

Science You Can Use *in 5 minutes*

Clearing the Air: The truth about smoldering duff

When smoke from a prescribed fire pops up on an otherwise clear day, people may question the rationale behind the haze. After all, smoke from wildland fires can be a major health hazard due to fine particulates (PM_{2.5}) and gaseous pollutants. At the same time, prescribed fires are one of our best tools to reduce hazardous fuels and restore fire-prone forests and grasslands. In recent years, land managers have been asked to expand the use of prescribed fire, but smoke is consistently cited as a barrier. [New research](#) by USDA Forest Service scientists sheds light on one key smoke challenge—long-term smoldering of decomposed organic matter, also known as duff.

The impact of smoke from fires depends on the emissions and heat released by the fire, the terrain, and how the atmosphere transports and disperses the smoke. Emissions are calculated using a number called an emissions factor (EF) that is specific to each pollutant. An EF estimates the amount of a pollutant released per ton of fuel burned. Emissions factors are influenced by the many variables that

affect combustion, including fire behavior (flaming or smoldering) and the properties of the fuel or vegetation (size, shape, condition, among others).

Most wildland fuels burn predominantly by flaming combustion. However, duff, peat, and large woody fuels usually burn without producing flames—that is, they smolder. Smoldering converts heated fuels into char, which is very inefficient. The EF for a common pollutant like PM_{2.5} is typically much higher in smoldering combustion than flaming combustion. Because smoldering produces less heat, the resulting smoke stays closer

to the ground and may be slow to disperse. For these reasons, PM_{2.5} and other pollutants emitted by smoldering combustion pose greater health hazards to nearby communities.

Duff is an important fuel component in conifer forests of the western United States. However, in the [First Order Fire Effects Model](#) (FOFEM), a widely used tool for planning prescribed burns, the default EF used to predict PM_{2.5} emissions from smoldering duff are based on studies of logging slash and other fuel types, not duff. Scientists have speculated that smoldering behavior and the resulting emissions would be



Smoldering duff continues to produce smoke after the flames die down. USDA Forest Service photo by L. Faulkenberry.

considerably different for duff, which could have big implications for smoke management.

To address the knowledge gap in duff emissions, Forest Service scientist Shawn Urbanski led a series of smoldering experiments in partnership with Oregon State University, using Douglas-fir duff from eastern Oregon. They found that previous estimates of EFs representing smoldering duff may underestimate $PM_{2.5}$ emissions from western conifer forests. In FOFEM, the default EF for $PM_{2.5}$ from smoldering duff is less than half of this study's estimate. Therefore, managers concerned with smoldering duff in western forests should use the *expanded* EF for $PM_{2.5}$ in FOFEM, which provides a more accurate estimate of duff emissions.

This research builds on years of work describing EFs and providing a better understanding of emissions from wildland fires. "Smoke from wildland fires is a given. With better information, we can more effectively plan prescribed burns and reduce smoke impacts to both firefighters and nearby communities," said Urbanski. The work is not done—scientists hope to expand the experiments to larger fuel beds and to examine emissions from large woody fuels at a new combustion research facility at the [Missoula Fire Sciences Laboratory](#).

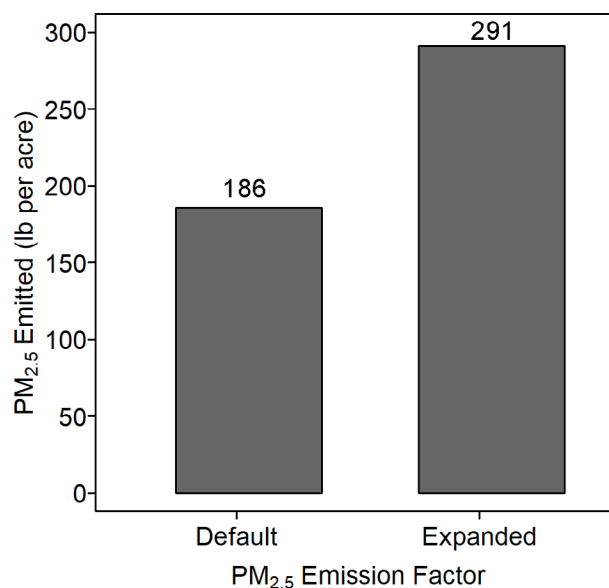
Further Reading

Urbanski, S.P.; Kay, S.; Baker, S.P.; et al. 2024. [Pollutant emission factors for smoldering conifer forest duff](#). Gen. Tech. Rep. RMRS-GTR-444. Fort Collins, CO: USDA, FS, RMRS. 45 p.

Clark, N.; Urbanski, S.; Goodrick, S. 2024. [Smoke 101 and differences between wildfire and prescribed fire smoke in the western U.S. Science You Can Use 101](#). Fort Collins, CO: USDA, FS, RMRS. 8 p.

Management Considerations

- The $PM_{2.5}$ emissions factor ($EF_{PM_{2.5}}$) commonly used for smoldering duff significantly underestimates emissions from smoldering duff in western conifer forests.
- Managers who use the First Order Fire Effects Model, or FOFEM, should use the expanded EF for $PM_{2.5}$ to estimate emissions from smoldering conifer duff.
- Because smoke from smoldering tends to remain near the surface, it can pose outsized health risks to fire crews and nearby communities.



FOFEM predicted $PM_{2.5}$ emissions from smoldering duff for a spring prescribed fire in interior Douglas-fir forest using FOFEM's default (left) and expanded (right) emission factors. Emissions shown are for duff only.

Featured Scientist

[Shawn Urbanski](#) is a Research Physical Scientist who addresses multiple aspects of wildland fire smoke: which pollutants are in smoke, the amount of smoke produced by fires, where the smoke goes, and the impact of smoke on air quality.

[Signe Leirfallom](#) is the author of this Science You Can Use.



[Rocky Mountain Research Station](#) is part of Forest Service Research and Development. While anchored in the geography of the West, our research is global in scale.

Our science improves lives and landscapes.