How does fire kill trees?

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Background

Each year wildland fires kill and injure trees on millions of forested hectares globally, causing both positive and negative impacts to plant and animal biodiversity, carbon storage, hydrologic processes, and ecosystem services. The underlying mechanisms of fire-caused tree mortality remain poorly understood, however, limiting the ability to accurately predict mortality, estimate fire-driven feedbacks to the global carbon cycle, extrapolate to novel future conditions, and implement appropriate management actions to increase forest resilience to wildfire.

Mechanisms of fire-caused tree mortality

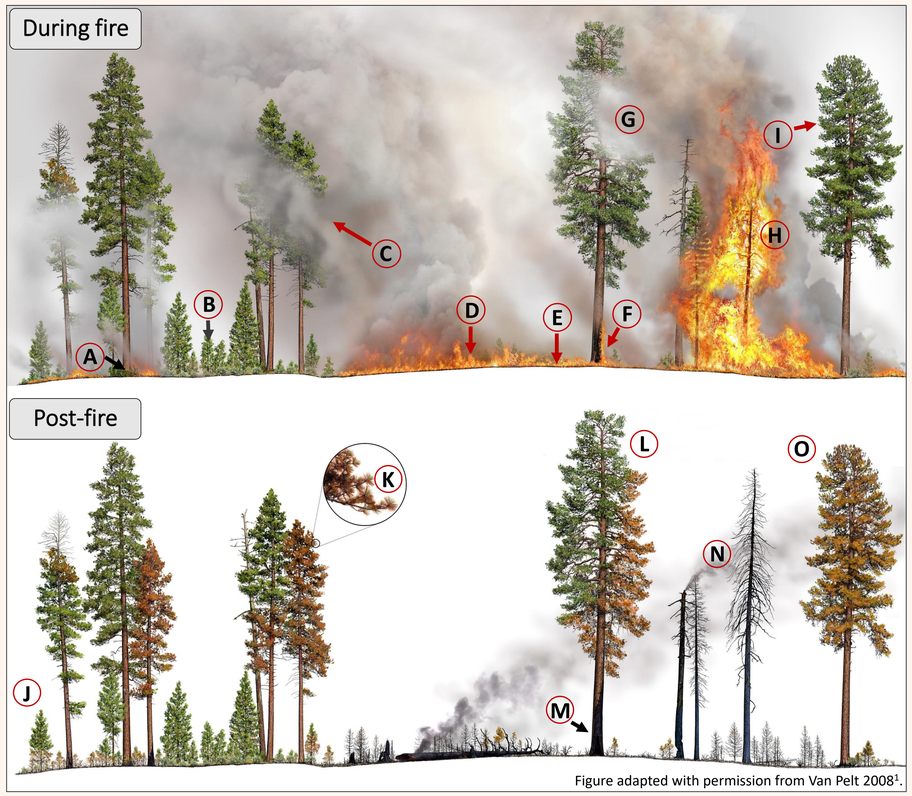


Figure adapted with permission from Van Pelt 2008[1].

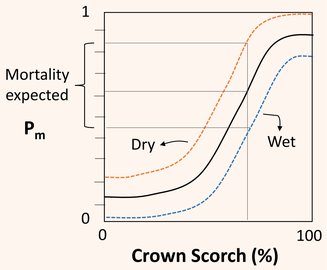
Pre-fire – Drought and competition can increase vulnerability to fire through increased plant-stress and by influencing the physical fire environment and increasing fire intensity.

During fire – Injuries occur to different parts of trees through heat transfer processes such as *convection*, *conduction* and *radiation*, and the assumed mechanism of tree death from fire is via heat injuries to crown, stem, and root tissues.

Post-fire – Mortality of fire-injured trees may be delayed post-fire. Fire-injured trees are more susceptible to other stressors, such as beetle attack and drought. Trees with adaptive traits—protective buds or ability to re-sprout—can recover more easily post-fire.

A. Thick bark insulates
B. Thin bark provides little insulation
C. Convection
D. Conduction and smoldering combustion
E. Soil heating and root injury
F. Bole heating and charring
G. Crown scorch and bud kill via convective or radiative heat (tissue occurs death when temperatures >60°C for 1 sec)
H. Flames consume live needles and kill buds
I. Radiation
J. Low scorch height may be ~50% of small tree
K. Needles scorched but buds remain alive
L. Canopy volume scorched ~30%
M. Heating to the stem can impair translocation of water, nutrients, and photosynthates
N. 100% canopy consumed
O. 100% canopy scorched

Modeling fire-induced tree mortality



- Crown scorch is widely considered the most important measure of fire-caused tree injury[2] because it:
  - Reduces short-term capacity for photosynthesis.
  - Requires stored carbon reserves to rebuild leaves.
- Bark thickness is another important factor because it protects the tree's main stem from heating.
- Factoring in climatic water stress (i.e. wet, dry) may improve predictions of post-fire tree death.[4]

Knowledge gaps and research needs

Fire-induced tree mortality is a result of a complex suite of direct and indirect factors. Disturbance interactions pre- and post-fire, competition, season, and soil type may all impact mortality. Current models attempt to incorporate some of these complexities, but their applicability for a wide range of species across geographic regions is uncertain.

Research needs:

- Further physiological research to identify cellular-level mechanisms causing mortality.
- Investigation into the connection between heating and physiological damage in different tissues, and how that varies with life stage, season, and tree physical characteristics.
- Further exploration of whether pre-fire tree stress—due to drought stress, disease, competition—influences physiological response to fire, repair post-fire, and ultimately, tree mortality.

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References

[1]Adapted from Van Pelt, R., 2008. Identifying old trees and forests in eastern Washington. Washington State Department of Natural Resources.
[2]Sieg, C.H. et al., 2006. Best predictors for postfire mortality of ponderosa pine trees in the Intermountain West. *For. Sci.* 52, 718-728.
[3]Midgley, J.J. et al., 2011. How do fires kill plants? The hydraulic death hypothesis and Cape Proteaceae "fire-resisters". *S. Afr. J. Bot.* 77, 381-386.
[4]Mantgem, et al., 2013. Climatic stress increases forest fire severity across the western United States. *Ecol. Lett.* 16, 1151-1156.