Wildland fire smoke as a vector for airborne microbes: concentrations, transport & health implications

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Wildland fire smoke has long been recognized as primarily a mixture of gases and particulate matter with the potential to impact air quality and human health. New research has revealed that smoke also carries elevated concentrations of viable microbes (bacteria and fungi) that have the potential to travel substantial distances from fire sources. Understanding smoke microbial emissions is critical for assessing risks to wildland firefighters and smoke-affected populations, as well as evaluating the ecological implications of fire-driven microbial dispersal. This research brief dives into the recent collaborative pyraoerobiology research led by the University of Idaho, which 1) provides the first quantifications of microbial concentrations and emission factors for wildland fire smoke, 2) examines microbial composition patterns across smoke plumes, 3) establishes that smoke-borne fungal pathogens retain their capacity to cause disease, and 4) demonstrates that fire likely serves as a significant mechanism for long-distance microbial transport.

The Northern Rockies Fire Science Network (NRFSN) serves as a go-to resource for managers and scientists involved in fire and fuels management in the Northern Rockies. Funded by the Joint Fire Science Program, NRFSN is one of 15 Fire Science Exchange Networks across the country. The network facilitates knowledge exchange by bringing people together to strengthen collaborations, synthesize science, and enhance science application around critical management issues.

NORTHERN ROCKIES FIRE SCIENCE NETWORK

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KEY MANAGEMENT FINDINGS

- Multiple human and animal fungal pathogens isolated from smoke have been confirmed capable of causing disease in laboratory mouse models.
- Wildland firefighters working near active high-intensity crown fires could inhale roughly ~614,000 fungal spores and over 3 million bacterial cells per hour, compared to 140,000 spores and 1.8 million bacteria in background conditions.
- Given much higher concentrations of bacteria and fungi in smoke, sheer inhalation volume (rather than microbe type) might be an important consideration for health risk.
- Transportation of bacterial cells for over 17km from the combustion zone has been shown in modeling results, demonstrating potential for substantial dispersal.
- Wildland fire smoke habors a diverse array of ecologically important and beneficial microbes, suggesting that smoke plumes may function as an aerial refugium, temporarily sheltering these organisms during fire events before depositing them back into ecosystems.
- Fire management practices that affect smoke intensity may influence bioaerosol emissions and associated exposures.

METHODS

Smoke was sampled from multiple wildfires between 2019 and 2024 across five U.S. states: California (oak woodlands and mixed-conifer forests), Utah (subalpine forest), Idaho (mixed-conifer forests), Florida (pine forests), and Kansas (tallgrass prairie). Sampling locations represented contrasting fire regimes, including frequently burned grasslands with one- to two-year fire return intervals and infrequently burned forests. The Utah sites on the Fishlake National Forest included high-intensity prescribed burns in subalpine fir and quaking aspen forests that had accumulated high fuel loads due to a western spruce budworm outbreak and 50 years of fire suppression.

Researchers utilized drones—uncrewed aircraft systems (UAS)—equipped with air sampling and environmental monitoring payloads to acquire samples before and during wildland fires. For smoke samples, they flew the UAS directly into the smoke near the combustion source where they collected 5–20 minute duration samples.

RESULTS

Bioareosol Concentrations and Cell Viability

Fungal spores were significantly elevated in smoke compared to background air across all ecosystems sampled. In Kansas tallgrass prairie, smoke contained over five times as many spores compared to background concentrations. In Utah subalpine forest, smoke contained four times as many spores compared to background levels. Although spore concentrations in smoke consistently exceeded background levels at each site, prairie smoke contained fewer spores than even the baseline background at the forest location, highlighting that absolute concentrations vary substantially by ecosystem while fire consistently elevates local concentrations.

Bacterial cell concentrations in forest fire smoke showed 2-4x increases over background conditions, with considerable variation across sampling. This variability likely reflects differences in season (spring vs. fall sampling), fire intensity, fuel composition, and meteorological conditions. 70–82% of bacterial cells appeared to be viable across both smoke and background samples. Smoke contained ~2-3 times as many viable bacterial cells as ambient air.

Microbial Emissions Factors

This research has produced the first emission factors for bacteria and fungi from wildland fires. Emission factors were calculated using the carbon mass balance method, where background-corrected bioaerosol concentrations were related to carbon concentrations in smoke and the carbon fraction of consumed fuels.

Figure 1. Sampling wildland fire smoke utilizing uncrewed aircraft systems (UAS) at the Konza Prarie Biological Station in Kansas.

Application of these emission factors to the 2025 Monroe Canyon Fire in Utah (14,827 ha burned) estimated that 644 metric tons of bioaerosol mass were emitted, with fungal spores comprising 99% of this mass (Fig. 2).

Patterns Across Smoke Plumes

Using coordinated UAS flights, researchers characterized how microbial composition changes as smoke travels. This "3D smoke transect" illustrated how the contribution of terrestrial sources, such as fuels and soils, to smoke microbes decreased with distance from the fire, while similarity to background air increased. Fire return intervals of the ecosystems burned also influenced smoke microbial composition with distinct assemblages in sites with different fire histories.

Microbial diversity decreased with distance from the combustion source, paralleling declines in PM2.5 (particulate matter 2.5 microns or less) concentrations. Hazardous air quality conditions

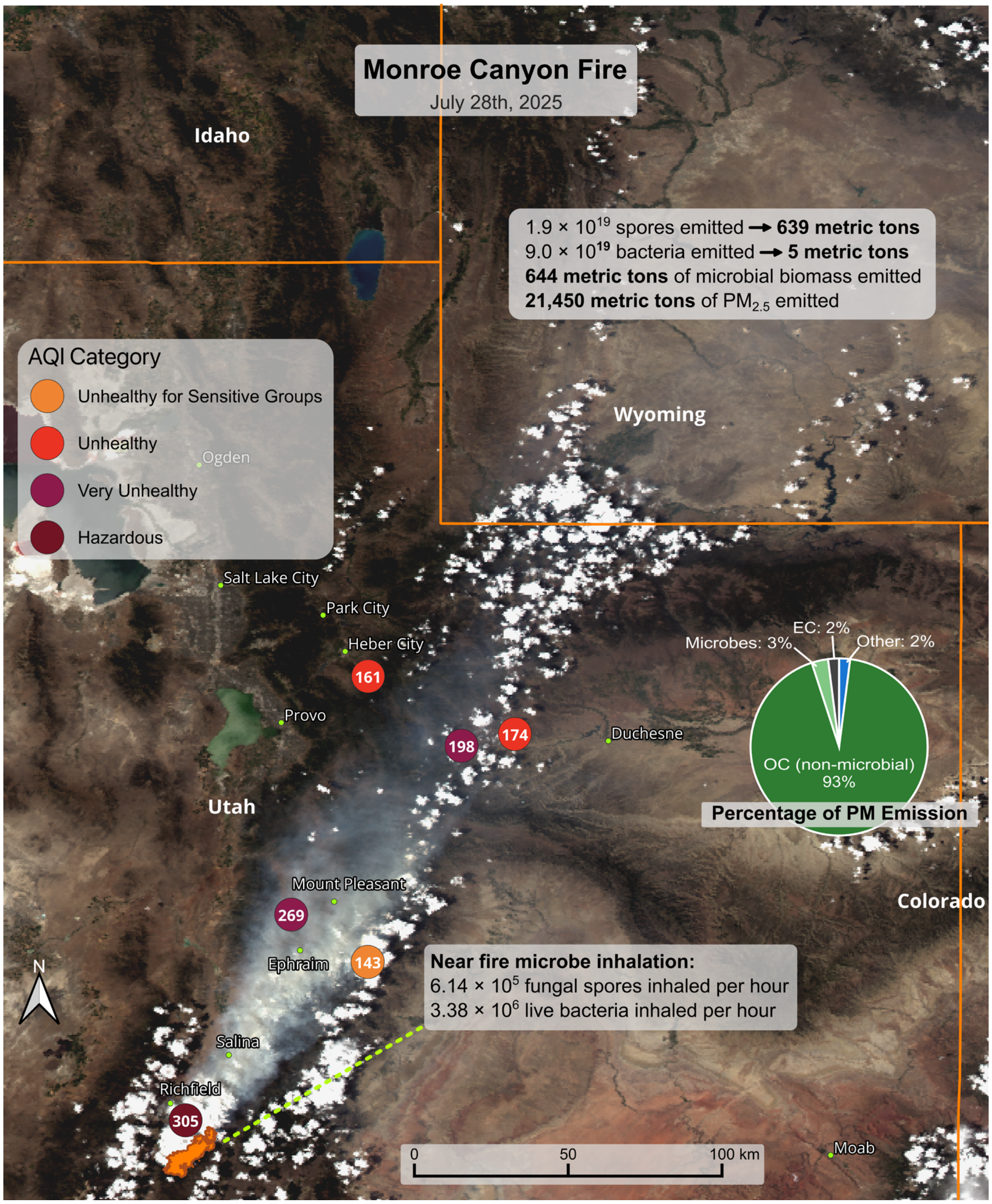

Figure 2. Adapted from Lampman (2025). MODIS satellite imagery of the Monroe Canyon Fire on July 28th, 2025, showing smoke plume extent and regional air quality impacts across Utah. PurpleAir monitoring data shown as colored circles with AQI values within them.

corresponded to over 8x higher microbial diversity compared to good air quality. Analysis of prarie smoke samples revealed that PM2.5 concentrations were positively associated with fungal spore concentrations. These findings indicate that fire behavior producing more particulate matter emits and transports a wider variety of terrestrial microbes.

Transport Modeling

Simulations of bacterial particle emission and transport demonstrated substantial dispersal potential. The particle transport modeling area covered 17 square kilometers, centered on a large prescribed burn unit in a subalpine fir forest site. Less than 0.05% of bacteria aerosolized were likely deposited within that area. The combined effect of high-wind boundary layer conditions and complex terrain transported approximately 280 quadrillion aerosolized cells outside the modeled area.

Fungal Pathogens and Health Implications

Across the five US states where researchers sampled prescribed and wildfire smoke, fungal species with known human pathogenic or allergenic properties were consistently detected. Culture-dependent methods yielded 13 human and 24 animal pathogens from smoke samples. Smoke also contained bacterial organisms closely related to human, animal, and plant pathogens.

To determine whether smoke-borne fungi remain viral after being aerosolized from combustion environments, four fungal isolates cultured directly from smoke were introduced to mouse models. *Aspergillus fumigatus* caused invasive pulmonary aspergillosis in immunocompromised mice. *Alternaria sp*. and *Cladosporium herbarum* caused airway-centered inflammation and obstructive lung physiology consistent with asthma. *Aureobasidium pullulans* caused granulomatous lung inflammation similar to hypersensitivity pneumonitis. These results demonstrate that fungi transported in wildfire smoke maintain their capacity to cause disease in animal models.

MANAGEMENT IMPLICATIONS

These findings have direct implications for wildland firefighter health and safety. Firefighters working in smoky conditions near active fires experience substantially elevated microbial exposures that may compound health effects from particulate matter and gaseous smoke components. The near-fire fungal spore concentrations documented in this work are 4x higher than the lowest concentrations known to cause reduced airway conductance and function, and to increase inflammation in nonsensitive individuals. These impacts do not depend on whether the spores have pathogenic traits. It should be noted that spore viability was not assessed for these data and different wildland fire situations could result in differing percentages of viable spores in the smoke.

The research establishes that deteriorating air quality, as measured by standard PM2.5-based indices, corresponds to increased microbial diversity and concentrations. This relationship suggests that existing air quality advisories intended to protect the public from particulate matter exposure may also provide protection from elevated microbe exposures. The identification of viable fungal pathogens in smoke provides context for epidemiological observations linking wildfire smoke exposure to increased fungal infections. Populations with compromised immune systems, chronic lung disease or asthma, or severe allergies may warrant additional caution during smoke events.

The presence of potential plant pathogens also has implications for agriculture and forest health in areas receiving smoke deposition. These laboratory studies have shown that smoke bioaerosols can colonize soil substrates and increase soil respiration, demonstrating that fire-dispersed microbes could influence ecosystem processes where deposited.

This research brief was written by Phinehas Lampman and Leda Kobziar (University of Idaho, Kobziar Fire Ecology Lab) with review by Ella Hall and Darcy Hammond (NRFSN).

Preliminary analyses suggests that lower intensity fires produce lower concentrations of microbes, which supports utilizing prescribed fire as a method for mitigating the negative smoke impacts associated with wildfires. It's also worth noting that most people breathe in fungal spores and bacteria every day without becoming ill—our immune systems routinely handle such exposures. The fungi identified in smoke are not necessarily exotic pathogens; they're mostly common environmental organisms found in soil, on plants, and in indoor and outdoor air throughout much of the world. For human health, the findings add biological context to what we already knew: wildfire smoke is something to take seriously, especially for vulnerable populations.

From an ecological perspective, this research indicates that fire serves as a biological transport mechanism, launching microbial communities into the atmosphere where they can travel substantial distances. Over 99% of modeled bacterial emissions traveled beyond a 17-kilometer modeling area, but longer-distance transport has yet to be tested in global circulation models. This smoke-mediated dispersal may influence ecosystem processes in ways not previously recognized, including post-fire recovery, biological connectivity across landscapes, and atmospheric processes such as cloud formation.

The emission factors derived from this research enable integration of microbial emissions into smoke models and air quality forecasts. As drought and other factors increase the scale and severity of wildfires, understanding fire-mediated microbial dispersal becomes increasingly important for managing public health, ecological, and atmospheric consequences of wildland fire.

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