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Tolerance of Seedlings of Ponderosa Pine, Douglas-fir, Grand Fir, and Engelmann Spruce for High Temperatures

Abstract

The heat tolerance of 2- to 4-week old seedlings of ponderosa pine (*Pinus Ponderosa* Dougl. ex Laws.), Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl.), and Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) was determined and compared by exposing them to various time-temperature combinations in a "dry water bath" apparatus. Isosurvival curves indicating the time-temperature combinations that resulted in approximately equal survival were constructed for each species. Small (2 to 4°C) but significant differences in heat tolerance were found among species with ponderosa pine having the greatest tolerance and Engelmann spruce the least. Douglas-fir and grand fir were generally intermediate in heat tolerance.

Introduction

Mortality of natural regeneration during the first growing season is common on many clearcut and shelterwood units in central Oregon because of high soil surface temperatures. Although the lethal high temperature range for tree seedlings as related to time of exposure has been established in general (Baker 1929, Lorenz 1939, Shirley 1936), there is considerable variation in results because of the variety of experimental methods used. Because comparisons of the heat tolerance of coniferous species in the Pacific Northwest are scarce (Minore 1979), more specific information is needed on the time-temperature relationships of major species. Such information could be used with data on soil surface temperature obtained in regeneration units to better evaluate causes of seedling mortality.

The purpose of this investigation was to estimate and compare the relationship between seedling survival and time of exposure to high temperatures for ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.), Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl.), and Engelmann spruce (*Picea engelmannii* Parry ex Engelm.).

Materials and Methods

Seedlings and Soil

Seeds of Douglas-fir, grand fir, and Engelmann spruce were obtained from the USDA Forest Service Wind River Nursery, Gifford Pinchot National Forest. These seeds were originally collected in the Mount Hood National Forest (Barlow and Bear Springs Ranger Districts) at an elevation of about 1100 m. Seed from ponderosa pine was collected in the Pringle Falls Experimental Forest, at an elevation of about 1500 m. Soil used in these tests came from the upper 25 cm in the Experimental Forest. This soil is a well-drained Regosol developing on Mazama pumice.

Experimental Design and Procedure

The experiment was a completely randomized design with a 6 x 8 factorial arrangement of treatments for each species. Six temperatures and eight exposure times were used. The temperatures tested were 48.9, 51.7, 54.4, 57.2, 60.0, and 62.8°C (120, 125, 130, 135, 140, and 145°F); the times of exposure were 1, 5, 10, 20, 30, 60, 180, and 300 minutes. Each of the 48 treatment combinations was replicated twice.

Seeds were germinated in vermiculite, and ten germinated seeds (radicle 1 to 2 cm long) were planted in the Mazama pumice soil in rectangular boxes (30 x 6 x 12 cm) in a single row about 3 cm apart. Boxes were placed in a greenhouse and seedlings grown for 2 to 4 weeks at a 24 to 32°C day and 6 to 10°C night temperature regime, with a 15-hour photoperiod. During this period, the soil was well watered and seedlings did not experience water stress. Seven to ten seedlings were present in each box when treatments were applied from March through June 1981. Batches of seed were germinated at various times during this period so all seedlings were 2 to 4 weeks old when treatments were applied.

Heat was applied directly to the lower stem of the seedlings by means of the "dry water bath" technique developed by Silen (1960) (Figure 1). Copper tubing connected to a circulating immersion heater in a water bath was placed on both sides of the seedlings and pressed firmly against the seedlings with clamps. No visible seedling damage was observed from use of the clamps. A thermometer in a copper tube attached to the tubing next to the seedlings was used to measure the temperature at the base of the seedlings.

was not appropriate. To illustrate the effect of time and temperature on survival, observed means of each treatment were plotted as a three-dimensional graph for each species. Isosurvival curves that estimated the time-temperature combinations resulting in survival of 10, 30, 50, 70, and 90 percent of the seedlings were constructed for each species using curvilinear equations of the form:

$$Y = a + b\,(1 - e^{-cx})^{d};$$

Where Y = temperature, x = time, and a, b, c, and d are regression coefficients. To develop these curves, percentage of survival was regressed on temperature for each time period. The

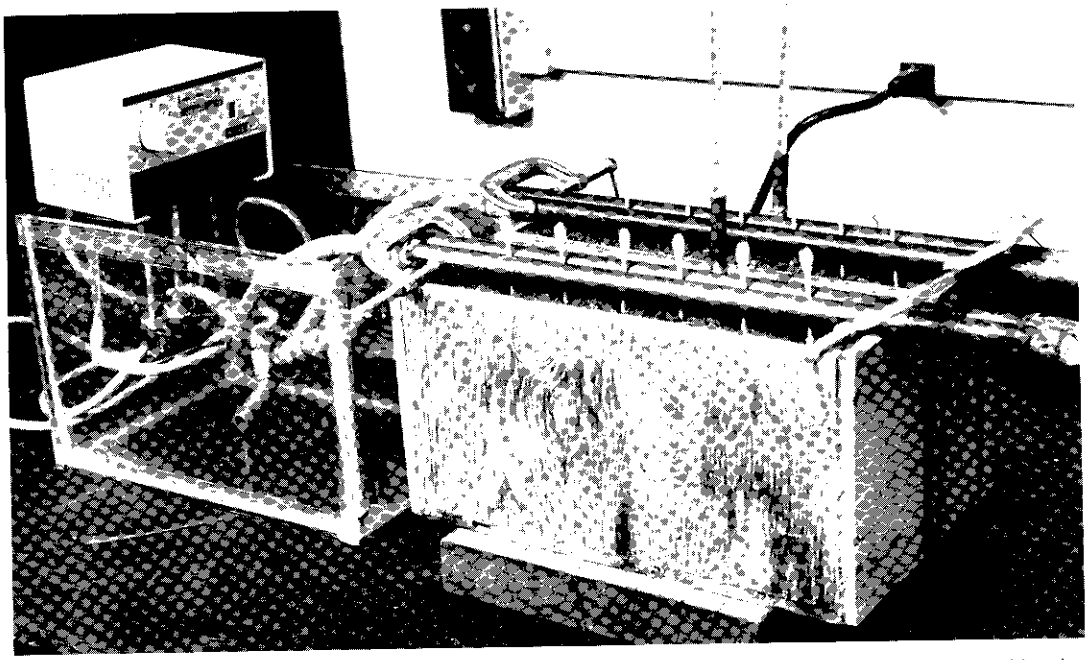

Figure 1. "Dry water bath" apparatus. Water is circulated from water bath by immersion heater through copper tubing that surrounds seedlings (represented by q-tips).

After seedlings in each box received a specific time-temperature treatment, they were returned to the greenhouse. In November 1981, the number of surviving seedlings in each replication was counted and the results expressed as a survival percentage. Because of the many treatment combinations that resulted in 100 or 0 percent survival, a standard two-way analysis of variance to test the time-temperature interaction

time-temperature data for each survival percentage (10, 30, 50, 70, and 90) was then obtained by reading the temperature at the point where each time curve intersected the survival percentage abscissa. To test for differences in heat tolerance among species, a single average isosurvival curve was constructed for each species and then converted to linear form by a logarithmic transformation of time. These linear curves were tested for significant differences in slope or level to determine differences among species.

Results and Discussion

Both the temperature to which seedlings were exposed and the length of the exposure had pronounced effects on seedling survival for all species (Figures 2-5). It was evident that time and temperature interact strongly to affect seedling survival. For ponderosa pine, for example, an exposure time of 180 minutes at a temperature of 48.8°C resulted in the same survival (100 percent) as an exposure time of 1 minute (Figure 2). But exposure to a temperature of 54.4°C resulted in 100 percent survival after 1 minute and only 15 percent survival after 20 minutes. The effect of different temperatures at a constant time was equally dramatic. After 1 minute of exposure there was about a 20 percent drop in survival as temperature was raised from 48.8 to 57.2°C. When seedlings were exposed for 20 minutes, however, survival decreased from 87 to 0 percent within the same temperature range, with most of the mortality occurring at 54.4°C.

The response of ponderosa pine and Douglas-fir to the treatments was similar except survival of ponderosa pine was generally higher at 48.8 and 51.8°C (Figures 2 and 3). No seedlings of either species survived temperatures of 54.4°C or higher when exposed for 30 minutes or longer.

Grand fir and Engelmann spruce seedlings were generally less tolerant of high temperatures than were ponderosa pine or Douglas-fir. More treatment combinations resulted in no survival (Figures 4 and 5).

Using the basic time-temperature survival data, a series of isosurvival curves were calculated for each species to show seedling survival within the range of times and temperatures used in this study (Figure 6). The curves illustrate the negative exponential relationship existing between time and temperature and show that a short period of high temperature resulted in the same survival rate as a longer period at a lower temperature. As time of exposure increased from 0 to about 15 minutes, the temperature that a seedling could tolerate decreased dramatically. At longer exposures (over 60 minutes), the effect of time was less important in seedling mortality. I estimated, for example, that about 30 percent of Douglas-fir seedlings would survive a temperature of 57.6°C for 4 minutes (Figure 6B), but at 60 minutes the temperature must be no higher than about 51.2°C to obtain the same rate of survival—a decrease of 6.3°C. When time of exposure increased from 90 to 300 minutes, however, the temperature to obtain a 30 percent survival rate only decreased from 50.8 to 50.0°C. Silen (1960) reports similar results for heat tolerance of 1-week-old Douglas-fir seedlings. About 30 percent of his seedlings survived a temperature of 60°C for 4 minutes, and a temperature of about 54.4°C for 60 minutes resulted in the same rate of survival. No time-temperature data were available for grand fir after 60 minutes because all of the treatment combinations resulted in zero survival (Figure 6C). These curves therefore have a linear form after 60 minutes in contrast to the more realistic gradual decrease in temperature with time of the other species.

The time-temperature isosurvival data are summarized in Table 1 for the four species for the 5- to 60-minute range. Ponderosa pine generally was able to withstand the highest temperatures at any exposure time, Engelmann spruce was the least tolerant. Differences of 2 to 4°C in heat tolerance were found between these species. Douglas-fir and grand fir were intermediate in their resistance to heat; they differed by only a fraction of a degree at some times and survival rates.

Statistical analyses of the average isosurvival curves showed there were significant differences ($P<0.01$) in levels of the ponderosa pine and grand fir curves and between the ponderosa pine and Engelmann spruce curves. Levels of the Douglas-fir and spruce curves also differed significantly ($P<0.05$); differences between Douglas-fir and grand fir curves were significant at the 10-percent level.

Based on this study, the relative heat tolerance of young seedlings of these species from highest to lowest is as follows: ponderosa pine ≅ Douglas-fir > grand fir ≅ Engelmann spruce. Direct comparison with other studies is difficult because of differences in seed source, age of seedlings, and experimental technique, but ponderosa pine is considered to have a high degree of heat tolerance (Roeser 1932). These results agree with the distribution of these species within plant communities along an elevational transect on the east slope of the Cascade Range;

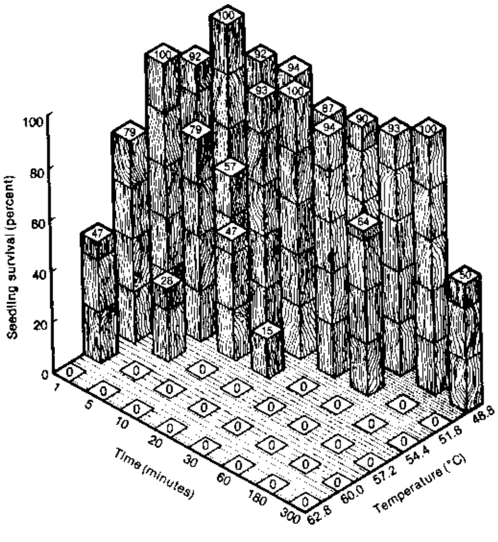

Figure 2. Effect of temperature and exposure time on survival of 2- to 4-week-old ponderosa pine seedlings. Numbers on tops of bars indicate survival percentages.

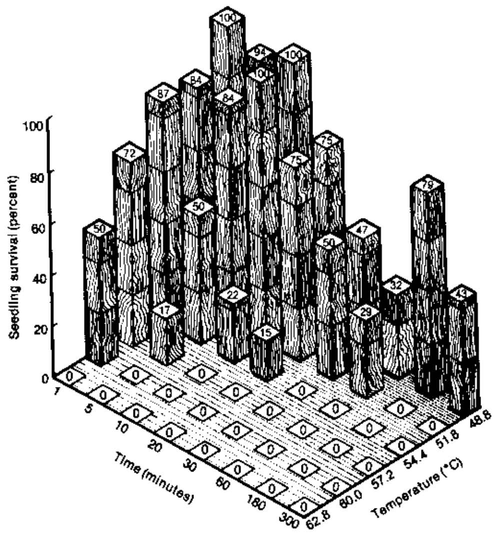

Figure 3. Effect of temperature and exposure time on survival of 2- to 4-week-old Douglas-fir seedlings. Numbers on tops of bars indicate survival percentages.

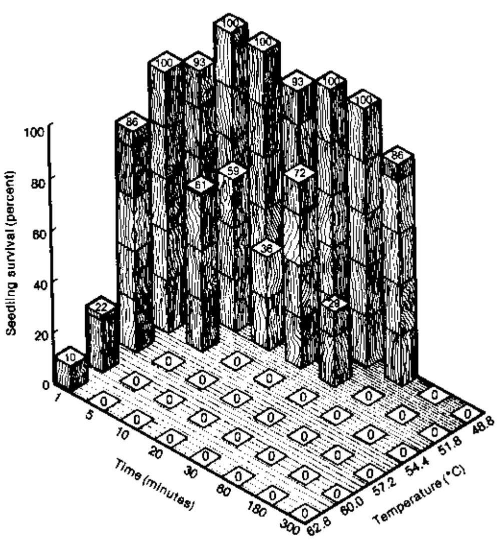

Figure 4. Effect of temperature and exposure time on survival of 2- to 4-week-old grand fir seedlings. Numbers on tops of bars indicate survival percentages.

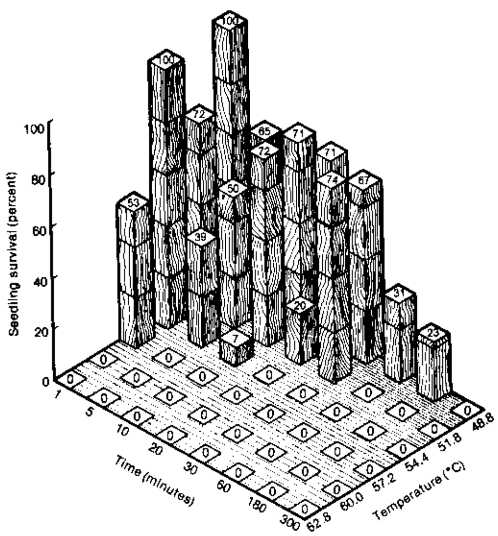

Figure 5. Effect of temperature and exposure time on survival of 2- to 4-week-old Englemann spruce seedlings. Numbers on tops of bars indicate survival percentages.

Figure 6. Isosurvival curves of 10, 30, 50, 70, and 90 percent for 2- to 4-week-old seedlings: (A) ponderosa pine, (B) Douglas-fir, (C) grand fir, (D) Engelmann spruce. Each curve gives estimates of the various time-temperature combinations resulting in equal survival.

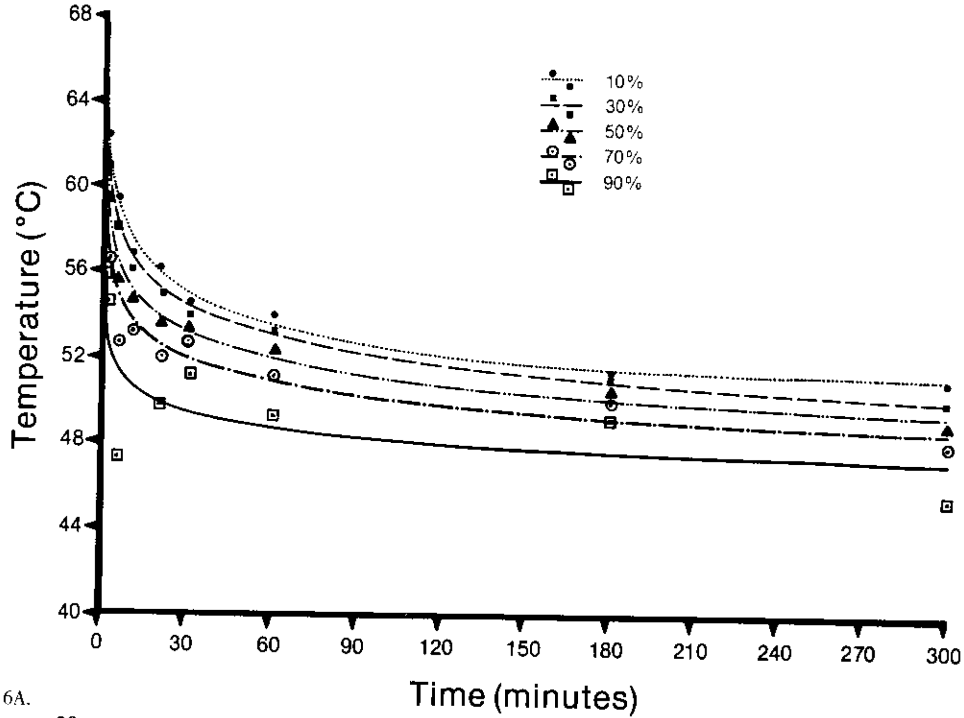

Figure 6A.

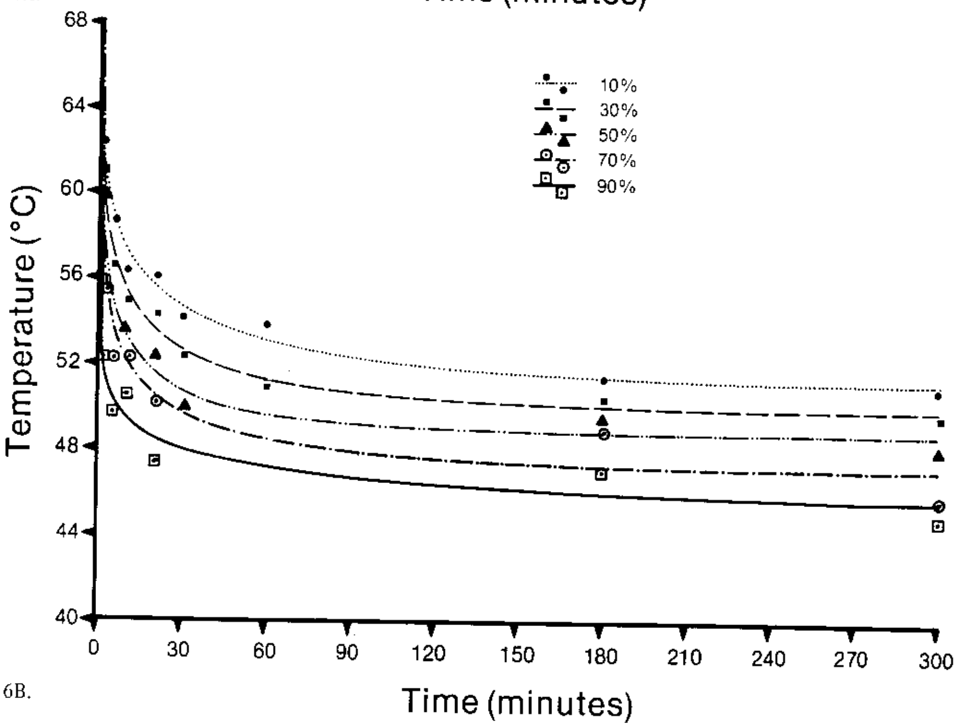

Figure 6B.

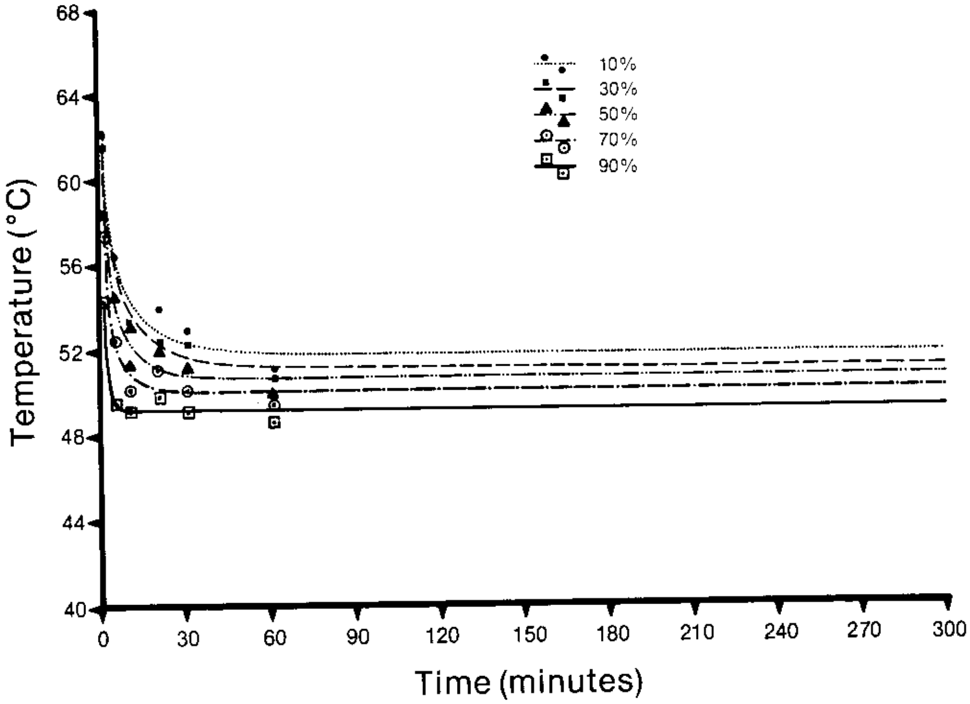

Figure 6C.

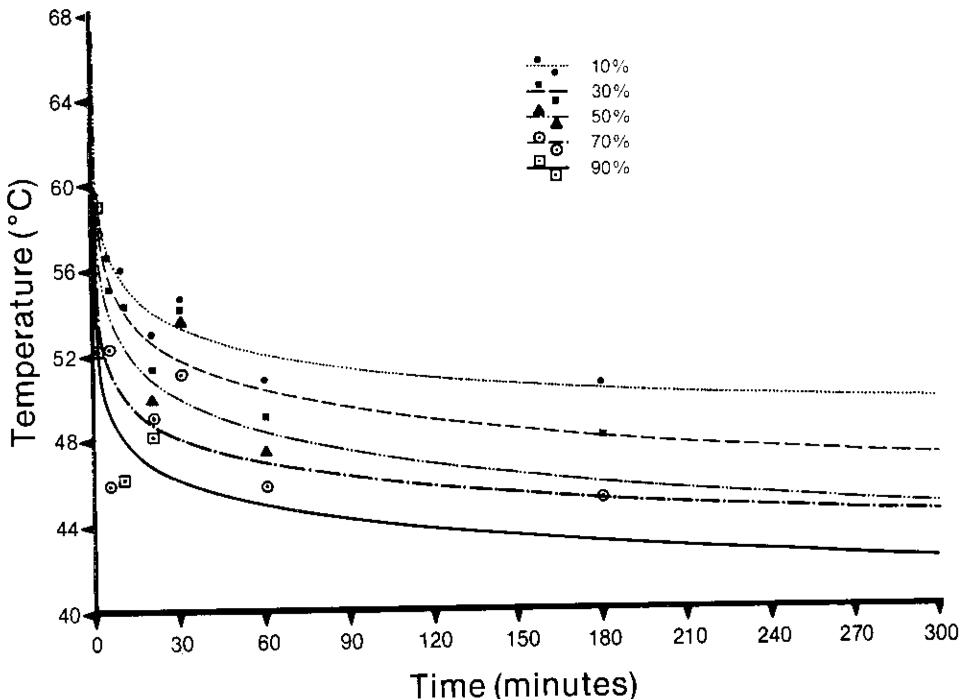

Figure 6D.

TABLE 1. Temperatures (°C) resulting in equal survival among four species at four time periods by percentage of survival.[1]

	10 percent survival	30 percent survival	50 percent survival	70 percent survival	90 percent survival
Ponderosa pine					
5 min	59.0	57.8	56.3	54.4	51.2
20 min	55.9	55.0	53.9	52.4	49.8
30 min	54.9	54.2	53.2	51.8	49.4
60 min	53.5	52.7	52.0	50.9	48.8
Douglas-fir					
5 min	58.4	56.8	54.8	53.3	50.2
20 min	55.4	53.6	51.5	50.3	48.5
30 min	54.5	52.6	50.8	49.6	48.0
60 min	53.0	51.3	49.7	48.4	47.3
Grand fir					
5 min	56.3	55.7	54.2	52.1	49.4
20 min	52.7	52.3	51.2	50.0	49.1
30 min	52.1	51.5	50.9	50.0	49.1
60 min	51.8	51.2	50.9	50.0	49.1
Engelmann spruce					
5 min	56.8	55.4	53.7	50.7	49.1
20 min	54.1	52.4	50.7	48.5	46.8
30 min	53.3	51.5	49.8	47.9	46.1
60 min	52.1	50.2	48.3	46.7	45.0

[1]Temperature values read from isosurvival curves.

ponderosa pine is found in warmer, low-elevation communities, and grand fir and Engelmann spruce occupy cooler, high-elevation sites.

It is apparent from these results, as well as those of earlier studies, that seedlings of many tree species suffer mortality from high temperatures within the range of about 48 to 68°C depending upon the length of exposure. In this study, the difference in temperature at a given time, resulting in equal mortality between the most and least resistant species (ponderosa pine and Engelmann spruce), was only 2 to 4°C. Although small, such differences were statistically significant and apparently confer a competitive advantage to establishment of ponderosa pine on warm, dry sites.

Obviously, the time-temperature relationships of these species as measured on single seed lots from specific geographic locations cannot be considered as representative of these species in all locations. Also, the response of seedlings to environmental factors in the greenhouse or growth chamber cannot be directly extrapolated to field conditions. Although the absolute degree of heat tolerance of each species may vary in response to different environmental conditions, it is reasonable to assume that the relative heat tolerance among these species will remain relatively unchanged with ponderosa pine retaining its advantage.

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