Silva Fennica 1993, Vol. 27 N:o 4: 277–281

Tree survival in wildfires

Taneli Kolström & Seppo Kellomäki

TIIVISTELMÄ: PUIDEN SÄILYMINEN ELOSSA METSÄPALOSSA

Kolström, T. & Kellomäki, S. 1993. Tree survival in wildfires. Tiivistelmä: Puiden säilyminen elossa metsäpalossa. Silva Fennica 27(4): 277–281.

The survival of forest tree species in wildfires was examined on two burnt stands. Norway spruce and birches proved to be sensitive to the effects of wildfire; almost all individuals of these tree species were killed by the fires. Scots pine was more tolerable to the effects of wildfire; i.e. one out of five pines survived. Fire tolerance increased as tree size increased.

Puiden säilymistä elossa metsäpalossa tutkittiin kahdella palaneella alueella. Kuusi ja koivu osoittautuivat herkiksi tulelle, ja nämä puulajit kuolivat melkein kokonaan metsäpalossa. Mänty sieti tulta jossain määrin ja viidennes paloalueen männyistä säilyi hengissä. Todennäköisyys säilyä hengissä kasvoi puun koon myötä.

Keywords: *Pinus sylvestris*, *Picea abies*, *Betula* spp., mortality, forest fires.
FDC 435 + 181.4

Author's addresses: *Kolström:* The Finnish Forest Research Institute, Joensuu Research Station, P.O. Box 68, FIN-80101 Joensuu, Finland; *Kellomäki:* University of Joensuu, Faculty of Forestry, P.O. Box 111, FIN-80101 Joensuu, Finland.

Accepted January 21, 1994

1 Introduction

Fire has played a major role in natural vegetation succession in boreal and temperate forests (see e.g. Sarvas 1937, Sirén 1955, Kozlowski and Ahlgren 1974). Spurr and Barnes (1980) formulate this by saying that "Fire is the dominant factor in forest history. The great majority of the forests of the world – excepting only the perpetually wet rain forests ... and the wettest belts of the tropics – have been burned over at more or less frequent intervals for many thousands of years." In this context they listed the following major functions and processes that are regulated by fire: regeneration and reproduction, seedbed preparation and dry-matter accumulation, competition reduction, nutrition, thinning, sanitation, succession, and wildlife, all of which are factors having powerful effect on growth and development of tree stands.

In the spruce dominated forests of northern Finland the interval between wildfires has been about 450 years (Hyvärinen and Sepponen 1988) and in southern Finland 238 ± 48 years (Tolonen 1978). Haapanen and Siitonen (1978) found the average time interval between fires to be 120 years in pine dominated stands. According to Zackrisson (1977) the time interval in pine stands of northern Sweden has been 46 ± 22 years on sites of *Calluna* type and in mixed stands

122 ± 81 years on sites of *Vaccinium myrtillus* type. Ahlgren (1974), however states that the fire hazard is usually less in mixed stands. In the boreal forests of North America, the estimated recurrence interval has varied between 50 and 200 years (Oliver and Larson 1990). Human impact has made fires more controlled and in some areas also more frequent (Tolonen 1978). Fires are classified into ground fires, surface fires, and crown fires according to the level at which they burn (Spurr and Barnes 1980). Surface fires are the most common type and they burn over the forest floor consuming humus and litter, killing plants and shrubs, and scorching the bases and crowns of trees.

In the past, shifting cultivation in agriculture and prescribed burning in forestry were the most common ways of using fire for management purposes (Viro 1969). Nowadays, the use of fire is regaining emphasis especially in the care of conservation areas. However, our knowledge of using wildfire for management purposes is limited. Of the few studies on the subject, Kalabokidis and Wakimoto (1992) examined the effects of fire on tree mortality in uneven-aged managed *Pinus ponderosa/Pseudotsuga menziesii* stands and found out that the use of prescribed fire is well-suited for management purposes. The differential fire resistance of tree species makes it possible.

The aim of this study was to examine which characteristics of trees are related to the survival of trees in wildfires. The effect of tree species, the survival of trees in wildfires and the size of trees that survived is analyzed.

2 Material and methods

The study was conducted on two sites in North Karelia (about 62°N, 30°E, c. 165 m asl) located in Patvinsuo National Park. The first one (Surkansuo) was classified as being of the *Myrtillus*-type in the Finnish classification (and thus of medium fertility) while the second one (Lahnasuo) was of the *Vaccinium*-type (rather poor in nutrients) (Cajander 1926). These two areas were burnt on 26.–27.6.1991. The fire was mainly a surface fire. The burnt area in both cases was c. 1.1 ha. In Surkansuo the burning was thorough but in Lahnasuo a small part of the area remained unburnt.

The stand of Surkansuo was a mixture of Scots pine (*Pinus sylvestris* L.) (37 % of the basal area), Norway spruce (*Picea abies* Karst.) (45 %) and birch (*Betula* spp.) (18 %). This 90-year-old stand had not been managed. The stand basal area was 34 m^2 ha^{-1}. There were some pines over 200 years of age in the area. Lahnasuo area was dominated by pines (92 % of the basal area) about 40 years of age. The stand basal area was 17 m^2 ha^{-1}.

Prior to being burnt, one permanent sample plot was founded in each stand. The size of the plot in Surkansuo was 40 m × 25 m and in Lahnasuo 30 m × 25 m. The plots were measured before burning. Forest site type, soil type, and soil stoniness were determined. All trees in plots were measured for their diameter at breast height, thickness of bark (sum of bark thickness on opposite sides), and location. Height of the living crown bottom, height of the dead crown bottom, and the width of the tree crown were measured from sample trees (30 for each plot). Trees that were still alive and those that had died in the fire were tallied in September 1992. The trees in the unburnt area and trees that had fallen over prior to the burning were ignored. The total number of trees analysed was 335.

A model for the height of the living crown bottom was estimated on the basis of data collected from the pine sample trees; i.e.

$$H_c = 0.3396 \cdot d_{1.3}^{1.018435}$$
$$R^2 = 0.934 \quad S_e = 0.407 \quad F(1,24) = 165.302 \qquad (1)$$

in which H_c is the height of the living crown bottom (m) and $d_{1.3}$ is the diameter at breast height (cm). The estimated model was used to calculate the height of the living crown bottom for the rest of the pines.

A logistic regression model was used in estimating the probability for pines to survive a forest fire. The general form of the logistic regression model is

$$prob(x) = \frac{e^z}{1+e^z} \qquad (2)$$

where Z is the linear combination

$$Z = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n \qquad (3)$$

where $\beta_0, \beta_1, \ldots, \beta_n$ are parameters and $X_1, \ldots, X_n$ independent variables.

3 Results

Scots pine was the only tree species that was able to partly survive in fire. Almost one out of five pines was alive after the fire. Spruces, birches, and other species were almost entirely killed by the fire with only a few percent of the spruces and birches being alive one year after the fire (Table 1).

Table 1. Proportion of dead and live trees after the fire in tree species.

	Dead, %	Live, %	Number of trees
Pine	82.2	17.8	135
Spruce	98.9	1.1	94
Birch	98.0	2.0	101
Other	100.0	0.0	5
Total	91.9	8.1	335

The live pines were bigger trees than those died in the fire ($p < 0.001$, $F(1,123) = 20.071$, Fig. 1). The mean diameter of live trees was 15.8 cm (SD = 8.1) while that of dead pines was 8.4 cm (SD = 7.0). There was also a statistically significant difference ($p < 0.001$, $F(1,122) = 14.629$) in bark thickness between live and dead trees. The mean bark thickness of live trees (6.5 mm) was almost twice that of dead trees (3.4 mm). Trees survived fire better if the height of the living crown bottom was higher (Fig. 2).

The probability for pines to survive a forest fire was estimated using a logistic regression model. Only pines with the breast height diameter of less than 25 cm were included in the model because the diameter distribution was not continuous for pines thicker than 25 cm. The diameter at breast height (1.3 m) was the only variable included into the model (Table 2). The model classified 83.97 % of pines correctly. Goodness of fit of the model has the value 97.161 (df = 129, sig. = 0.9835). A pine with diameter at the breast height of 20 cm has a possibility of 0.5 to survive a forest fire (Fig. 3).

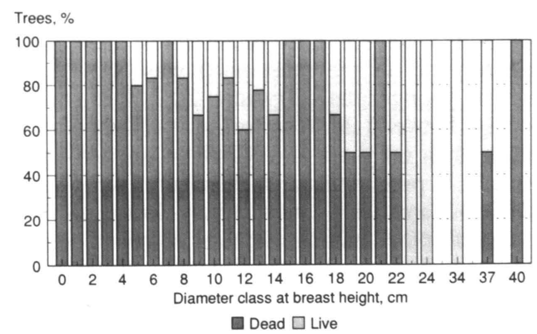

Fig. 1. The proportion of dead and live pines after the fire by diameter classes (1 cm). Diameter class 0 consists of trees shorter than 1.3 m.

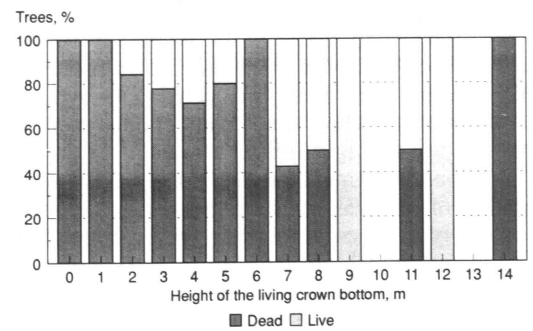

Fig. 2. The proportion of live and dead pines after the fire arranged according to the heigth of the living crown bottom. Class 0 consists of trees with the height of the living crown bottom less than 1 m from the ground level.

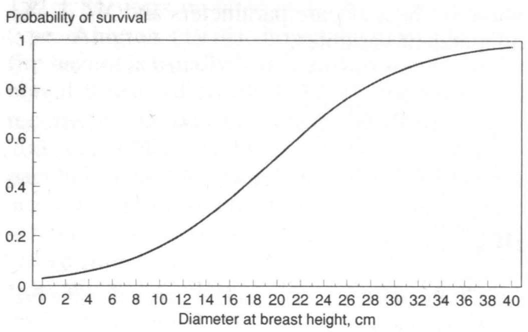

Fig. 3. The probability for Scots pine surviving a surface forest fire.

Table 2. Logistic regression model of Scots pine survival in a forest fire.

Variable	Coefficient	Standard error	Wald	df	Sig.
Constant	–3.4655	0.5854	35.0486	1	0.0000
$d_{1.3}$	0.178	0.0427	17.4019	1	0.0000

4 Discussion

The data used in the study was of small size and confined to two different areas burnt during the same summer. Scots pine was present in both areas. Norway spruce and birches were present in only the other burnt area, and thus on only one sample plot. Therefore, while the data gives very limited possibilities for generalizations, it does give an idea as to how different tree species behave in forest fires. The effect of fire on spruces and birches is very clear; these tree species are absolutely intolerant to fire. Large Scots pines, on the other hand, can survive forest fires. This presupposes that the fire does not spread to the crowns of the trees or the development of heat and smoke is not too intense (Uggla 1958). For example, more red pines (*Pinus resinosa*) are destroyed in fires due to the crown damage rather than stem damage (Van Wagner 1970). The temperature required to destroy the crown is less than that which destroys the cambium of the stem. The thick bark of the stem also prevents the phloem from being desiccated. The bark of spruces and birches in not thick enough to prevent injuries (Uggla 1958).

The presented model used to calculate the probability of survival gives a rough estimate of the mortality of pines as related to forest fires. The estimated model can be used in predicting the survival of pines in forest fire (see e.g. Keane et al. 1989). It should be noticed, however, that the fire employed in this study was a surface fire and did not reach the crowns of the trees. While no measurements were made of the intensity of the fire, it could not have been very high because a small part of Lahnasuo remained unburnt. The characteristics of fire, (i.e., frequency, intensity, and burning pattern) are primarily controlled by climate, fuel accumulation, and flammability, and soil-site conditions (Spurr and Barnes 1980). The allometric relationship in trees explains the similar effect that diameter at the breast height, bark thickness, and height of the living crown bottom have on the mortality of pines in forest fires. Therefore, it was not surprising that the diameter at breast height was the only variable included in the model for predicting the survival of pines.

According to Saari (1923) fires in relatively young stands (20–60 years) and in uneven-aged stands were most common, 20 % and 57 % of burned area for stands, respectively. Unfortunately Saari (1923) did not measure the survival of trees in single stands but he classified the nature of damages in different stands. The proportion of severe fires (main forest destroyed entirely or for the most part) was 50.0 % in stands younger than 20 years, 20.7 % in stands of age between 20 to 60 years, 9.4 % in stands older than 60 years and 7.2 % in uneven-aged stands. In pure pine stands the figures were 63.6, 27.7, 4.8 and 5.1 %, respectively. In the present study all pines having diameter at breast height less than 5 cm died in the fire and a 20-cm pine had a possibility of 0.5 to survive. This indicates that the effect of fire in the plots was strong.

The knowledge of the behaviour of different tree species in forest fires is very limited. Some pine species can utilize (and indeed need) the fire for their natural regeneration. The fire-adapted characteristics of jack pine (*Pinus banksiana*) are well-known, but pitch pine (*Pinus rigida*) and pond pine (*Pinus serotina*) also have serotinous cones (see e.g. Ahlgren 1974, Goldammer 1978). Pines such as pitch pine, shortleaf pine (*Pinus echinata*), and pond pine can develop basal crooks that bring dormant buds in contact with mineral soil. Thus, they are able to form a new terminal shoot from a protected bud in the bole bark and to develop new branches after a fire (Little and Mergen 1966). There is evident need for more knowledge about fires and the behaviour of different tree species in fires. In future, fires will be one of the most important factors made use of in the management of national parks and other conservation areas.

References

Ahlgren, C.E. 1974. Effect of fires on temperate forests: North Central United States. In: Kozlowski, T.T. & Ahlgren, C.E. (eds.). Fire and ecosystems. Academic Press, New York. p. 195–223.

Cajander, A.K. 1949. Forest types and their significance. Acta Forestalia Fennica 56. 71 p.

Goldammer, J.G. 1978. Feuerökologie und Feuer-Management. Albert-Ludwigs-Universität Freiburg, Freiburger Waldschutz-Abhandlungen, Band 1, Heft 1. 150 p.

Haapanen, A. & Siitonen, P. 1978. Kulojen esiintyminen Ulvinsalon luonnonpuistossa. Summary: Forest fires in Ulvinsalo strict nature reserve. Silva Fennica 12(3): 187–200.

Hyvärinen, V. & Sepponen, P. 1988. Kivalon alueen paksusammalkuusikoiden puulaji- ja metsäpalohistoriaa. Summary: Tree species history and local forest fires in the Kivalo area of Northern Finland. Folia Forestalia 720. 26 p.

Kalabodikis, K.D. & Wakimoto, R.H. 1992. Prescribed burning in uneven-aged stand management of Ponderosa pine/Douglas fir forests. Journal of Environmental Management 34: 221–235.

Keane, R.E., Arno, S.F. & Brown, J.K. 1989. FIRE-SUM – an ecological process model for fire succession in western conifer forests. USDA Forest Service, Intermountain Research Station, General Technical Report, INT-266. 76 p.

Kozlowski, T.T. & Ahlgren, C.E. 1974. (eds.). Fire and ecosystems. Academic Press, New York. 542 p.

Little, S. & Mergen, F. 1966. External and internal changes associated with basal-crook formation in pitch and shortleaf pines. Forest Science 12: 268–275.

Oliver, C.D. & Larson, B.C. 1990. Forest stand dynamics. McGraw-Hill, Inc., New York. 467 p.

Saari, E. 1923. Kuloista: Summary: Forest fires in Finland. Acta Forestalia Fennica 26. 155 p.

Sarvas, R. 1937. Kuloalojen luontaisesta metsittymisestä. Referat: Über die natürliche Bewaldung der Waldbrandflächen. Acta Forestalia Fennica 46(1). 47 p.

Sirén, G. 1955. The development of spruce forest on raw humus sites in northern Finland and its ecology. Lyhennelmä: Pohjois-Suomen paksusammalkankaiden kuusimetsien kehityksestä ja sen ekologiasta. Acta Forestalia Fennica 62(4). 408 p.

Spurr, S.H. & Barnes, B.V. 1980. Forest ecology. Third edition. John Wiley & Sons, New York. 687 p.

Tolonen, M. 1978. Palaecology of Lake Ahvenainen, S. Finland. I. Pollen and charcoal analysis and their relation to human impact. Annales Botanici Fennici 15. 208 p.

Uggla, E. 1958. Skogsbrandfält i Muddus nationalpark. Summary: Forest fire areas in Muddus national park, northern Sweden. Acta Phytogeographica Suecica 41. 116 p.

Van Wagner, C.E. 1970. Fire and red pine. Proc. 10th Annu. Tall Timbers Fire Ecol. Conf. p. 211–214.

Viro, P.J. 1969. Prescribed burning in forestry. Communicationes Instituti Forestalis Fenniae 67(7). 49 p.

Zackrisson, O. 1977. Influence of forest fires on the North Swedish boreal forest. Oikos 29: 22–32.

Total of 19 references