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Fire effects on germination of seeds from *Rhus* and *Rubus*: competitors to pine during natural regeneration

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Abstract. Throughout the southeastern United States, *Rhus* and *Rubus* species are common associates of the southern pines on a wide array of upland site and stand conditions. Because of their ability to overrun disturbed sites, these species are categorized as competitors to pine during stand regeneration. Since prescribed burning is often used for site preparation in advance of pine regeneration, this study investigated the effect of fire on the germination of seeds from three pine competitors (*Rubus argutus* Link, *Rhus copallina* L. and *Rhus glabra* L.). During dormant-season burns, sumac seeds were located 45 cm above litter, within the F layer of a reconstructed forest floor, and at the interface of the forest floor and mineral soil. During growing-season burns, fresh blackberry fruits were placed at heights of 0, 15, 30, and 45 cm above the surface litter of a reconstructed forest floor. In subsequent germination tests, sumac seeds from within the F layer of burned litter had significantly higher germination rates for smooth sumac (31 %) and shining sumac (42%) as compared to unburned control seeds (1–5%). In general, germination rates for sumac seeds placed in the air or on mineral soil during burning were no better than control seeds. Seeds from blackberry fruits that were located at heights of 15, 30, and 45 cm had germination rates that were comparable to unburned control seeds (18%), but seeds from fruits placed on the litter during burning had <1% germination. Results suggest that sumac seed germination may be enhanced by the heat from prescribed burning, whereas blackberry seeds showed more germination response to multiple germination cycles which indicated a potential for long-term storage in the soil seed bank.

Introduction

Forestry benefits from prescribed burning include: site or seedbed preparation, control of unwanted vegetation, disease control, thinning of dense young pine stands, increased growth and yield of pines, and improvement of wildlife habitat (Crow and Shilling 1980; Davis 1959). Therefore, prescribed burning continues to be widely used in southern pine management. Prescribed burning can also have positive and negative effects on wildlife habitat by increasing certain essential nutrients and palatability of forage, by initially reducing leafy biomass followed by increases, and by initially decreasing fruit yields followed by increases (Landers 1987). Consequently, it is important to determine the effects of prescribed fire on early successional plant species that can hinder natural pine regeneration while making a positive contribution to wildlife habitat.

In many studies of different natural reproduction methods, we have observed a fairly common group of woody and herbaceous competitors to loblolly (*Pinus taeda* L.) and shortleaf (*Pinus echinata* Mill.) pines on a variety of different stand and site conditions (Cain and Barnett 1994; Shelton and Murphy 1994; Cain and Shelton 2001). Moreover, many of these pine competitors develop from seeds disseminated on the site after reproduction cutting or from the seed bank (Shelton and Cain 2002). Blackberry (*Rubus argutus* Link), shining sumac (*Rhus copallina* L.), and smooth sumac (*Rhus glabra* L.) were chosen for this investigation because they occur throughout the southeastern U.S., are predominant vegetation components in naturally regenerated pine stands (Cain 199 1, 1999; Shelton and Murphy 1994) and plantations (Miller et al. 1999; Schabenberger and Zedaker 1999) and are important food sources for wildlife (Landers 1987; Matthews, Jr. and Glasgow 198 1; Oefinger, Jr. and Halls 1974). Furthermore, in a IO-year evaluation of vegetation structure in uneven-aged stands of loblolly and shortleaf pines subjected to periodic prescribed burns in southeastern Arkansas, *Rubus* and *Rhus* species were found to be common components of the understory (Cain et al. 1998).

In a study of competing vegetation within 13 pine plantations that were established simultaneously in seven states, extending from Louisiana to Virginia, in the southeastern U.S., Miller et al. (1995) found that *Rubus* was one of the most common species on all sites through the first 8 years after study initiation. in the same study, *Rhus copallina* and *R. glabra* were two of the most common nonarborescent woody species during the first 8 years. Consequently, it is important to investigate factors, such as fire, that may stimulate seed germination of these prolific competitors to pine regeneration.

Because blackberry and sumac seeds have hard, impermeable seed coats, germination has been improved when seeds are scarified with concentrated sulfuric acid for up to 1 hr for blackberry (Brinkman 1974b) and from I to 3 hr for the sumacs (Brinkman 1974a). Sumorization, or heat pretreatment of seeds before they germinate (Barbour et al. 1987), may also enhance germination of blackberry and sumac seeds.

The purpose of the present investigation was to experimentally determine if germination of sumac seeds and seeds from fresh blackberry fruits might be enhanced when subjected to simulated prescribed burns, depending upon vertical placement of the seeds or fruit above and within a reconstructed forest floor.

Methods

Study area

The study was located on forest lands of the School of Forest Resources, University of Arkansas at Monticello. The study site is situated in the West Gulf Coastal Plain at 91°46′W and 33°37′N. Elevation of the forested area is 98 m with rolling topography. The soil is a Sacul loam (clayey, mixed, thermic, Aquic Hapludult), described as a moderately well drained upland soil with a site index of 24 m for loblolly pine at age 50 (USDA 1976). The growing season is about 240 d, and annual precipitation averages 134 cm with seasonal extremes being wet winters and dry autumns.

Burn beds

Within a pine seed-tree area, a 10 m by 10 m study site was prepared by using a small tractor and push-blade to remove vegetation and roots, thereby exposing mineral soil. Within the cleared area, two 1.5 m by 2.1 m beds were framed with steel railings, and the soil in each bed was leveled with hand tools and allowed to settle.

A forest floor was reconstructed within each bed to ensure uniform fuel conditions for burning (Hungerford et al. 1994) as well as uniform litter layers for seed and fruit placement (Shelton 1995). Undisturbed forest floor material for the burn beds was obtained 100 m from the burn site from beneath a closed forest canopy where pine basal area averaged 21 m^2/ha. The forest floor was typical of similar stand conditions found elsewhere in the South (Switzer et al. 1979). To facilitate reconstruction on the burn beds, forest floor material was collected in three layers – L, upper F, and lower F using 0.12 m^2 sampling frames. The L layer refers to the litter layer consisting of unaltered dead remains of plants (Pritchett 1979). The fermentation (F) layer was immediately below the L layer and consisted of fragmented, partly decomposed organic materials that were sufficiently preserved to permit identification as to origin (Pritchett 1979). For this experiment, the F layer was subdivided into upper and lower zones based on visual evidence of decay. Each layer was removed separately; then layers were transferred from the undisturbed forest floor in paper bags and reconstructed on the burn beds during the day of removal. Within the burn beds, a 0.95 m by 1.52 m interior plot was subdivided into twelve 0.12 m^2 cells (replications) for placement of the reconstructed forest floor.

To coincide with seasonal maturity of sumac and blackberry seeds, prescribed burns were conducted on January 30, 1998 to test their effect on sumac seeds and on June 17, 1998 to test their effect on blackberry fruits (Table 1). Wind for the simulated fires was provided from two 0.56 m^2 electric box-fans positioned side-by-side at ground level. Fan-blade rotation was varied during burning to maintain a constant wind speed at the fire front. Fuel burned with the wind (headfire), and wind speed was determined using an electronic Turbo-Meter@ wind speed indicator'. While burning was in progress, flame lengths were ocularly estimated to the nearest 0.15 m. Fireline intensity was calculated from flame lengths (Alexander 1982).

To measure temperatures generated by the fires, Tempil® temperature indicator pellets with known melting points were placed atop the burning litter or suspended above the litter on fiberglass cords. The melting temperature for these pellets ranged from 48 to 804 °C in increments of ≈55 "C. For the blackberry burns, Thermax® temperature indicator strips ranging from 37 to 110 °C in increments of ≈6 °C were

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Table 1. Fuel and weather conditions during simulated prescribed burns in southeastern Arkansas, U.S.A.

Fuel and weather variables	Burn conditions by species	
	Sumac	Blackberry
Date of burns	January 30, 1998	June 17, 199X
Days since last precipitation	4	1.5
Time of burning (CST)	1245- 1320	0950- 100s
Dry bulb temperature (°C)	17	28
Relative humidity (%)	43	42
Wind direction	South	South
Wind speed[a] (km/hour)	6.X	6.8
Fine fuel moisture (%)	19	18
Forest floor weight (Mg/ha)	26.4	20.5
Litter depth before burning (mm)	39.0	32.9
Litter depth after burning (mm)	21.0	1 x.7
Mean fireline intensity[b] (kW/m)	31.0	43.4
Maximum fire temperature (°C)	400	400
Rate of spread (m/hour)	79.3	128.0

[a] Wind speed generated by two electric box-fans.[b] $I = 259.8L_f^{2.174}$, where L_f = ocular estimates of flame length in meters(Alexander 1982). Based on melting point of Tempil® temperature pellets placed on the surface litter.

used in addition to Tempil pellets to determine the lower range of heat above the burning litter.

Shining sumac and smooth sumac seeds were obtained in early autumn 1996 from forested stands in southeastern Arkansas. Seeds were collected from a minimum of 25 plants for each species. Seeds were removed from fruits by hand rubbing on wire mesh, and void seeds were separated from filled seeds by floating off the empty seeds in a water bath. Filled seeds were air dried for 24 hr after cleaning and were retained in refrigerated storage at 4 °C until needed for this study.

Forest-floor litter for this burn was collected in mid-November 1997, 2 months before burning and transferred onto the burn beds. At the time of burning, the L layer averaged 10 mm in thickness; the upper-F layer averaged 4 mm; and the lower-F layer averaged 25 mm.

For each of 12 replicated cells in the burn beds, 45 sumac seeds were used -900 seeds per species, including control seeds. To relocate all seeds per treatment cell after burning, the seeds were glued at 1.0 cm intervals with high-temperature silicone onto fiberglass cords; control seeds were glued in a similar fashion. This process was done 24 hr before burning to permit the glue to cure. At the time of burning, moisture content averaged 12% (oven-dry basis) for the sumac seeds.

Just before fire ignition, three fiberglass cords containing 15 sumac seeds each were transferred to the center of the 12 cells per burn bed at one of three randomly assigned locations in or above the reconstructed forest floor. The fiberglass cords were either stretched between steel pins at 45 cm above the litter surface to simulate seed retention on living plants within the flame zone, placed at the midpoint of the lower-F layer, or placed at the lower-F and mineral-soil interface (Figure 1).

Blackberry burns

Fresh blackberry fruits for the study were obtained in mid-June 1998 from two forested pine stands in southeastern Arkansas. Fruits were collected based on their size and ripeness from 25 blackberry canes per location. From a random sample of 100 berries, the mean weight of individual berries averaged 1.6 g (fresh-weight basis) and each yielded 60 seeds per fruit. This sample of fruits was macerated by hand and washed over wire mesh to obtain clean seeds. Filled seeds averaged 50 seeds per fruit and were separated from void seeds by floating off the empty seeds in water.

The remaining fresh fruits were prepared for placement on the burn beds or used

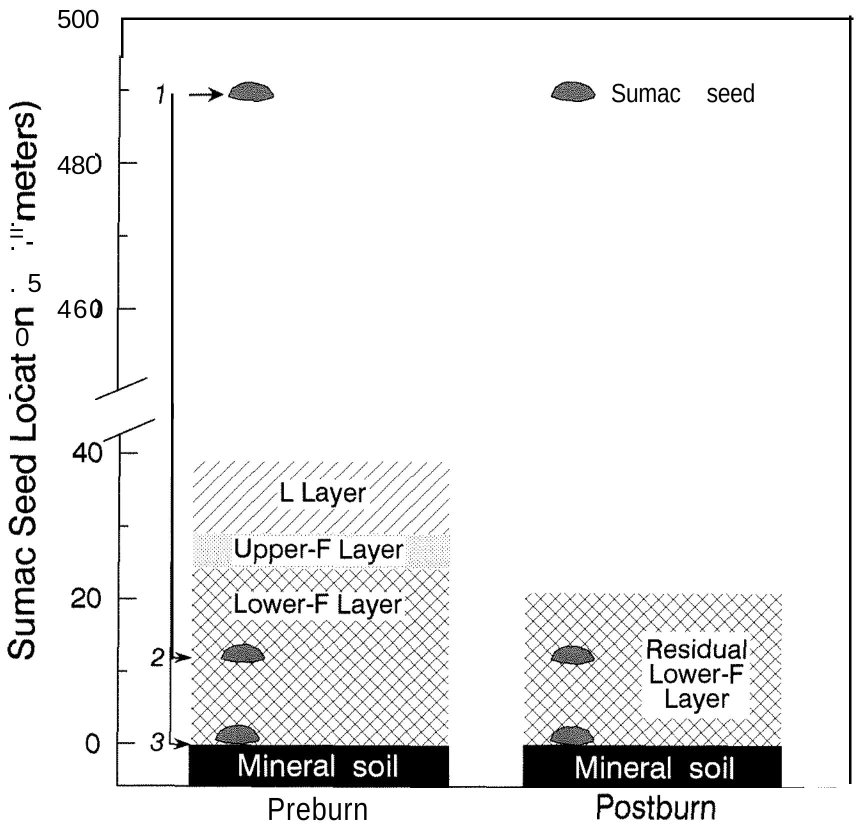

Figure 1. During the simulated prescribed winter burns, sumac seeds were located (1) 45 cm above the surface litter to simulate seed retention on living plants, (2) placed at the midpoint of the lower-F litter layer, or (3) placed at the lower-F and mineral-soil interface

as controls. For each of 12 replicated cells in the burn beds, eight blackberry fruits were used. To relocate all fruit per treatment cell after burning, the fruits were glued at 3.0 cm intervals onto fiberglass cords with high-temperature silicone; control fruits were glued in a similar fashion. This process was done 24 hr before burning to permit the glue to cure. At the time of burning, moisture content for the blackberry fruits averaged 700% (oven-dry basis).

Forest-floor litter for this burn was collected in early April 1998, 2 months before burning and transferred onto the burn beds. At the time of burning in June, the litter averaged 32.9 mm in thickness.

Just before fire ignition, two fiberglass cords containing four blackberry fruits each were transferred to the center of the 12 burn cells at one of four randomly assigned locations on or above the litter. Cords were placed on the L layer, or they were stretched between steel pins at three heights (1.5, 30, and 45 cm) above the litter (Figure 2). Since prescribed burning is often scheduled while fruit are still on forest vegetation, we placed blackberry fruits at specified heights above the forest floor to simulate natural conditions of fruit location. Heights of 15, 30, and 45 cm were selected because they were well within the flame zone.

Post-Burn procedures

To determine fuel moisture at the time of burning, separate 0.28 m^2 subplots containing a reconstructed forest floor were set up at the burn site for the winter sumac burn and for the summer blackberry burn. Immediately after the burns, three unburned litter samples were taken from these subplots within each of three litter layers (L, F,, and F_L). Moisture determination was on an oven-dry basis. After the burns, four 0.09 m^2 samples of residual litter were taken from within the burn beds to determine the weight of this residual unburned material on an oven-dry basis.

Blackberry fruits exhibited a noticeable color change (from black to red) as a result of being subjected to the fires. Consequently, immediately after the burns, the percentage of each berry's surface that exhibited a color change was assessed by ocular estimation to the nearest 10 percent relative to fruit placement, on or above the burn beds.

Following each burn, sumac seeds or blackberry fruits were removed from the fiberglass cords and prepared for germination tests. Blackberry fruits were macerated by hand in running tap water on 0.5 mm sieves to separate seeds from the pulp. The pulp mass was allowed to air dry at room temperature overnight; then seeds and pulp were forced through 2.0 mm sieves to remove the larger pulp. Residual seeds were dispersed onto moist, sterile-sand flats for germination tests. Percentage germination was based on the number of sound sumac or blackberry seeds per replicate.

In addition to unburned control seeds, a concentrated sulfuric acid treatment was used for a subset of unburned sumac and blackberry seeds as recommended by Brinkman (1974a, 1974b). The acid soak lasted 1.5 hr for sumac seeds (four replications of 45 sound seeds each) and 20 min for blackberry seeds (four replications of sound seeds from eight berries each). Germination rates from these

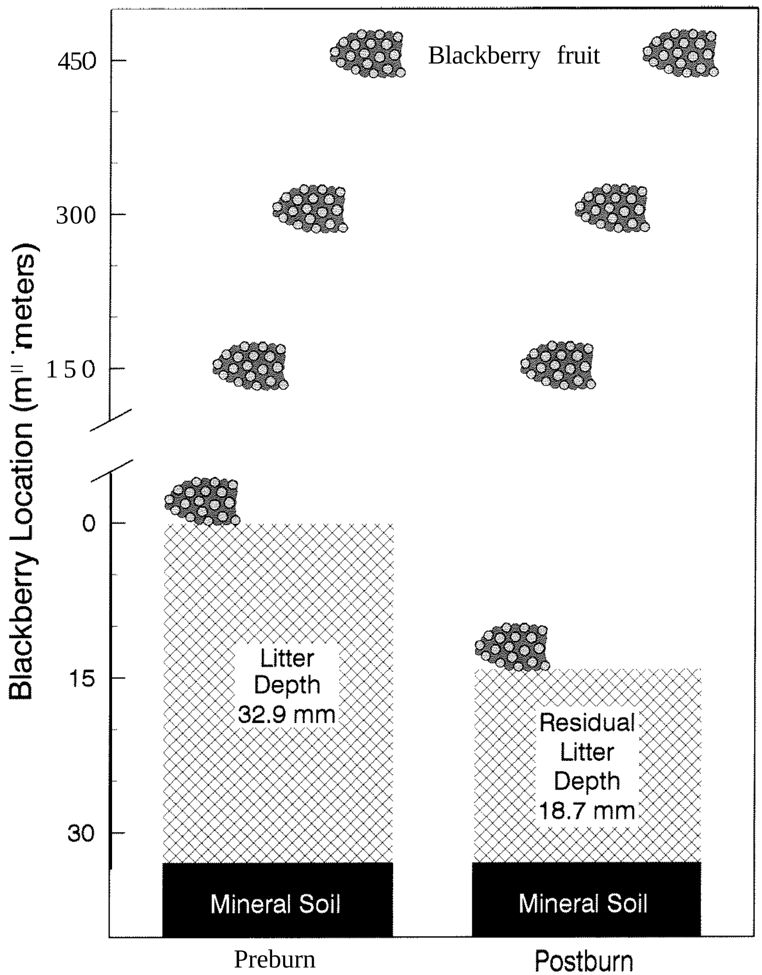

Figure 2. During the simulated prescribed summer burns, blackberry fruits were placed on the surface of the litter, or they were located at three heights (15, 30, and 45 cm) above the litter to simulate fruit retention on living plants

seedlots were used as viability standards for each species but were not included in the statistical analyses.

For the sumac seeds, the germination phase lasted 6 months during which two germination tests were conducted. Seeds were stratified at 4 °C for 60 days before the germination tests, which ran for 30 days each. Germination tests were conducted using 16 hr of full-spectrum fluorescent light and 8 hr of darkness during each 24 hr. Temperature in the germination room was maintained at 21 "C. Germination was considered complete when the radicle had emerged from the seedcoat and was at least 2.5 mm in length (Doucet and Cavers 1996).

To simulate natural seed dispersal during late summer, blackberry seeds were not stratified before the first 60-day germination test. Subsequently, stratification and germination tests of blackberry seeds alternated at 60-day intervals through a total of five iterations over a period of 18 months. Stratification and germination standards were the same as described for sumac seeds.

Data analysis

The sumac and blackberry experiments were randomized complete block designs with four replications of each treatment. Blocking was based on distance from the fans. Analysis of variance was used for individual species to compare the germinative capacity of seeds relative to their location within or above the forest floor (SAS Institute, Inc. 1989). Color change of blackberry fruits was also assessed by analysis of variance. Germination percent and color change were analyzed following arcsine square-root proportion transformation, but only nontransformed percentages are reported. The REGW Multiple Range Test was used to partition mean differences among seed locations in the burn beds. Significance was accepted at the $\alpha=0.05$ probability level.

Results

Sumac burns

Preliminary testing of seed placement on the L layer or at the interface of the L and upper-F layers during burning showed that sumac seeds were completely consumed by the fire. Therefore, seeds were placed within or below the lower-F layer in the main study to test their potential for survival. The headfires fully traversed the burn beds, leaving no unburned gaps and consumed 18 mm of the forest floor which included all of the L and upper-F layers and a portion of the lower-F layer (Figure I). Moisture content of the lower-F layer averaged 235%. Before the burns were conducted on January 30, 1998 (Table 1), forest floor weight averaged 26.4 Mg/ ha. After burning, the residual forest floor averaged 17.5 Mg/ha. Surface temperatures reached 400 °C during the burns.

Germination of unburned, acid-treated seeds averaged 7 1% for smooth sumac and 42% for shining sumac. Germination of smooth sumac and shining sumac seeds subjected to burning averaged highest (3 1.3% and 42.2%, respectively) when seeds were located within the lower-F layer at the time of burning (Figure 3). Germination of smooth sumac seeds located within the lower-F layer averaged 26 percentage points higher than the mean of the other three treatments. Statistically, there was no difference in the germinative capacity of smooth sumac seeds that served as unburned controls (0.6%) and those that were located 45 cm above the litter (7.2%) or located on mineral soil (6.7%). For shining sumac, germination of seeds located within the lower-F layer averaged 37 percentage points better than unburned control seeds (5.0%), but germination was statistically no better than that of seeds at 4.5 cm above the litter (13.4%) or those on mineral soil (30.4%). For sumac seeds that were classified as viable, better than SO% had germinated within 3 months after the burns.

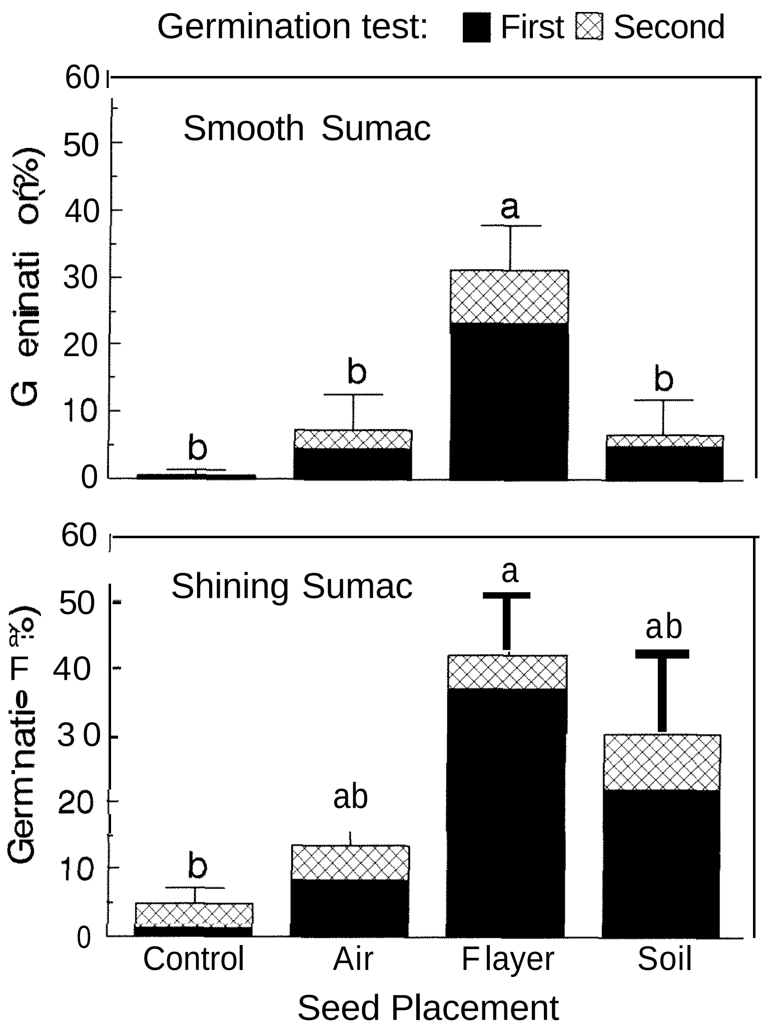

Figure 3. Cumulative germination (mean + S.E.) of unburned sumac seeds (control) and seeds that were located 45 cm above the surface litter (air), placed at the midpoint of the lower-F litter layer (F layer), or placed at the lower-F and mineral-soil interface (soil) during simulated prescribed winter burns. Within species, treatment bars labeled with the same letter are not significantly different (Smooth sumac: $P <$ 0.01, MSE=0.0193; Shining sumac: $P =$ 0.04, MSE = 0.0432)

Blackberry burns

As with the winter burns, those conducted in summer completely traversed the burn beds, consuming 14.2 mm of the forest floor (Figure 2) and reducing its weight from 20.5 Mg/ha down to 16.0 Mg/ha. Moisture content of the lower-F layer averaged 39%. Surface temperatures reached 400 °C during burning (Table 1). Less fuel consumption from the summer burns as compared to the winter burns was attributed to the rate of spread during the summer burns, which was 1.6 times faster than during the winter burns.

Although fresh blackberry fruits had a moisture content of 700% and none were completely consumed by the fires, seeds from fruit placed on the litter surface during burning averaged less than 1.0% germination during the next 18 months (Figure 4). The germination of seeds on the litter was significantly less than all other treatments which averaged about 18%. Unlike sumac seeds that produced their highest germination within three months after burning, blackberry seeds tended to germinate most prolifically during the fourth iteration, which occurred from 12 to 14 months after burning (Figure 4). Germination of unburned, acid-treated blackberry seeds averaged 73%, which was three times better than seeds from any of the burn treatments.

Blackberry fruits exhibited a unique response to burning by changing from black to red in color, depending on their location at the time of burning. Maximum color change occurred when blackberry fruits were placed on the litter (95% change) and at 15 cm above the litter (81% change) (Figure 5). At those locations, fruit color change was significantly different than when placement was at 30 cm (48% change)

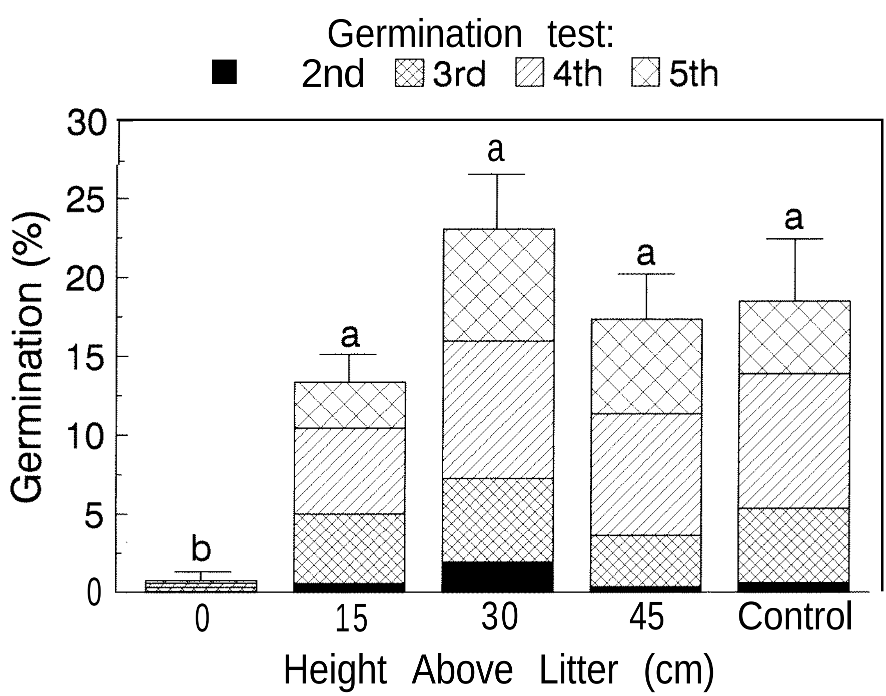

Figure 3. Cumulative germination (mean + S.E.) of blackberry seeds taken from unburned control fruit, fruit on the litter layer (0 cm), and fruit located at three heights (15, 30, and 45 cm) above the litter during simulated prescribed summer burns. The first germination test of blackberry seeds is not shown because it produced zero values for all treatments. Treatment bars labeled with the same letter arc not significantly different ($P < 0.01$, MSE = 0.0066)

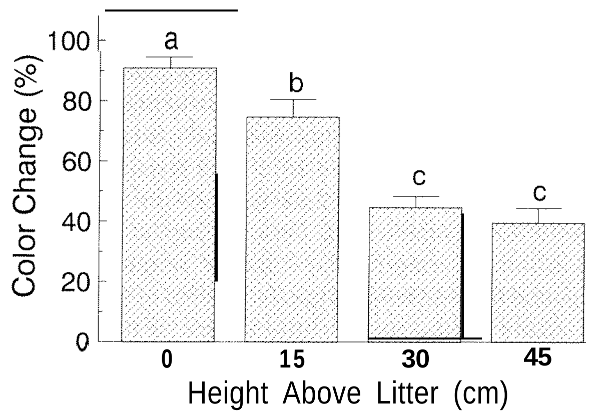

Figure 5. Color change (mean +S.E.) from black to red for blackberry fruits subjected to simulated prescribed summer burns relative to fruit location on the litter (0 cm) or at three heights (15, 30, and 45 cm) above the litter. Treatment bars labeled with the same letter are not significantly different ($P < 0.01$, MSE = 0.0130)

or at 45 cm above the litter (44% change). These results tended to parallel the range in temperatures on and above the litter while the burns were in progress. On the litter, temperatures reached 400 "C; at 15 cm above the litter, temperatures reached 160 °C; and at 30 and 45 cm above the litter, temperatures were > I IO °C but < 160 °C.

Discussion

Stone and Juhren (195 l) proposed that heat may impact seed germination by altering the permeability of the seed coat to water; destroying or driving off chemical inhibitors in the seed coat, endosperm, or embryo; or altering the metabolic pattern of the embryo. But according to Heit (1967), a hard seed coat is the only deterrent to the germination of *Rhus copallina* and *R. glabra*, whereas *Rubus* spp. have both hard seed coats and dormant embryos. For example, only 1 % of the acid-treated *Rubus* seeds germinated during the first germination cycle as compared to over 90% for the *Rhus*.

In the present study, simulated prescribed winter burns generated moist heat within the lower-t; litter layer and thereby improved the germination of shining sumac and smooth sumac seeds at that depth when compared to the germination of unburned control seeds. For shining sumac, germination from seeds placed at that depth was the same as achieved by treatment with concentrated sulfuric acid for 1.5 hr. An additional 13 mm of unburned, wet litter (235% moisture content) in the lower-l; layer appears to have served as a heatshield and nullified the lit-e effect for sumac seeds located at the lower-F/mineral-soil interface because germination of seeds at that depth was no better than untreated controls.

Sumac seeds that were placed 45 cm above litter and subjected to dry heat (> 110 but <160 °C) during the burns had no better germination than untreated controls. French and Westoby (1996) reported that seeds from plants in fire-prone environments do not survive heating to 150 °C but are likely to tolerate moderate heating of 80 °C without affecting seed viability; however, both temperature and its duration are important. In a study of *Rhus javanica* L. seed germination, Washitani (1988) found that the most favorable temperature regimes for improving germinability ranged from 65 to 75 °C and reported that those temperatures frequently occurred on denuded ground in Japan during midday hours of summer. Likewise, Stone and Juhren (1951) reported that soil temperatures at a depth of 6.3 mm often reach 60 °C for several hours daily during summer on exposed sites in southern California. According to Washitani (1988) an important agent for breaking the dormancy of water-impermeable seed coats is heat that may come from fire or soil insolation.

Seeds from fresh blackberries that were placed on the surface of the litter during burning averaged < 1.0% germination through five cycles of germination and stratification; this suggests that a temperature of 400 °C resulted in thermal inactivation or damage to the embryos, as proposed by Washitani (1988). When fresh blackberry fruits were placed at heights of 1.5 to 45 cm above the litter during burning, seed germination ranged from 13% to 23% but was no better than germination from unburned control seeds (18%). Keeley and Fotheringham (1998) proposed that heat shock triggers germination of some species of plants but has no stimulatory effect on other postfire species that are chemically stimulated by combustion products. If the blackberry seeds in the present study had been left to germinate under field conditions after burning, they may have performed differently than those in the laboratory. However, acid treatment of blackberry seeds for 20 min resulted in 73% laboratory germination through five germination cycles.

Blackberry seeds have been found to germinate over a period of several years without special treatment, and maximum germination was obtained in the third year (Heit 1967). Similarly, in the present study, blackberry seeds exhibited their highest germination during the fourth cycle under laboratory conditions, which would correspond closely with 3 years in the field and suggests the potential for long-term storage in the soil seed bank.

Management Implications

In operational prescribed winter burns (Cain 1993) conducted on sites similar to those described here, fireline intensities were greater (163-464 kW/m), fine-fuel moisture was lower (6-15%) and wind speeds were higher (5-21 km/h) than reported in the present simulated burns. Under those environmental conditions, it is unlikely that either blackberry or sumac seeds would remain viable during prescribed burns if they are located on the litter layer or in the upper-F layer of the forest floor. However, fruits eaten by animals may be embedded in an entirely different matrix, altering seed response to fire.

Heat pretreatment of the impermeable seedcoat by dormant-season burning has the potential for enhancing the establishment of both shining sumac and smooth sumac from seeds that are located within or above the litter. Because blackberry seeds have both an impermeable seed coat and a dormant embryo, their germination was not improved by the growing-season burns tested in this study. Late-summer burns that generate temperatures ≥400 °C and are applied when blackberry fruits ripen may have the potential for destroying the seeds. Even so, individual blackberry canes and sumac plants that are exposed to full sunlight can potentially produce hundreds of viable fruits from year to year. So, from the standpoint of managing for natural pine regeneration, selective herbicides applied in the spring or early summer, before sumac and blackberry seeds mature, may be more effective for reducing their presence than burning because herbicides would be less likely to destroy established pine seedlings and would not stimulate the germination of seeds that respond to heat shock or chemical products of combustion within the soil seed bank.

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