How To Estimate Tree Mortality Resulting From Underburning

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Prescribed burning beneath standing timber is widely used to accomplish objectives such as preparing land for reforestation, reducing fuels, improving livestock range, and modifying wildlife habitat. Such burning is usually guided by written plans that set forth general objectives and a firing pattern to accomplish them. The plan typically specifies acceptable levels of mortality in standing trees and describes desired fire behavior, particularly flame length. This article offers two nomograms to facilitate effective planning and successful burning. One nomogram is intended for estimating levels of mortality for various scorch heights among tree species common to the Northwest. A second nomogram is useful for determining the flame length that will keep tree mortality within specifications. The nomograms can also be used to estimate numbers, sizes, and species of trees to leave in a partial cut and also to identify trees that will die and should be salvaged after an unplanned fire.

How the Nomograms Were Developed

The mortality nomogram was derived from a study of 2,356 trees from 43 prescribed fires in Washington, Idaho, Oregon, and Montana. Species included were both Pacific Coast and Intermountain varieties of Douglas-fir (*Pseudotsuga menziesii* (Mirb) Franco), western larch (*Larix occidentalis* Nutt.), western red cedar (*Thuja plicata* Donn.), western hemlock (*Tsuga heterophylla* (Raf. Sarg.), Englemann spruce (*Picea engelmannii* Parry), lodgepole pine (*Pinus contorta* Dougl.) and subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.). Tree height ranged from 20 to 220 feet (6.1 to 67 m) and tree diameter, from 3 to 65 inches (7.6 to 165 cm). Based on species, diameter at breast height, and published equations, computed bark thickness ranged from 0.1 to 4.3 inches (0.25 to 10.9 cm). Crown volume scorched was measured visually in the field and ranged from 0 to 100 percent. Fuels ranged from light natural accumulations to moderate logging slash. Fire behavior fuel models (Anderson 1982) included 8, 11, and 12. The 10-hour time lag National Fire Danger Rating System (Deeming et al. 1977) moisture content ranged from 5 to 25 percent, and the 1000-hour moisture content, from 11 to 30 percent. Fires were conducted from May through October. Mortality was monitored for at least 2 years following the fires. Mortality on the 43 individual plots ranged from 0 to 97 percent. Mortality for the individual species ranged from 15 percent for western larch to 87 percent for western hemlock and Engelmann spruce.

How Fire Kills Trees

Fire kills trees in several ways: crown injury, cambium injury, and root injury. Trees of different species and ages vary in resistance to fire injury. Larger trees have proportionately more foliage above lethal scorch height in a given fire. The amount of crown injury a tree receives depends on scorch height, tree height, and crown base height. Species differ in the timing of bud break and also in the degree to which their buds are shielded from heat. Species with large buds and twigs tend to be more resistant to fire injury. Shallow-rooted species have greater susceptibility to root injury than deep-rooted species.

Fire resistance among trees of different species and sizes mainly depends on differences in bark thickness. Large trees of thick-barked species may have bark 100 times as thick as small trees of thin-barked species. Field determination of bark thickness is time consuming and may be impractical in operational situations, but bark thickness can be estimated from species and diameter.

The Model

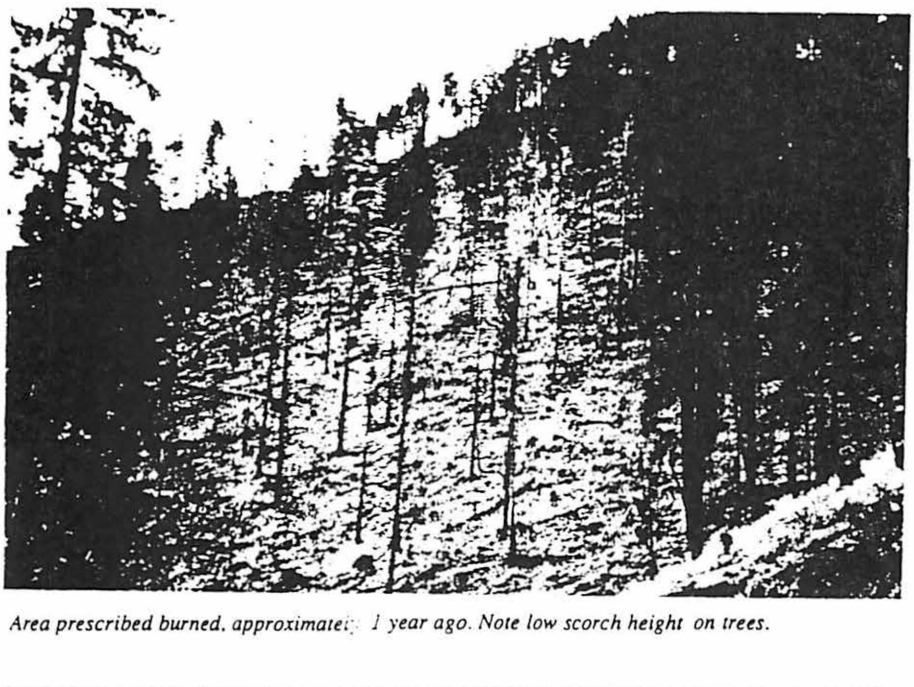
The model assumes that differences in mortality between species are due only to differences in bark thickness. We used published equations to compute bark thickness from species and diameter. Computed bark thickness was then used with observed crown volume scorched (percent) to predict tree mortality.

The prediction equation generated was:

$$P_m = 1/(1 + exp(-(1.466 - 4.862\,B + 1.156\,B^2 + 0.000535\,C^2)))$$

where P_m is the predicted probability of mortality, B is bark thickness in inches, and C is percentage of crown volume scorched. For each species the difference between predicted and observed mortality was less than 15 percent, except Engelmann spruce, which was 30 percent. Predicted mortality was within 20 percent of observed mortality for all except 5 of the 43 sample fires. The model has

Moderate logging-slash area being prescribed burned.



Area prescribed burned, approximately 1 year ago. Note low scorch height on trees.

an underlying assumption of a fire of average duration. Fires of very long duration can kill cambium through even the thickest bark and can result in higher than predicted mortality. Thick layers of dry duff may result in long periods of smoldering even after the flame front has moved through the stand. Heavy concentrations of logs near trees will also result in extended duration of burning and a corresponding underprediction of mortality. Conversely, mortality will likely be overpredicted in light, patchy surface fires.

Mortality Nomogram

The equation was used to develop the mortality nomogram (fig. 1). The nomogram allows the manager to determine the maximum scorch height compatible with a chosen level of mortality, using inputs of species, diameter, tree height, and crown ratio.

The lower left quadrant of the nomogram shows diameter and bark thickness for the seven species studied. These relationships were taken from the literature (Ryan 1982). The upper left quadrant shows the relationship between bark thickness, percentage crown volume scorched, and tree mortality. This is the graphical representation of the mortality prediction equation. The curved lines are mortality contours showing probability of mortality for various combinations of bark thickness and crown volume scorched.

The right side of the nomogram shows the relationship between percent crown volume scorched, crown ratio (upper right quadrant), and tree

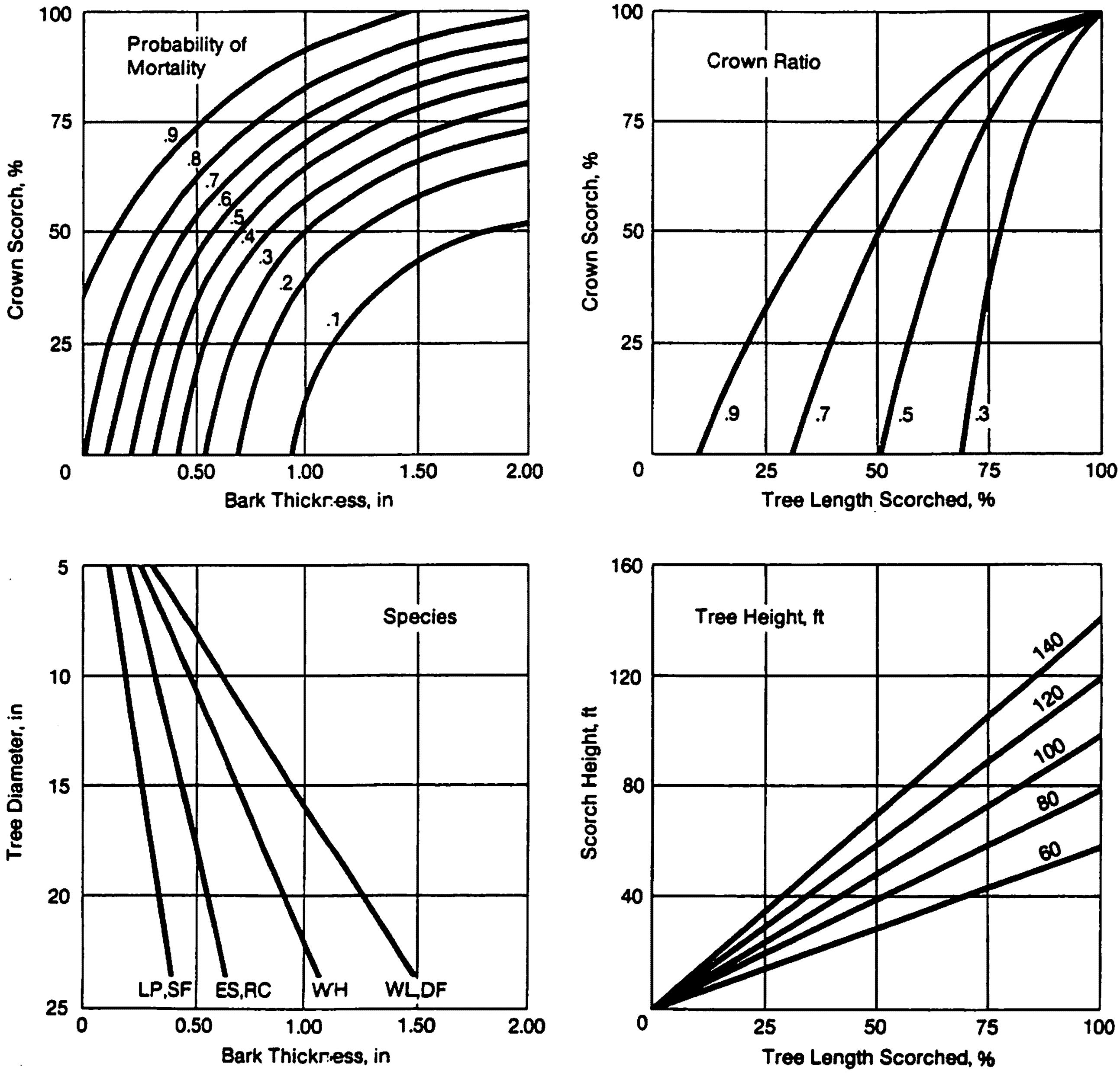


Figure 1—*Tree mortality nomogram for use in prescription development. Key to symbols is as follows: LP identifies lodgepole pine; SF, subalpine fir; ES, Englemann spruce; RC, western red cedar; WH, western hemlock; WL, western larch; and DF, Douglas fir. Figure can be enlarged on copier for field use.*

height and average scorch height (lower right quadrant). We assumed that tree crowns take the form of symmetric parabolas and that scorch heights are uniform within a tree.

Scorch Height Nomogram

Figure 2 is a nomogram for predicting scorch height. The nomogram is based on Van Wagner's (1973) equation for predicting crown scorch height from air temperature, windspeed, and Byram's (1959) fireline intensity. The relationship is shown in terms of both fireline intensity and flame length, based on Byram's (1959) relationship between the two. The figure was developed for midflame windspeeds of 5 miles per hour (8 km/h), an average value for prescribed underburns. Higher windspeeds result in lower levels of crown scorch height for a given flame length or fireline intensity. The differences are small for windspeeds between 0 and 10 miles per hour (0 and 16 km/h). Managers who are interested in solutions for other windspeeds should refer to Van Wagner's equation or graphical representations by Albini (1976).

How To Use the Nomograms

To use the mortality nomogram (fig. 3), choose an acceptable level of mortality (e.g. 20 percent or a 0.2 probability of mortality). Acceptable mortality will depend on the value of the trees and the objectives of the fire. Successful underburning involves choosing and staying within a reasonable level of mortality. Data from these fires indicate that it is

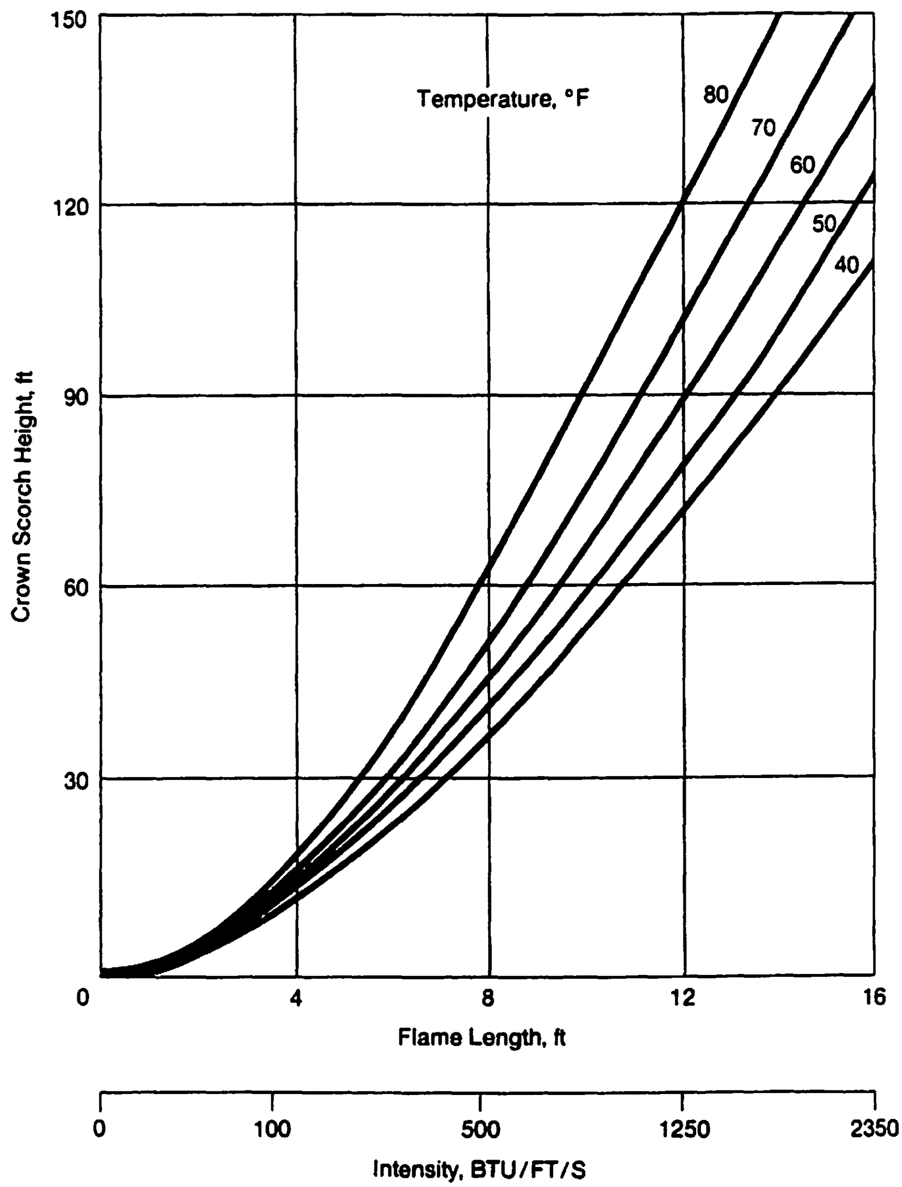


Figure 2—*Van Wagner's crown scorch height model, shown for a midflame windspeed of 5 miles per hour (8 km/h) and a range of ambient temperatures. Figure can be enlarged on copier for field use.*

unreasonable to expect to underburn without some mortality, so it is not possible to select zero mortality.

Once an acceptable level of mortality has been chosen for a particular species, the nomogram can be used

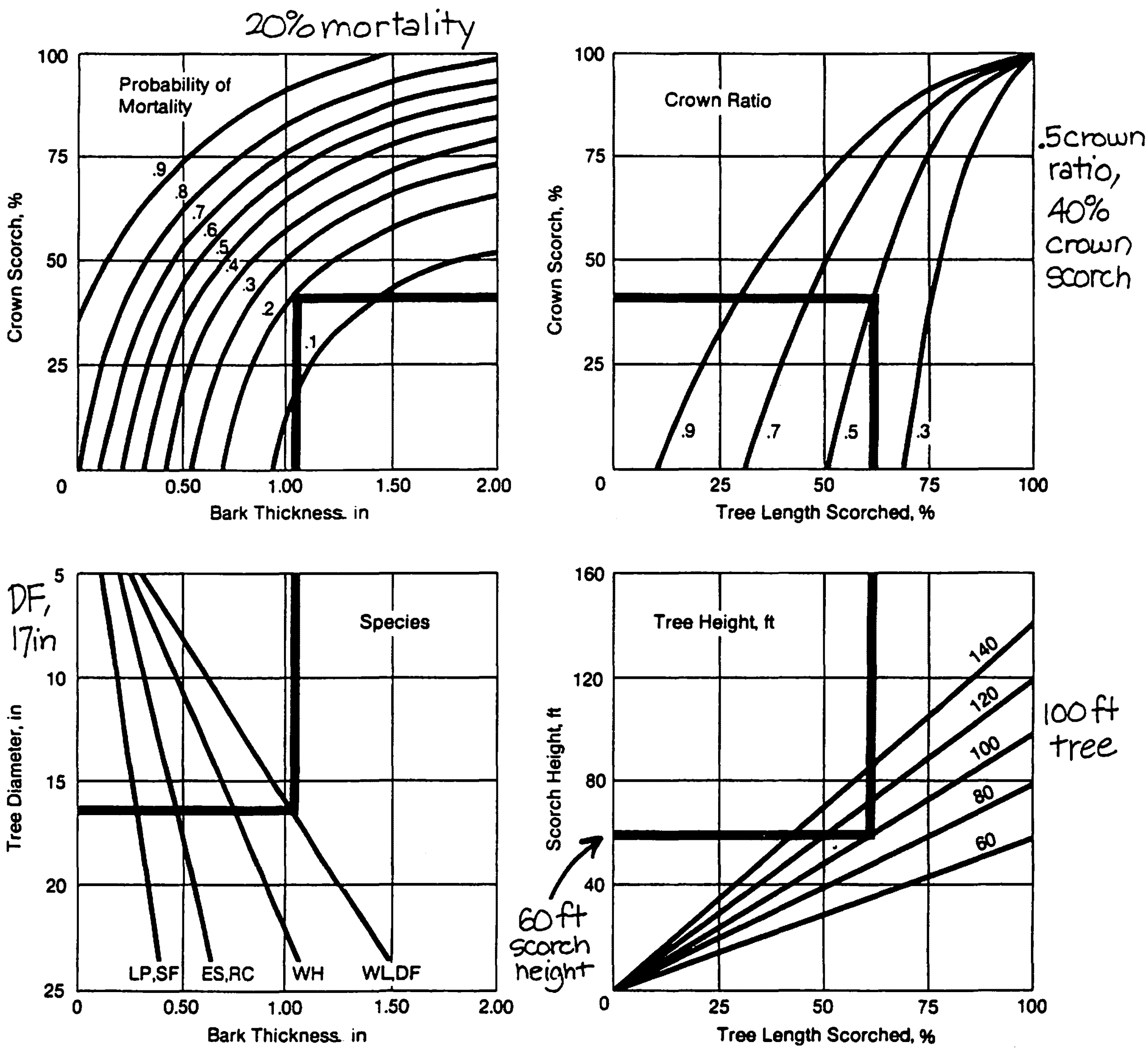


Figure 3—*This figure illustrates the use of the mortality nomogram to set scorch height limits for a prescribed underburn in which the target leave trees are Douglas fir, 17 inches (43.2 cm) in diameter at breast height, 100 feet (131 m) tall with a crown ratio of 0.5, and an acceptable mortality of 20 percent.*

to develop a burning prescription.
For example, consider a shelterwood harvest with Douglas-fir leave trees averaging 17 inches (43.2 cm) in diameter, 100 feet (13.1 m) tall, with a crown ratio of 0.5. Entering the nomogram at the lower left at observed tree diameter, draw a horizontal line until you intersect the correct species line. Then turn a right angle and draw a line straight up. Where the line crosses the top edge of the lower left box, bark thickness can be read, if desired, but it is not necessary to do so. In this example, bark thickness of a 17-inch (43.2 cm) Douglas-fir is seen to be about 1.1 inches (2.8 cm). Continue the line straight up until it intersects the target mortality rate curve (0.2). At this point, turn a right angle again, to the right. This time, when passing from the upper left to the upper right quadrant, it is possible to read off crown volume scorched (percent). This example shows that a little more than 40 percent of the crown volume of these trees may be scorched without exceeding the target mortality of 20 percent. If that is all you want to know, stop there.

To convert percentage crown volume scorched to scorch height, continue working clockwise through the nomogram. Make a right angle turn down intersecting the curve representing the appropriate crown ratio, and then continue down to the appropriate tree height curve. Make another right angle turn to the left. Read allowable scorch height (in this example 60 ft or 18.2 m) off the vertical axis of the lower right quadrant. This is the maximum scorch height that can be had and still limit the mortality to the desired level.

If desired, continue on to figure 4, and determine the maximum allowable flame length. To keep scorch heights to 60 feet (18.2 m) on a 60 °F day, flame lengths should be kept between 9 and 10 feet (2.7 and 3 m). This value can be used in conjunction with fuel models and fire behavior predictions to develop a prescription for burning (Puckett

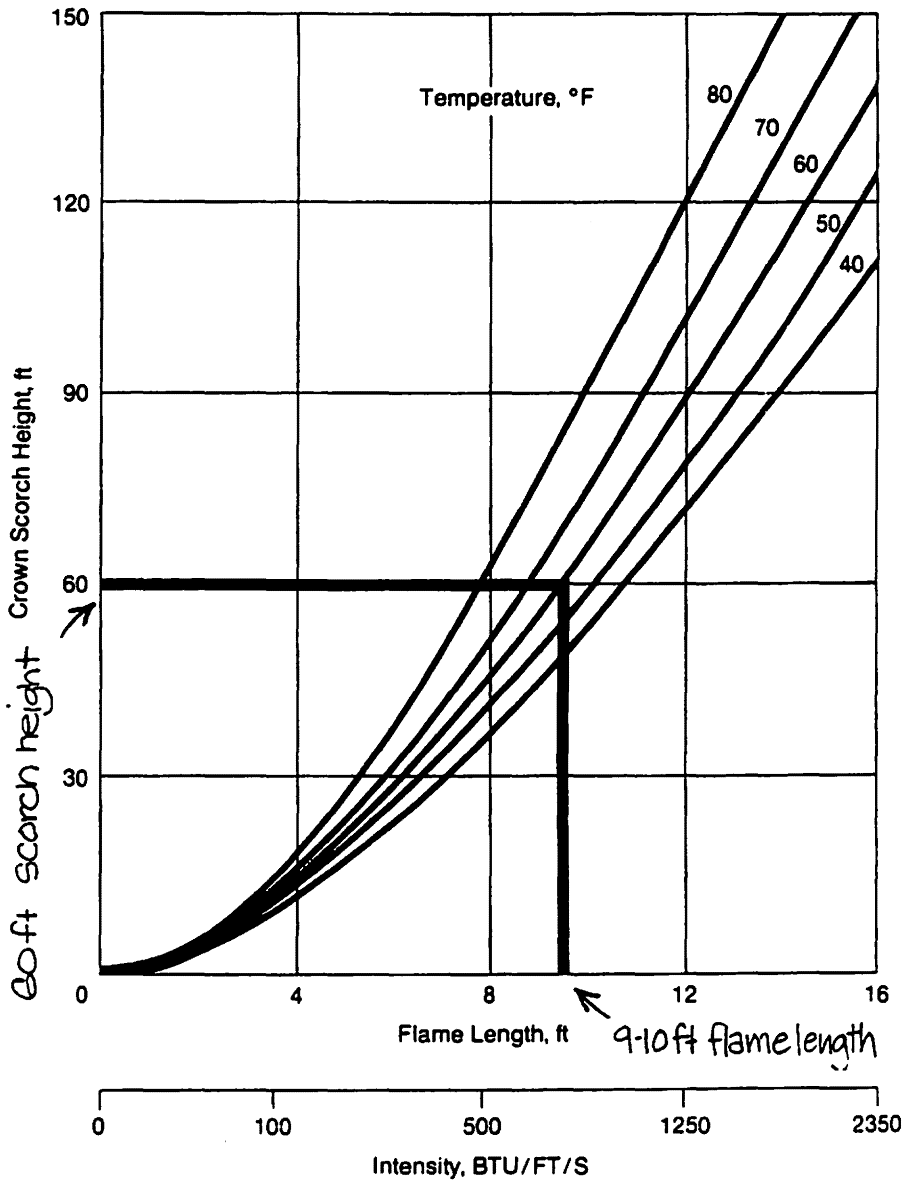


Figure 4—*This figure illustrates the use of the scorch height nomogram to set flame length limits for a prescribed underburn on a 60 °F day, in order to limit scorch height to 60 feet (18.2 m).*

et al. 1979; Rothermel 1983; Andrews 1986). Field crews can attempt to limit the flame length to this level through ignition pattern modifications.

Additional Applications

In some applications of prescribed fire, tree mortality is desired. For example, a manager may wish to eliminate encroaching Douglas fir from a grassland. In these situations, a nomogram can be used to determine the minimum flamelengths necessary to achieve the fire objectives.

A nomogram can also be used earlier in the planning process, at the time of developing the silvicultural prescription. One can determine how many trees of each species to leave in order to achieve the desired number and species proportions after fire treatment. To do this, select a reasonable expected crown scorch height, and for each component of the stand work in from both sides to find the expected mortality level in the upper left quadrant of the nomogram (fig. 1).

The nomogram can be used to develop a marking guide for a salvage sale after fire injury has occurred. In this case, crown volume scorched can be observed; therefore, the right side of the nomogram is not needed. Work backward through the left half of the nomogram to find the minimum diameter for leave trees. ■

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