



Spatial Distribution of Ponderosa Pine Seedlings Along Environmental Gradients Within Burned Areas in the Black Hills, South Dakota

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Abstract—In 2000, the Jasper fire in the Black Hills, SD, created a mosaic of burned and unburned patches of different sizes within the contiguous ponderosa pine forest. To study the spatial regeneration of ponderosa pine seedlings and the ecological gradients existing between burned and unburned areas two years after fire, we used a transect approach. We demonstrated that seedling establishment was prolific within the peripheral part of the burned areas due to the presence of seed sources close by, the seedbed conditions, and the relatively low competitive pressure. This transect study provides information to consider when managing forests after fire.

Introduction

Regeneration of *Pinus ponderosa* (ponderosa pine) has been previously described as prolific in the Black Hills of Wyoming and South Dakota (Shepperd and Battaglia 2002) compared to the common pattern encountered in the Rocky Mountain and Southwest areas. This prolific regeneration is due to local climate conditions and more particularly to abundant precipitation occurring during spring and early summer. However, the unprecedented size and severity of the fire that occurred in 2000 in the Black Hills (Jasper fire) may affect the future establishment of ponderosa pine seedlings in this area. Ponderosa pine has long been considered a species very well adapted to fire (Vlams and others 1955; Weaver 1967, 1974) because of its high tolerance to heat and high regeneration abilities after fire. Dispersal distance of ponderosa pine seeds is considered to extend to approximately 75 m to 100 m from the seed trees (Barrett 1966), with a minor influence of secondary dispersion factors on dispersal distance (Vander Wall 1997). Oliver and Ryker (1990) reported 8 percent seedfall at 120 m from seed source in central Oregon. Seed dispersal distance is not the only factor affecting ponderosa pine seedling distribution. Post-fire environmental conditions may also affect seedling establishment. Ponderosa pine has propensity for developing seedlings on mineral soil seedbeds, such as after severe fire (Harrington and Kelsey 1979). The seedlings benefit from the ash-covered soils, whereas unburned compacted litter would allow little moisture for seedling survival (Biswell 1973, Harrington and Kelsey 1979). The reduction of litter by fire favors ponderosa pine seedlings by reducing shade and mechanical obstructions to seedling emergence (Schultz and Biswell 1959). Finally, water and nutrient supply can limit the establishment of ponderosa pine after fire, in conjunction with the competition pressure that herbaceous species can exert on seedlings (Elliott and White 1987, Larson and Shubert 1969). Consequently, areas subject to high herbaceous recovery after the Jasper fire may obstruct ponderosa pine seedling establishment.

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We set out to determine the favorable and unfavorable environmental conditions for seedling establishment within the Jasper fire. We estimated the spatial distribution of seedlings by using transects running from unburned areas to the center of burned areas. This paper discusses the benefits of using a transect-based approach for defining areas where rehabilitation operations can be useful and other areas where they could threaten seedling regeneration.

Study Area

The study area is located in the south-central Black Hills (South Dakota) on the western section of the limestone plateau on the Black Hills National Forest. The elevation varies from 1800 m to 2200 m. The southern Black Hills is characterized by a continental climate, with average annual precipitation around 400 mm (Driscoll and others 2000), mostly occurring from April to July. Mean annual temperature is around 9 °C, with a mean annual high of 17.2 °C and mean annual low of 2.1 °C (Shepperd and Battaglia 2002). The vegetation is mainly ponderosa pine forests, with *Populus tremuloides* (aspen), *Quercus macrocarpa* (bur oak), and *Picea glauca* (white spruce) groves. Pine regeneration in this area, under natural conditions or silvicultural treatments, is among the most successful in the western United States (Shepperd and Battaglia 2002) and most of the germination occurs in early summer, during the months of May and June when precipitation is abundant and temperature starts increasing. The Jasper fire burned 33,000 ha of ponderosa pine forests in August and September 2000 in the Black Hills of South Dakota, and it was the largest fire recorded in the history of the Black Hills. It created a variety of competitive environments. Our study took place within this area two years after the fire, from May to October 2002.

Methodology

We established 20 transects within 10 burned patches of different sizes (two transects per patch). To allow a regular and dense sampling pressure, we prioritized the utilization of a high number of small plots. To enhance the effects of distance on seedling establishment and environmental variables, we chose rectangular plots having their longest side (6 m) perpendicular to the line of the transect and the smallest side (2 m) parallel to the transect. The distance between each plot was chosen to be twice the width of the plots to favor independence between plots. Transects began 36 m within the unburned areas (-36 m) and extended to the center of the burned areas (distance depending on the size of the burned patch). The unburned edge corresponded to 0 m. The shortest transect was 66 m long (from -36 m to +30 m) and the longest was 288 m (-36 m to +252 m).

Within the plots, we counted the new 2002 germinated ponderosa pine seedlings. We recorded the ground and vegetation conditions, the floristic richness, the topographic conditions, and other tree characteristics, at 2 x 6 m scale (total of 24 variables). The 24 variables measured in each 2 x 6 m plot are summarized in table 1 and all the variables are described thereafter.

Table 1—Environmental variables taken into account to explain seedling distribution.

Ground covers	BGR	% cover burned ground
	BL	% cover burned litter
	BSH	% cover burned shrubs
	CRY	% cover mosses + lichens
	GRV	% cover gravel
	RCK	% cover rocks
	UGR	% cover unburned ground
	SL	% cover scorched litter on burned ground
	UL	% cover unburned litter on unburned ground
	VEG	% cover understory vegetation
	WDB	% cover woody debris
Topography	ASP	Aspect
	SLP	Slope
Vegetation covers	BTRA	% cover dead trees <10 m
	BTRB	% cover dead trees >10 m
	UTRA	% cover alive trees <10 m
	UTRB	% cover alive trees >10 m
	C	% cover shrubs
	D	% cover stratum 0.1 - 0.5 m
	E	% cover stratum <0.1 m
Other variables	TOTC	% cover whole vegetation
	MeanDm	Mean tree DBH
	MeanHg	Mean tree height
	BasArea	Basal area
	Moist	Soil moisture
	Temp	Soil temperature
	Richn	Floristic richness
	Tree #	Tree density

Ground Conditions Per Plot

1. Within the 2 x 6 m plots, ground cover appearance was measured using estimated percentages of: unburned ground (UGR); unburned needle litter (ULUG); scorched needle litter on burned ground (ULBG); burned ground (BGR); burned needle litter (BLi); Cryptogam, i.e., bryophytes in this study (Cry); rock (RCK); gravel (GRV); woody debris (WDB); and the total cover of understory vegetation (E). The total cover of these variables equaled 100 percent of the ground cover seen from above and excluding the overstory canopy.
2. Vegetation conditions per plot: The percent cover and burn status of vegetation per stratum (0-10 cm high = stratum E; 10-50 cm high = stratum D; 50-200 cm high = stratum C; burned shrubs 50-200 cm high = stratum BSH; “unburned” trees <10 m = stratum UTRB; “burned” trees <10 m = BTRB; “unburned” trees >10 m = UTRA; “burned” trees >10 m = BTRA) and understory + overstory vegetation (TOTC) on the ground were also recorded. The “burned” or “unburned” status of the trees was established in relation to the percentage of the needle canopy burned (>50 percent / <50 percent). The total cover of these different strata may be greater than 100 percent.
3. Topography: Slope (SLP) and aspect (ASP) were recorded for each plot.

4. Other variables per plot: The number of trees (>3 m tall and with DBH >7 cm) (Tree#) was counted and their diameter and height were measured and means were calculated for each plot. The floristic richness, defined as the number of species in each plot (Richn), was measured for information about plant diversity.

Statistical Analyses

The distribution of the ponderosa pine seedlings along the transects was analyzed using non-linear regressions. Relationships were explored between average seedling density in June 2002 and distance from the unburned areas. Nineteen out of 20 transects were used for the analyses, from -36 m up to 150 m; plots located farther than 150 m were used only as observations due to low sample size. One transect was not used for analysis because of the high number of seedlings in some of the plots (up to 115 seedlings per plot at -12 m), corresponding to 55 times the average number of seedlings in any other plot.

To test the influence of environmental variables on seedling emergence in June, a PLS (Partial Least Squares) regression was performed between the 28 environmental variables, used as explanatory variables (table 1), and the number of seedlings per plot used as the dependent variable. This analysis was conducted on the 406 individual plots located along the 19 transects at up to 150 m from the edge. The PLS provides for each explanatory variable a regression coefficient, either negative or positive, with the dependent variable, and thus a hierarchy of the influence of the explanatory variables on the dependent variable.

The regressions were created using SPSS (SPSS Inc., Chicago IL) and Statistica (Statsoft France 1997); the plots within transects were examined using SAS Proc Mixed (SAS Institute Inc., Cary NC) and found to be relatively uncorrelated (serial $\gamma = 0.19$). The PLS were performed using ADE-4 (Thioulouse and others 1997).

Results

Average seedling density in June across the 19 transects varied with the distance from the edge (figure 1). This transect approach allowed us to determine different distances from the unburned areas where a change occurred in the distribution of the seedlings: (1) from -36 to -6 m, the distribution was regular and the average seedling density was about 350 seedlings per ha; (2) from 0 to 24 m, the seedling density increased to an average of 660 seedlings per ha and reached up to 1125 seedlings per ha at 12 m; (3) from 30 to 60 m, the seedling density decreased drastically with an average density of 110 seedlings per ha; and (4) after 60 m from the unburned areas, the seedling density averaged 40 seedlings per ha. In addition, some seedlings were encountered at up to 180 m from the unburned areas.

To explain the irregular distribution of the seedling density, the quantifiable environmental conditions were studied as explanatory variables of the number of seedling per hectare. The PLS regression performed between the 28 variables and the seedling densities per ha (figure 2) demonstrated that the seedling densities were explained by one combination of the different variables (first component significant $p = 0.04$) and were positively

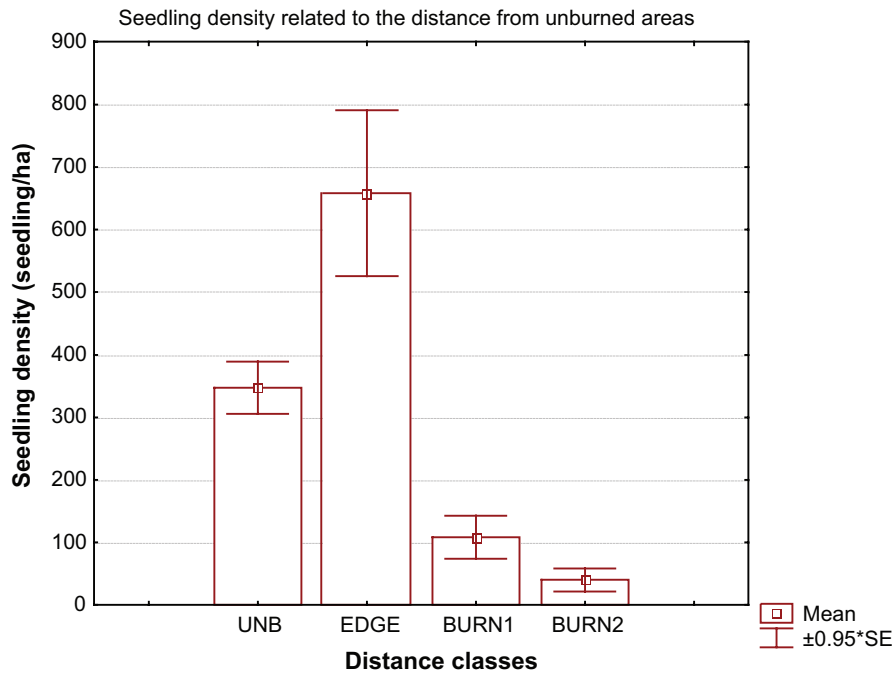


Figure1—Ponderosa pine seedling densities per distance classes: UNB = -36 m to -6 m; EDGE = 0 m to 24 m; BURN1 = 30 m to 60 m; BURN 2 = 66 m to 150 m.

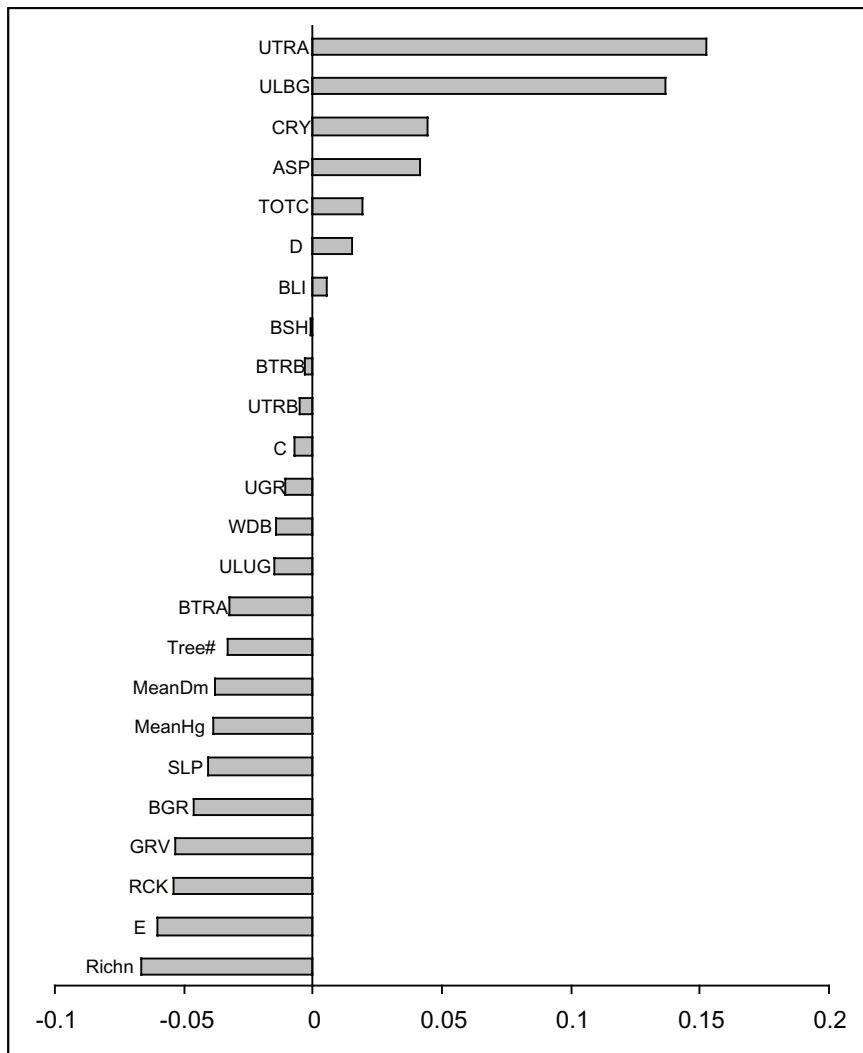


Figure 2—Graphic representation of the regression coefficients of environmental variables on seedling density; Partial Least Squares regression, 1st component. UTRA: Unburned trees <10 m; ULBG: Scorched litter cover; Cry: Cryptogamous cover; ASP: Aspect; TOTC: Total understory cover; D: Small unburned shrubs; BLI: Burned litter; BSH: Burned shrubs; BTRB: Burned trees >10 m; UTRB: Unburned trees >10 m; C: High unburned shrubs; UGR: Unburned ground; WDB: Woody debris cover; ULUG: Unburned litter; BTRA: Burned trees <10 m; Tree#: Tree number; Mean Dm: Mean tree diameter; Mean Hg: Mean tree height; SLP: Slope; BGR: Burned ground; GRV: Gravel cover; RCK: rock cover; E: Herbaceous cover; Richn: Floristic richness.

correlated to the abundance of live trees >10 m high (seed sources) and to the abundance of scorched litter on top of burned ground, and negatively correlated to the high floristic richness and to high covers of vegetation <10 cm high (indicating high competition pressure). Figure 2 shows the regression coefficient of each variable with the seedling density.

Discussion

The results of our study show that seedlings regenerated very well close to the edge between burned and unburned areas. Seedling establishment was explained by the presence of seed sources close by and by the burned soil conditions characteristic of moderately burned areas where scorched needles are still present in the trees after the fire. Seedlings also established better in areas where the competitive pressure from other species was lowest. Burned ground alone didn't appear to be a favorable environment for seedling establishment, whereas scorched litter on top of burned soil was one of the factors explaining seedling distribution. The area along the edge between the burned and unburned areas and extending around 30 m into the burned area constitutes the best condition, because of the short distance of seed dispersal, favorable seedbed conditions, presence of scorched trees, and lower competition pressure. It is possible that the presence of scorched trees also provided shade to the seedlings, which are moderately shade tolerant.

Thanks to the quantification of environmental variables along the transects, we can explain the spatial distribution of the seedlings: (1) from -36 to -6 m, seed sources are abundant but soil conditions are not optimal and competition pressure is high; (2) from 0 to 24 m, the seed sources are close enough to provide seeds, canopy and soil conditions are optimal, and competition pressure is lowered; (3) from 30 to 60 m, foreseeable diminution of seed arrival increased by the unfavorable seedbed conditions; (4) 66 m and farther, the seed dispersal is probably responsible for the decrease in seedling establishment compared to the area included between 30 and 60 m from the edge, the other conditions staying pretty similar between those two areas.

This study allowed us to give a spatial dimension to the regeneration success of ponderosa pine after fire in the Black Hills. According to our results, areas located farther than 30 m from the unburned areas, even if they still receive good quantity of seeds from the seed sources, should constitute an issue for seedling regeneration. This means that we can expect slower natural forest recovery in burned patches larger than 60 m of diameter and that artificial regeneration may be needed in those areas. Seedling establishment in the area included between the edge and 30 m should be very good and no salvage operations are necessary to favor regeneration in such areas or in small burned patches in order to preserve the re-establishment of ponderosa pine in burned areas.

Figures 3 a,b,c show the distribution of this area of good seedling establishment within three different burned patches (small patch, large patch, large patch after salvage). The small patch has a high percentage of good conditions for regeneration. The large patch without salvage has a small percentage of good conditions for regeneration. Using the same definition of good conditions (area located close to the edge, close to seed sources, with abundant scorched litter on top of burned ground and lower floristic richness and cover), the large patch after salvage does not present good conditions for regeneration, because the scorched trees have been cut down and

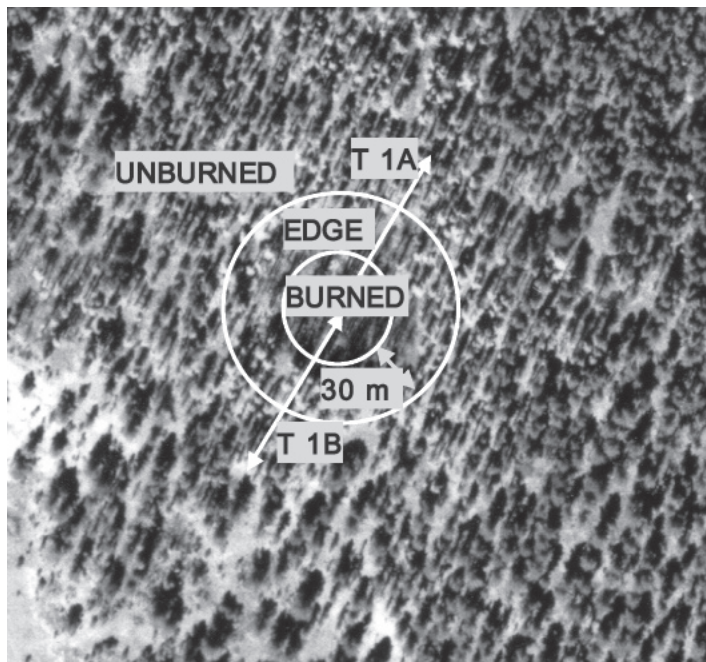


Figure 3a—Small burned patch and representation of burned, unburned, and edge conditions.

Figure 3b—Large burned patch and representation of burned, unburned, and edge conditions.

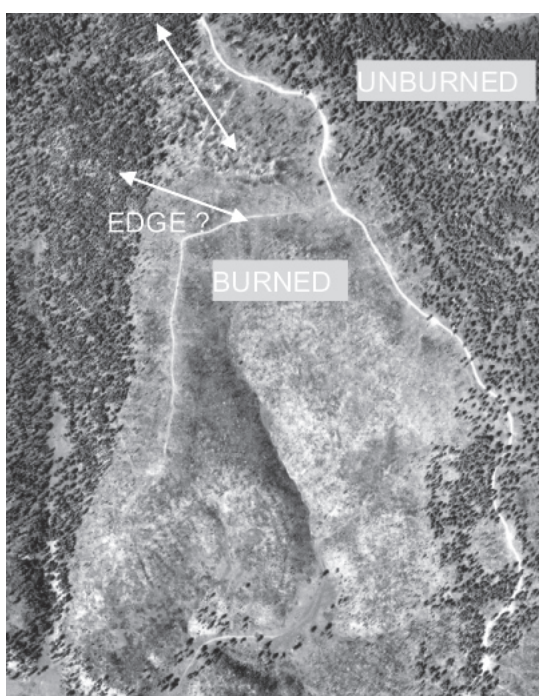
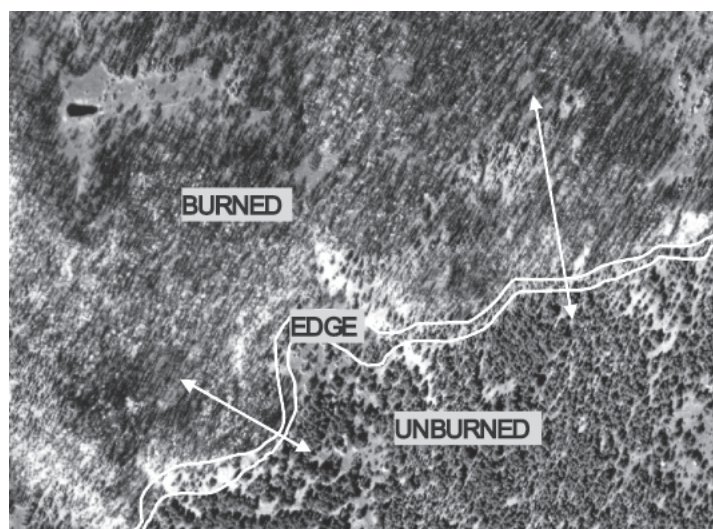


Figure 3c—Large burned patch after salvage and representation of burned, unburned, and edge conditions.

taken away. The preservation of a strip of scorched trees providing good soil conditions and moderate shade for seedlings at the beginning of the burned area would have preserved those good seedling establishment conditions.

Most of the previous post-fire vegetation assessments aimed to look at the influence of one component of the fire regime on plant regeneration. Fire intensity, fire frequency, and fire season have often been the main subjects of interest (Bond and van Wilgen 1996). However, some authors are now interested in showing the effects of spatial characteristics of the disturbance on post-fire regeneration (Turner and others 1997, Bonnet and others 2002). The effect of the size of the burned patch on ecological gradients can be assessed by the use of transects (Whittaker 1960). The originality of our study was to use a transect approach in order to quantify and explain the regeneration as a function of the distance from the edge. This approach used the multiple components of the post-fire environment to explain the spatial patterns of the regeneration. It does not assume *a priori* the role of fire severity but instead decomposes the environmental conditions into basic components and quantifies the role of each of them to explain the regeneration patterns. The approach we used in this paper to determine the conditions of regeneration for ponderosa pine and their spatial distribution within burned areas can provide information for foresters in making decisions related to post-fire logging.

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