 30°C in Ellensburg and 33°C in Goldendale. Maximum relative humidity levels were at or near 100% for

TABLE 1. Characteristics of twelve study sites located in three areas east of the Cascade Mountains in eastern Oregon and Washington.

						Proportion of stems (%) by DBH Class (cm)				Shade (%) by distance from stream edge (m)						Basal Area (ft^2/ac) by distance from stream (m)				
Watershed/Stream	Sample Dates	Grade (%)	Width (m)	Aspect (°)	Elevation (m)	0-10	10-20	20-40	>40	0	5	10	20	30	Control	0	5	10	20	30
Teanaway	7/17-7/25																			
Jack Creek		2	3.9	350	796	0	80	19	1	78	92	64	32	26	3	20	20	20	20	20
Middle Creek		4	1.8	190	753	0	90	2	8	6	7	2	22	100	0	3	3	0	0	50
Wilson Creek		9	4.2	228	978	0	60	20	20	27	38	78	93	22	0	3	20	40	70	50
Cooke Creek		3	5.0	280	893	0	10	80	10	39	62	53	74	6	7	40	60	60	50	70
Klickitat	7/27-8/5																			
Dry Creek trib.		6	1.4	66	911	0	60	35	5	95	90	98	40	6	17	80	50	60	10	20
Highland Canyon (rb)		2	1.5	79	881	0	30	50	20	78	91	82	70	11	15	70	100	120	70	40
Highland Canyon (lb)		2	1.5	259	881	0	20	50	30	49	78	60	65	67	1	60	70	80	80	90
West Prong Creek		4	4.0	56	729	0	20	40	40	58	95	72	27	44	3	70	50	50	80	100
Grande Ronde	8/8-8/12																			
Grossman Creek		3	2.0	340	1151	10	20	50	20	78	80	65	40	100	0	45	60	70	80	100
Gordon Creek		3	2.8	70	972	0	25	50	25	83	75	85	50	20	0	150	130	100	70	90
Indian Creek		3	1.3	70	1185	10	25	40	25	25	80	79	85	80	0	80	140	130	160	150
Little Catherine Creek		3.5	5.0	300	1094	10	25	50	15	28	53	82	80	85	0	30	100	150	200	220

TABLE 2. Volume occupance (%) of grasses (G), shrubs (S), and tree branches (T) in a 1 m x 0.5 m cylinder at transect points in streams of three watersheds. Distances values 0, 5, and 10 m are means of 3 replicates (C is control.)

Watershed/Stream	Volume Occupance (%)											
Distance (m)	G	S	T	G	S	T	G	S	T	G	S	T
Teanaway		Jack			Middle			Wilson			Cooke	
0	0	2	10	1	0	0	2	26	0	0	0	0
5	1	15	37	62	12	0	1	2	1	2	3	0
10	10	19	23	43	29	0	0	3	2	2	2	0
20	5	0	0	5	0	10	0	1	0	10	0	0
30	0	15	0	0	2	5	0	2	0	0	5	0
C	0	0	0	1	20	0	2	0	0	2	0	0
Klickitat		Dry			Highland (rb)			Highland (lb)			West Prong	
0	0	1	3	2	4	5	0	75	0	0	1	0
5	0	43	10	2	2	13	3	2	0.3	0.3	1	0
10	0	9	3	1	1	0	0	29	0	0	3	0
20	5	0	0	3	2	0	2	0	0	0	2	0
30	1	2	0	1	2	0	1	0	0	1	15	0
C	0	20	0	10	0	0	5	0	0	0	0	0
Grande Ronde		Grossman			Gordon			Indian			Little Catherine	
0	8	13	0	0	3	0	25	16	0	0	5	0
5	13	29	3	3	33.3	0	3	5	0	7	15	5
10	0	25	5	2	12	3	0	8	0	3	16	3
20	10	40	10	10	50	0	10	0	10	0	10	0
30	0	10	0	10	30	0	0	10	0	0	15	0
C	5	10	0	10	60	0	10	30	0	5	0	0

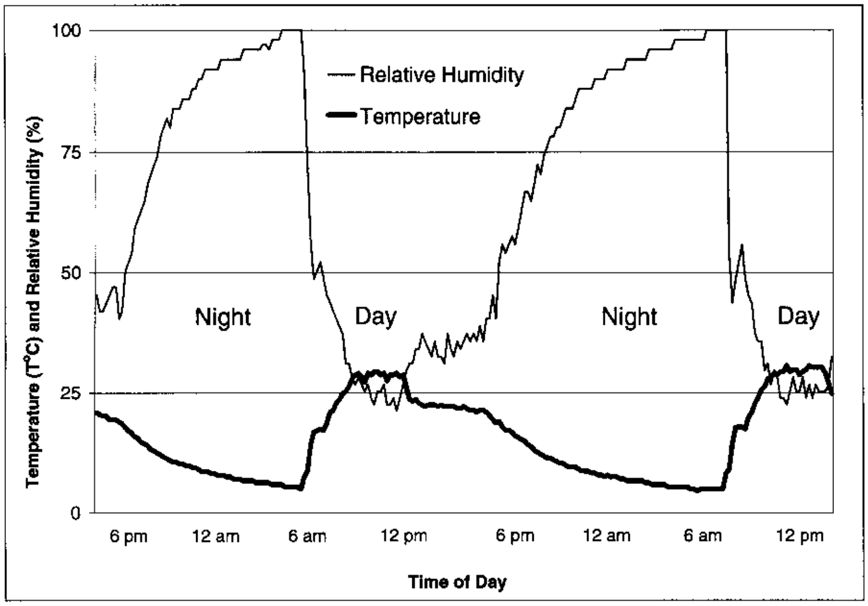

Figure 3. Example of diurnal pattern of temperature and relative humidity observed at all sites during the study.

all sites at all transect points. These values were reached nightly and remained near 100% until after sunrise, sharply declining as air temperature rose (Figure 3). Quality assurance tests after the study found all but one of the relative humidity instruments to meet the standard, with duplicate precision of daily mmRH was greater than 98% for the instruments.

At all sites there were significant differences (P value < 0.05) in mean minimum relative humidity (mmRH) across the 30 m transect except for one, Grossman Creek (Table 3). In the successive contrasts 9 of 12 had significant differences in mmRH between stream edge and 5 m. Two of the remaining three had a significant difference between 5 to 10 m from the stream edge. Between transect points 10 m from the stream and beyond there were few additional changes in mmRH, only two for each the 10–20 m and 20–30 m comparisons (Table 3). Figure 4 illustrates the general decreasing trend of mmRH with distance from the stream edge. The figure includes the control site, which was in an opening with minimal shade and farther from the stream than the 30 m transect points. At only the Klickitat sites did all 4 sites during a sampling interval respond similarly (Figure 4), suggesting that even with similar climate, local topography can influence gradient structure.

Results of the comparison of mean length of time less than 50% relative humidity had largely identical results (Table 4). In general, distance from the stream and the length of time RH was less than 50% were positively correlated. Overall the length of time of RH < 50% stabilized 5 to 10 m from stream edge (Figure 4; Table 4).

At one stream, Highland Canyon Creek, transects were deployed on both sides of the stream. Results of mmRH and length of time less than 50% RH were very similar on each side with one exception. Between 10–20 m on the left bank there was no difference in length of time less than 50% (Table 4). This is likely a result of a topographic feature, as there is negative slope between those two transect points (Table 5).

The effect of local topography on the RH gradient can be seen in many of the sites. Middle and Wilson Creeks have the least topographic slope (Table 5) and only minor changes (+ and -) in mmRH. At the Grande Ronde sites, the site with the highest near stream slope, Gordon Creek, had the most pronounced change in mmRH and time <50% between 0 and 5 m (Tables 3 and 4; Figure 4). The same pattern was observed at the Klickitat sites, Dry and Highland Canyon Creeks. Vegetation density and structure did not exert as strong an influence as local topography. Mean minimum relative humidity was regressed against percent shade and basal area and had coefficients of determination (r^2) ranging from 0.09 (West Prong Creek) to 0.80 (Little Catherine) (Table 6). Only four site regressions were significant (P< 0.05). Overall differences in microclimate conditions across the gradient followed no pattern with the exception of higher daytime relative humidities very close to the stream.

Discussion

These study sites were located in a variety of locations with different site conditions across the eastside of the Cascade Mountains in Washington and Oregon. While there are certainly other conditions represented east of the Cascades that may exhibit different moisture gradient conditions (such as in larger streams and rivers or within a

TABLE 3. Analysis of variance (ANOVA) probability values of mean minimum relative humidity (mmRH) across 30 m transect and orthogonal contrasts between adjacent transect points for mmRH at twelve sites in eastern Oregon and Washington.

			Orthogonal Contrasts (P-values)			
Watershed	Stream	ANOVA	0-5 m	5-10 m	10-20 m	20-30 m
Teanaway	Jack Creek	< 0.001	<0.001	<0.001	0.041	0.281
	Middle Creek	0.0001	0.734	0.013	0.395	0.867
	Wilson Creek	0.0001	<0.001	0.016	0.688	0.055
	Cooke Creek	0.0069	0.056	0.140	0.342	0.130
Klickitat	Dry Creek trib.	< 0.001	<0.001	0.036	0.028	0.418
	Highland Canyon (rb)	< 0.001	<0.001	1	0.275	0.466
	Highland Canyon (lb)	< 0.001	<0.001	0.803	0.177	0.930
	West Prong Creek	< 0.001	<0.001	0.314	0.372	0.778
Grande Ronde	Grossman Creek	0.0568	0.947	0.028	0.882	0.772
	Gordon Creek	< 0.001	<0.001	0.007	0.417	0.007
	Indian Creek	< 0.001	0.047	0.074	0.067	0.013
	Little Catherine Creek	< 0.001	<0.001	0.260	0.525	0.820

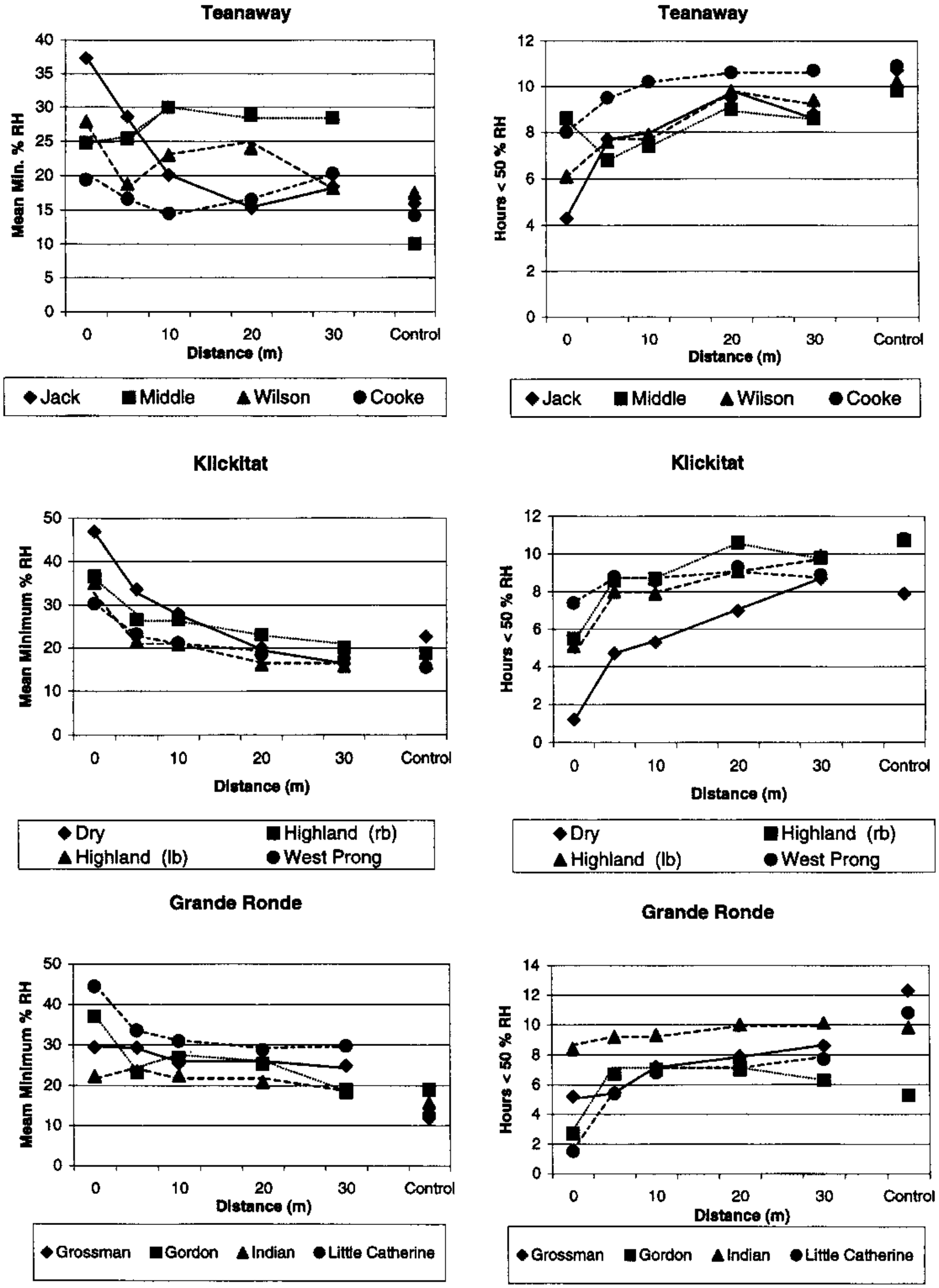

Figure 4. Mean minimum relative humidity (mmRH) and % time < 50 % RH in four stream riparian areas for each of three locations.

TABLE 4. Analysis of variance (ANOVA) probability values of length of time relative humidity (RH) < 50% across 30 m transect and orthogonal contrasts between adjacent transect points for length of time (hrs.) < 50% RH at twelve sites in eastern Oregon and Washington.

			Orthogonal Contrasts (*P*-values)			
Watershed	Stream	ANOVA	0-5 m	5-10 m	10-20 m	20-30 m
Teanaway	Jack Creek	<0.001	<0.001	0.914	0.004	0.347
	Middle Creek	0.0026	0.0011	0.326	0.033	0.679
	Wilson Creek	<0.001	0.001	0.372	<0.001	0.547
	Cooke Creek	<0.001	<0.001	0.015	0.333	0.722
Klickitat	Dry Creek trib.	<0.001	<0.001	0.141	0.008	0.016
	Highland Canyon (rb)	<0.001	<0.001	0.791	0.012	0.419
	Highland Canyon (lb)	<0.001	<0.001	0.858	0.033	0.252
	West Prong Creek	0.011	0.005	0.675	0.215	0.536
Grand Ronde	Grossman Creek	<0.001	0.564	0.002	0.415	0.453
	Gordon Creek	<0.001	<0.001	0.307	0.947	0.440
	Indian Creek	<0.001	<0.001	0.754	<0.001	0.661
	Little Catherine Creek	<0.001	<0.001	0.073	0.485	0.938

TABLE 5. Topographic slope between successive transect points (Distances 0, 5, and 10 m values are means of 3 replicates.).

	Distance Interval (m)			
Stream	0-5	5-10	10-20	20-30
Jack Creek	10	9	12	20
Middle Creek	9	2	6	8
Wilson Creek	7	7	4	4
Cooke Creek	31	23	4	17
Dry Creek trib.	29	12	3	64
Highland Canyon (rb)	51	67	16	46
Highland Canyon (lb)	21	-6	11	41
West Prong Creek	14	3	1	-3
Grossman Creek	7	40	33	30
Gordon Creek	32	2	5	7
Indian Creek	15	9	30	52
Little Catherine Creek	13	13	48	30

TABLE 6. Coefficients of determination and probability values for regressions at each site of mean minimum relative humidity with percent shade and basal area as the independent variables.

Location	r^2	*P*-value
Teanaway Watershed		
Jack Creek	0.65	0.015
Middle Creek	0.52	0.055
Wilson Creek	0.17	0.46
Cooke Creek	0.13	0.66
Klickitat Watershed		
Dry Creek trib.	0.66	0.012
Highland Canyon (rb)	0.16	0.48
Highland Canyon (lb)	0.55	0.04
West Prong Creek	0.09	0.67
Grande Ronde Watershed		
Grossman Creek	0.23	0.35
Gordon Creek	0.3	0.23
Indian Creek	0.26	0.3
Little Catherine Creek	0.8	0.0015

different range of elevation), these sites do represent major areas of eastside forests. Moderately open stands are common within the forested stands of these areas (Quigley et al. 1997). The actual edge of the regulated buffer and the managed stand also varies, although the edge between the regulated buffer and the existing stand in all cases of these study sites occurred within the 30 m study width. The percent shade and basal area of the 30 m transect point was representative of the adjacent forest with shade ranging from 6–100% and basal area 20 to 220 ft^2/ac; however, given the silvicultural prescription of selective harvest, the canopy cover was not uniform. The inability of shade and basal area to explain the relative humidity gradient in the regression analyses at these sites is likely due to the high variability in shade and basal area in these forest types both in the unmanaged riparian buffer and the upland stand.

These site conditions were very different from the westside study sites that have been used to assist in the understanding of microclimate gradients in riparian ecosystems in the west. The original study of microclimate gradients in the

Pacific Northwest by Chen et al. (1995) compared the distance from clear-cut edges into a mature forest. That approach is different from this study which is from a stream edge out into an adjoining forest. This study considers additional factors that can influence local climate such as valley structure and the stream as a water source that were not included in the Chen et al. study. Topographic and stream factors likely contribute to the steep gradients observed in this study. The lack of change in relative humidity seen after usually 10 m in this study, was a shorter distance than observed by Brosofske et al. (1997). Using an approach similar to the one employed in this study, Brosofske found little change in relative humidity after 31 m in western Washington riparian areas. This difference between eastern and western Cascade sites is likely due to climatic (cooler with more precipitation) and biological factors such as a denser and more uniform forest.

The extreme dry condition of low elevation forests of eastern Washington and Oregon creates an arid environment that aids in maintaining a naturally low tree density, with openings common, and sets the stage for a much more frequent fire regime (Agee 1993). With the Cascade Mountains intercepting moisture carried in air masses moving east, the summer air is dry. Therefore riparian zones are the critical habitat areas for a wide array of organisms. The results of this study found that area to be very narrow.

The sources of moisture in these dry habitats will be the remaining soil moisture, moisture carried by the atmosphere, any transpiration, and the stream itself. While the atmosphere may occasionally bring precipitation, the available soil moisture will be steadily decreasing as the summer progresses. During spring and early summer, evaporation from the soil and transpiration from the surrounding forest are likely major contributors to local air moisture content (Spurr and Barnes 1973). Growth and associated transpiration slows steadily as summer continues, with little to any new growth occurring during mid to late summer (Oliver and Ryker 1990). One response of plants to periods of water stress is the partial or full closing leaf stomata, limiting water losses to the atmosphere (Kozlowski et al. 1991). The remaining sources of air moisture are either direct, through stream evaporation, or indirect, through the limited transpiration of riparian vegetation immediately adjacent to the channel. This limits the amount of moisture available, such that only narrow bands of unique microclimate can be supported.

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