

INTRODUCTION

Extensive outbreaks of mountain pine beetle (MPB), spruce beetle (SB), and other insects are altering forest stand structure throughout the Western United States, and thereby increasing the natural heterogeneity of fuel distribution. Riparian forests frequently occur as narrow linear features in the landscape mosaic and can contribute to the spatial complexity of forest stands and fuel loads. These streamside forests are valued for providing aquatic and terrestrial habitat, serving as sources of in-stream and floodplain large wood, and maintaining streamside microclimates and stream water quality. Despite the ecological importance of riparian forests, few data exist on riparian stand attributes and fuel characteristics in watersheds affected by recent beetle outbreaks. This lack of knowledge, combined with administrative regulations for riparian management, present additional challenges to resource specialists planning fuel treatment projects in beetle-infested watersheds. To address this need, we measured stand characteristics and fuel loads in streamside and adjacent upland stands. Within selected watersheds on the Medicine Bow-Routt and Arapaho-Roosevelt National Forests (Colorado and Wyoming), we sampled 30 paired riparian and upland plots during the 2012 field season. Our objectives were to (1) quantify riparian forest characteristics, specifically species composition, structure, and extent of insect-caused mortality; (2) characterize riparian fuel profiles; and (3) compare riparian forest

attributes and fuels with those of adjacent uplands. Here, we present preliminary results on basal area, stand structure, and woody surface fuels in riparian and upland stands.

METHODS

Site Selection

Potential study watersheds (those with >50 percent infestation) were selected using aerial detection survey maps of mountain pine beetle infestation compiled by Forest Service, U.S. Department of Agriculture Region 2 Forest Health Monitoring Program. Criteria were conifer-dominated riparian areas along gentle-to-moderate gradient, moderately confined stream segments with floodplains 10 to 15 times wider than the stream channel within the elevation range 2500–3200 m. Potential riparian study locations were identified through examination of topographic maps, digital elevation models, forest vegetation maps for selected watersheds, and suggestions from local land managers.

Plot-Level Data

The approximate center of each 0.05-ha circular riparian plot was established randomly along the selected stream segment; however, riparian plots were located as close to adjacent streams as possible, with the streamside plot perimeter along the bank. Upland plots were located 200–400 m upslope from each riparian plot. Plot location (UTM point), slope, and aspect were recorded at plot center. Within

CHAPTER 13.

Forest Attributes and Fuel Loads of Riparian vs. Upland Stands in Mountain Pine Beetle-Infested Watersheds, Southern Rocky Mountains

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each plot, information recorded on all live and dead trees [≥ 5 cm diameter at breast height (d.b.h.)] included: species, d.b.h., crown position class (dominant, codominant, intermediate, or suppressed), percent live crown, and crown base height (noncompacted). Evidence of MPB incidence and damage was recorded for each standing lodgepole pine tree (*Pinus contorta* var. *latifolia*, live or dead); similarly, SB incidence was recorded for each standing Engelmann (*Picea engelmannii*) and Colorado blue spruce tree (*Picea pungens*). Trees were categorized as: uninfested (no evidence of beetle), infested with MPB, or infested with SB. We recorded data on the lower canopy strata (< 5 cm d.b.h.) to assess ladder fuels (Lutes and others 2006, Ottmar and others 2007) and advance regeneration (Collins and others 2012, Kayes and Tinker 2012). Information recorded on live saplings in two diameter classes (stems ≥ 2.5 cm and < 5 cm d.b.h., and stems < 2.5 cm d.b.h.) included species, d.b.h., and estimated height. Within the inner 0.0125 ha of each plot (radius = 6.31 m), live seedlings were tallied by species and height class (< 0.5 m or ≥ 0.5 m). Surface woody fuel loads were estimated using the planar intersect method (Brown 1974) for 1-hour, 10-hour, and 100-hour size classes. Three transects (12.63 m) were established from plot center on randomly selected bearings. Along each transect, 1-hour fuels were tallied for the first 6.3 m, and 10-hour and 100-hour fuels were tallied for the entire transect (Lutes and others 2006, Riccardi

and others 2007). Length and two diameters were measured on each coarse woody fuel piece (1000-hour; diameter > 7.6 cm) that occurred within the plot perimeter. Depth of litter and duff was measured every meter along each transect (12 depths per transect; 36 depths per plot).

Data Analysis

We calculated fuel loads for 1-hour, 10-hour, and 100-hour size classes as described in Brown (1974). For large woody fuels (1000 hour), length and diameters of each piece were used to calculate individual piece volume, approximating the piece as a cylinder. Total wood volume was summed for each plot in cubic meters. We assumed an average density of 400 kg m^{-3} , calculated kg m^{-3} of coarse fuels, and then converted to Mg ha^{-1} for each plot. We compared stand characteristics and fuel loads in 30 pairs of riparian and upland plots in mountain pine beetle-infested stands using one-way analysis of variance (SAS Institute Inc. 2011). We verified normality and homogeneity of variance (Levene's test) and assigned statistical significance at the $\alpha = 0.05$ level.

RESULTS

Stand Structure

Compositional differences in the riparian and upland stands are reflected in the relative basal area for the three dominant species, lodgepole

pine, Engelmann spruce, and subalpine fir (*Abies lasiocarpa*) (fig. 13.1). Upland stands have higher basal area of lodgepole pine, especially dead basal area, which accounts for nearly 32 percent of the upland total basal area (live + dead). Riparian stands have higher basal area of Engelmann spruce, especially live basal area, which accounts for 31 percent of the riparian total basal area. Live and dead basal area of subalpine fir was similar across stand types (fig. 13.1). Other species that occurred in riparian plots were quaking aspen (*Populus tremuloides*), mountain alder (*Alnus incana* ssp. *tenuifolia*), Colorado blue spruce, and willow (*Salix geyeri*). Collectively, these species contributed about 6 percent of the total riparian basal area. Additional species in upland plots were ponderosa pine (*Pinus ponderosa* ssp. *scopulorum*) and Douglas-fir (*Pseudotsuga menziesii*), which together only contributed about 2 percent of the total upland basal area.

Riparian and upland stands did not differ significantly in either total basal area or dead basal area (table 13.1). However, live basal area was significantly higher in riparian stands, accounting for 59 percent of the total basal area. In upland stands, live basal areas composed only 50 percent of the total basal area. Across all plots, nearly 92 percent of the lodgepole pine dead basal area was attributed to MPB, and approximately 60 percent of the Engelmann spruce dead basal area was attributed to SB.

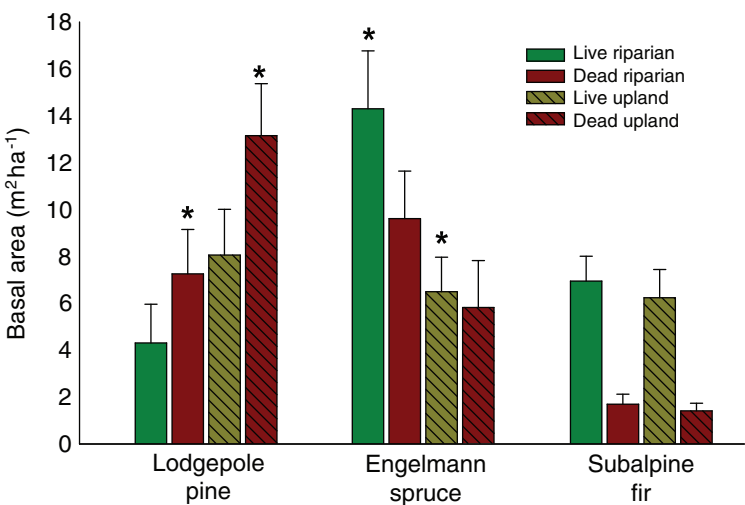


Figure 13.1—Basal area (live and dead, d.b.h. ≥5 cm) for lodgepole pine, Engelmann spruce, and subalpine fir in riparian and upland stands. Data are means and standard errors for 30 riparian and 30 upland plots. Asterisks indicate significant differences between riparian and upland stands.

Table 13.1—Live, dead, and total basal area (d.b.h. ≥5 cm) for riparian and upland stands

Stand type	Live basal area	Dead basal area	Total basal area
	-----m ² ha ⁻¹ -----		
Riparian	26.6 ± 2.7 ^a (6.8–64.6)	18.9 ± 2.5 (0.1–48.4)	45.5 ± 3.1 (16.3–79.6)
Upland	21.0 ± 1.9 ^a (7.1–50.7)	20.6 ± 2.2 (2.4–50.1)	41.7 ± 3.0 (20.2–87.0)

Note: Data are means, standard error, and range for 30 riparian and 30 upland plots.

^a Significant difference between riparian and upland stands ($\alpha = 0.05$).

Regeneration

In riparian stands, average density of live saplings was approximately 400 stems ha⁻¹ for each diameter size class, slightly lower but not significantly different from densities in upland stands (table 13.2). Subalpine fir dominated the lower canopy strata in all stands, comprising 53 percent of the larger diameter class saplings (stems ≥2.5 cm and <5 cm d.b.h.) in riparian plots and 51 percent in upland plots, and approximately 48 percent of the smaller diameter class saplings (stems <2.5 cm d.b.h.) in both riparian and upland plots. Densities of lodgepole pine saplings were three- to fourfold higher in the upland stands. Densities of Engelmann spruce saplings were not significantly different in riparian and upland stands.

Stem densities of taller seedlings (≥0.5 m and <1.4 m) were greater overall in riparian plots, most notably for Engelmann spruce (table 13.2). Subalpine fir dominated the seedling stratum (<1.4 m) in all plots, comprising approximately 86 percent of the shorter seedling size class (<0.5 m) in both riparian and upland stands, and 56 percent (riparian) and 76 percent (upland) of the taller seedling size class. Densities of lodgepole pine seedlings were twofold higher in the taller size class and eightfold higher in the shorter size class in the upland stands.

Table 13.2—Density (stems ha⁻¹) of advance regeneration, including two diameter classes of saplings (stems ≥2.5 cm and <5 cm d.b.h.; and stems <2.5 cm d.b.h.), and two height classes of seedlings (stem height ≥0.5 m and <1.4 m and stem height <0.5 m)

Stand type Tree species	Saplings		Seedlings	
	D.b.h.: ≥2.5 cm and <5 cm	D.b.h.: stems <2.5 cm	Height: ≥0.5 m and <1.4 m	Height: <0.5 m
-----stems/ha ⁻¹ -----				
Riparian				
Lodgepole pine	39 ± 14 ^a	50 ± 25 ^a	93 ± 69 ^a	24 ± 14 ^a
Subalpine fir	214 ± 47	187 ± 39	1513 ± 317	4186 ± 2300
Engelmann spruce	113 ± 27	98 ± 20	793 ± 274 ^a	631 ± 210 ^a
Colorado blue spruce	3 ± 2	9 ± 6	11 ± 7	8 ± 4
Ponderosa pine	0	0	0	0 ^a
Quaking aspen	25 ± 18 ^a	27 ± 16 ^a	290 ± 190	72 ± 59
Mountain alder	5 ± 2 ^a	17 ± 8 ^a	0	0
Willow spp. ^b	1 ± 1	10 ± 6	0	0
Total	401 ± 51	397 ± 47	2700 ± 512 ^a	4921 ± 2303
Upland				
Lodgepole pine	157 ± 65 ^a	140 ± 52 ^a	184 ± 91 ^a	192 ± 80 ^a
Subalpine fir	264 ± 57	204 ± 34	1200 ± 283	3754 ± 1026
Engelmann spruce	91 ± 16	71 ± 15	187 ± 69 ^a	369 ± 106 ^a
Colorado blue spruce	0	0	0	0
Ponderosa pine	1 ± 1	1 ± 1	0	5 ± 5 ^a
Quaking aspen	1 ± 1 ^a	2 ± 1 ^a	0	0
Mountain alder	1 ± 1 ^a	4 ± 4 ^a	0	0
Scouler's willow	3 ± 3	2 ± 1	0	0
Total	517 ± 84	423 ± 60	1570 ± 310 ^a	4321 ± 1031

D.b.h. = diameter at breast height.

Note: Data are means and standard error for 30 riparian and 30 upland plots.

^a Significant difference between riparian and upland stands ($\alpha = 0.05$).

^b Combined stems for Geyer's willow (*Salix geyeri*) and Drummond's willow (*Salix drummondiana*).

Surface Woody Fuels

One-hour fuel loads were higher in riparian stands (table 13.3). However, the mass of 10-hour, 100-hour, and 1000-hour fuel size classes were similar in riparian and upland stands. In addition, the depths of litter and duff layers were comparable in riparian and upland plots (table 13.3).

DISCUSSION

The riparian stands sampled in this study are dominated by the same overstory species as surrounding uplands and are drier than most other riparian plant associations in the region (Carsey and others 2003). Yet, they are managed differently from adjacent uplands to protect and sustain valued functions, notably provision of aquatic and terrestrial habitat. Results from this study provide discussion information to riparian managers and planners.

Comparison of basal area in riparian and upland stands revealed both similarities and differences. Riparian and upland overstories are both dominated by lodgepole pine, Engelmann spruce, and subalpine fir (figs. 13.1 and 13.2). However, stand types differ in percent of standing dead and live trees, and the proportion of basal area accounted for by lodgepole pine and Engelmann spruce (fig. 13.1). Live basal area is currently higher in riparian stands (table 13.1), but may approach upland levels of mortality as SB populations continue to spread. Dead basal area and total basal area (live + dead) did not differ significantly across stand types (table 13.1). Differences in live basal area have been attributed to moister site conditions in riparian areas, as well as successional dynamics among the three dominant species following disturbance (Romme and Knight 1981). Natural disturbance regimes in riparian

Table 13.3—Surface woody fuel loads (Mg ha^{-1}) and litter and duff depths (cm) in riparian and upland stands

Stand type	1 hour	10 hour	100 hour	1,000 hour (sound + rotten)	Litter depth	Duff depth
	----- Mg ha^{-1} -----				-----cm-----	
Riparian	0.73 ± 0.08^a (0.13–1.97)	1.49 ± 0.14 (0.03–3.46)	2.16 ± 0.30 (0–7.67)	44.56 ± 4.89 (0.15–110.08)	1.7 ± 0.1 (0–30.0)	3.6 ± 0.5 (0–33.0)
Upland	0.49 ± 0.04^a (0.09–1.23)	1.40 ± 0.10 (0.45–2.57)	2.52 ± 0.25 (0.52–5.37)	46.51 ± 5.77 (2.89–123.30)	1.4 ± 0.1 (0–11.5)	3.2 ± 0.3 (0–24.0)

Note: The 1-, 10-, 100-, and 1,000-hour fuels correspond to woody material 0–0.6, 0.6–2.5, 2.5–7.6, and >7.6 cm in diameter, respectively. Data are means, standard error, and range for 30 riparian and 30 upland plots.

^a Significant difference between riparian and upland stands ($\alpha = 0.05$).

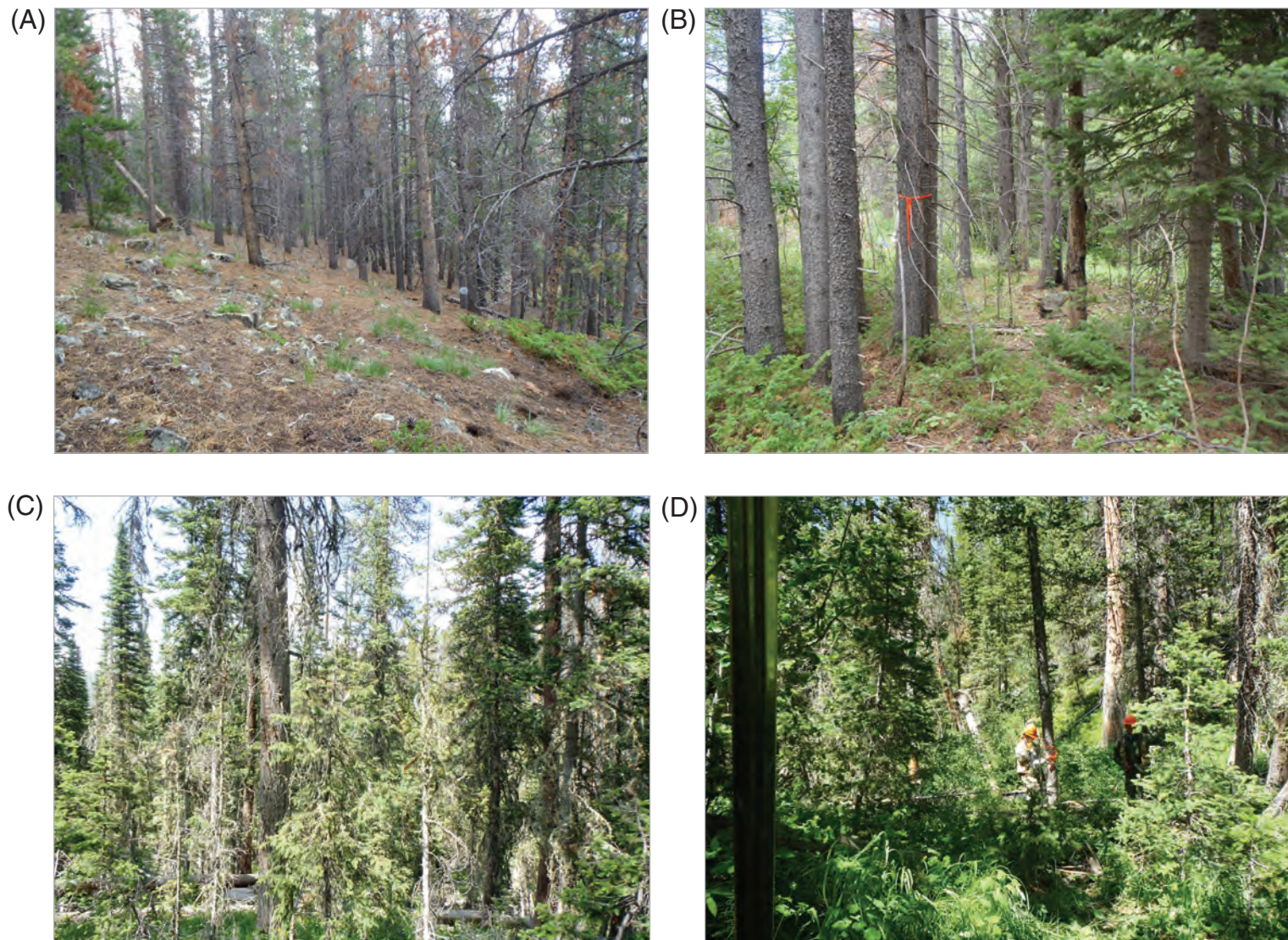


Figure 13.2—A range of stand conditions were sampled in both upland and riparian plots. However, similarities can be seen across stand types in these photos of paired upland and riparian plots. (A, upper left) Bennet Creek, Roosevelt National Forest, Colorado, upland; (B, upper right) Bennet Creek, riparian; (C, lower left) Cortez Creek, Medicine-Bow National Forest, Wyoming, upland; (D, lower right) Cortez Creek, riparian. (Photos by Robert Bazan, USDA Forest Service, Rocky Mountain Research Station)

and upland stands likely differ somewhat in the study area, but have not been studied directly. Generally, fire return intervals are less frequent in valley bottoms (Dwire and Kauffman 2003), and the role of insect infestations on stand development is assumed to be spatially heterogeneous, depending largely on site conditions (Kulakowski and Jarvis 2011). Comparison of relative basal area is also a way to assess standing fuels, which currently appear to be similar across stand types. However, fuel distribution and corresponding fire risk will change as the stands continue to respond to overstory mortality.

Riparian and upland stands contained high densities of understory regeneration in all size classes, similar to results reported in other studies of post-outbreak forest conditions (table 13.2) (figs. 13.2C and 13.2D) (Collins and others 2012, Kayes and Tinker 2012). Higher densities of lodgepole pine in upland plots and Engelmann spruce in riparian plots reflect the influence of site conditions and overstory composition (table 13.2). The dominance of subalpine fir in the lower canopy strata has been observed throughout post-outbreak forests in Colorado and southern Wyoming, and will strongly influence future stand development (table 13.2) (Collins and others 2012, Kayes and Tinker 2012, Pelz and Smith 2012). Although stem densities of taller seedlings are higher in riparian stands, densities of all other size classes of regeneration are comparable across stand types (table 13.2). In general, saplings and other regeneration size classes are considered ladder fuels, i.e., fuels that provide vertical continuity

between strata, thereby allowing fire to carry from surface fuels into the crowns of trees (Lutes and others 2006).

Fine surface fuel loads and depths of litter and duff were surprisingly similar in riparian and upland stands (table 13.3). We anticipated that fuel bed depth, primarily litter layer and 1-hour fuels due to high needle and small twig input, may be greater in upland stands due to the condition of the overstory strata, which were largely composed of dead lodgepole pine in the “gray stage” of post-outbreak (Simard and others 2011). Higher 1-hour fuel loads in riparian stands may be due to greater productivity and differences in shrub composition. Preliminary analysis of coarse woody fuels (1000 hour) showed that loads were similar in both stand types (table 13.3), with some differences in extent of decay (data not shown).

In many forested landscapes, riparian areas burn less frequently or less severely than surrounding uplands (Dwire and Kauffman 2003). This has been attributed to the tendency for fire to burn uphill rather than downhill and the reduced probability of lightning strikes in valley bottoms (Romme and Knight 1981). Differences in moisture content of various fuel strata may also be a critical feature in determining how some riparian stands burn relative to uplands. Riparian microclimates, mostly higher humidity and cooler temperatures (Brosofske and others 1997), likely slow the rates of fine fuel drying and decay of coarse wood, thus reducing the probability of fire ignition and spread. In a Wyoming subalpine

forest, Romme and Knight (1981) found that late-season moisture of fine woody surface fuels (1–10 cm, which includes 1-hour, 10-hour, and 100-hour fuels) were consistently higher in valley bottoms relative to uplands. In Douglas-fir stands (Blue Mountains, northeastern Oregon), Agee and others (2002) found that understory shrub and herbaceous foliar moisture was considerably higher in riparian areas relative to uplands. Fuel moisture can affect the rate of spread, fuel consumption, and fire-caused mortality for wildland and prescribed fires. More data are needed on relative moisture content of riparian and upland fuelbeds, especially during drought years and late in the fire season.

CONCLUSIONS

1. Sampled stands—both riparian and upland—are dominated by lodgepole pine, Engelmann spruce, and subalpine fir, but differ in relative proportions of lodgepole pine (higher in uplands) and Engelmann spruce (higher in riparian). Although live basal area is higher in riparian stands, neither dead basal area nor total basal area (live + dead) differed significantly across stand types. For current purposes of planning fuel management projects, standing fuels (trees) are similar across stand types. However, fuel distribution and corresponding fire risk will change as the stands respond to overstory mortality.
2. All size classes of understory regeneration were abundant in both riparian and upland plots. Lower canopy strata were dominated by subalpine fir, which accounts for nearly half of the understory stem density across stand types. Lodgepole pine regeneration was higher in upland stands and Engelmann spruce regeneration was slightly higher in riparian stands. Considering only stem density, ladder fuels (regeneration strata) are relatively similar in riparian and upland stands.
3. With the exception of 1-hour fuels, fine fuel loads and depths of litter and duff are similar in riparian and upland stands. Coarse fuel loads (1000 hour) are also similar across stand types.
4. A more complete comparative analysis of riparian and upland stand structure and fuel loads is underway. Examination of the contribution of live shrub biomass and herbaceous biomass to riparian and upland fuel loads is in progress. However, notable differences between riparian and upland stands are not expected. Canopy, size class distribution of live and dead trees, and understory data will be examined in more detail to determine the role of MPB and SB in the development of future forests and fire risk for riparian and upland stands.

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