Joint Fire Science Program

Fire Science Brief

RESEARCH SUPPORTING SOUND DECISIONS

Time to go: An Alaska Fire Service fire crew member retreats
from a pre-burn survey site as flames form the 2004 Chicken Fire approach.

Chasing Flame: Gauging Smoke Production and Forest Floor Consumption In Boreal Ecosystems

Summary

Detailed information on fuel consumption and emissions from wildland fire in Alaska's boreal forests has been in short supply. Research has been limited by reliance on prescribed burns for data collection in a region where weather, freezing and thawing permafrost and limited resources make controlled fire very challenging to accomplish. For this study, researchers tried a different approach: rapidly deploying and sampling on active wildfires. They were richly rewarded when the study period coincided with the record-setting fire season of 2004 when over six million acres burned in Alaska. With so many fires, many conveniently burning along the state's few highways, researchers were able to far exceed their original goals. The result is a model that uses upper forest floor fuel moisture content and pre-burn forest floor depth to project consumption and emissions for boreal forest types, now incorporated into Consume 3.0.

Key Findings

- The study generated the first ground sampling emissions data to be collected during active wildfires in the Alaska boreal region.
- The 2004 fire season provided an exceptionally broad range of fuel moistures rarely observed in Alaska, supplying a complete spectrum of forest floor moisture conditions for the resulting fuel consumption model.
- Resulting fuel consumption models and emission factors enable Consume, version 3.0, to predict the amount of fuel consumption, emissions, and heat release from the burning of forest floor material during wildland fires in Alaska and other boreal forest regions.

The slow, smoky smolder

Over 3 million acres are burned annually on average during wildland fires in the state. 2004 set a record with over 6 million acres burned. These fires send hundreds of thousands of tons of pollutants and particulate matter into the atmosphere. Although the consumption of tree crowns, shrubs, downed branches, trunks, dead trees and litter can be a significant source of pollutants, they often represent less than 20 percent of the total fuel available for consumption by fire in this ecosystem. The bulk of the fuel rests in the boreal forest floor—a mother lode of carbon composed of deep layers of lichen, moss, peat, and duff. It's a layer cake of organic combustibles often stacked on a stratum of active permafrost that freezes and thaws throughout the year. Reaching depths of 50 inches or more, this organic layer is loaded with anywhere from a few tons to over 200 tons of biomass per acre—all ready to literally go up in smoke under the right conditions.

Combustion of this material is highly inefficient and generally occurs during the smoky smoldering phase. When moisture levels are 30 percent or below, dry moss and duff will burn on its own until quenched from above by rainfall or from below by a wet layer. Once it ignites it can smolder slowly for weeks or months, generating tremendous quantities of smoke over long periods. This can mean hazardous air quality for downwind residents and communities, low visibility and lingering regional haze.

Moss and duff are capable of smoldering for weeks or months after the passing of active flames.

Managers have other concerns when the boreal forest floor is consumed by fire. The prolonged heat produced during the smoldering period can damage soil, increase erosion or melt permafrost that hasn't been liquefied in years. It can also change the type of vegetation communities that regenerate after fire by replacing pre-fire tree species with something altogether different. Alaska's boreal forest managers have long needed a tool that helps them anticipate how much of the forest floor is likely to burn away during a fire, how much smoke will result and what the other fire effects might be. Consumption and emissions research in Alaska has lagged behind that of the Lower 48, so managers have had to feel their way through fire season without much concrete data to guide them through planning and decision-making. Roger Ottmar, principal investigator and research forester with the Fire and Environmental Research Applications Team (FERA) at the Pacific Northwest Research Station in Seattle, explains why. "It's very difficult to do any prescribed burning up there," he says. "We've always relied on controlled burns for studying fuel consumption, but they often don't happen because the opportunities for burning are so limited. Either we don't get the weather or we lose support to the Lower 48 during wildfire season. Plus, the burns that do happen tend to represent the higher end of the moisture spectrum when burning conditions are less extreme, which limits the range of data we can collect."

"We've always relied on controlled burns for studying fuel consumption, but they often don't happen because the opportunities for burning are so limited."

Racing flames in a record year

So for this study, Ottmar and his team tried a different approach. They let wildfires tell the story. "We chased them and put plots in front of flaming fronts," he says. "We were hoping of course for a decent wildfire season so we could pull this off. It just so happened that 2004 was the biggest wildfire season they'd ever had." The ambitious project included researchers from several agencies studying various subjects, all taking advantage of the opportunity to work on active wildfires in boreal forests. Ottmar's FERA team, along with the Fire Chemistry Project of the Missoula Fire Laboratory led the aggressive field effort to gather fuel consumption and emissions data during the 2003 and 2004 fire seasons. A record season in Alaska provided the perfect location and conditions for performing scientific studies on active wildfire for several reasons. First, the fire season started in late June and extended until September allowing a range of fuel conditions to be sampled. Second, a large portion of the acres on f re occurred along major roads providing for easy access and f re safety zones for protection. Third, there was so much f re that the researchers had plenty of areas to study.

By starting the work in 2003 Ottmar and his teams had the chance to get their feet wet and their sampling protocols worked out. By the time the 2004 season began everything was in place, including outstanding support from Randi Jandt and the Alaska Fire Service (AFS). They provided the services of former smokejumper Jake Dollard as project liaison, giving sampling teams helpful credibility with f re crews. “Jake was a tremendous help because when researchers just show up in a f re camp they usually aren’t given the time of day,” Ottmar explains. “But when you can show that you’re familiar with how Alaska burns, that you’re safe and following protocols, it really helps. We were welcomed with open arms.”

Rare access and moisture conditions

Moisture levels in the sponge-like boreal forest f oor have the capacity to f uctuate tremendously because of all the water bound up in freeze/thaw cycles. In late spring and early summer, the ice layer that formed during the winter months on the forest f oor begins to thaw. The top layers become ice-free and all the water soaks into the moss and peat layers below creating a soggy stew. Water can’t drain out because deeper layers of ice remain frozen, often until late June. When this melts it’s like pulling the drain plug in a bathtub. All the moisture from the organic layer drains away and the moss, duff and peat dry out fast. Typically it stays dry only for a short while, until rains return later in July. But 2004 was different. July and August remained dry providing an opportunity to measure forest f oor consumption under low fuel moisture conditions not seen in thirty years. “When you get organic layers where the moisture is 50 percent or less it’s very rare,” Ottmar explains. “It will smolder away on its own for months. Some areas of deep organic layer smoldering from 2004 are believed to have popped up like an underground coal f re the next year after the winter. That was really exceptional.” The situation allowed them to start the season under relatively wet conditions with organic layer moistures of 200 to 300 percent (holding two to three times its own dry weight in water) and f nish with levels as low as 30 to 40 percent. They were able to measure fuel consumption under wet conditions, dry conditions and everything in between all in one season.

As if the researchers needed anything else to go their way, many of the 2004 f res burned adjacent to one of the very few major highways in the state, giving them easy, unprecedented access. “The biggest f re came right down the highway so we had good safety zones and access,” Ottmar says. “This allowed us to get in there, put our plots in and get out without helicopters. It was nothing short of phenomenal.”

Decoding depth and moisture

Previous studies of wildf re in boreal ecosystems observed that forest f oor reduction from f re didn’t have much to do with consumption of trees, logs and branches. In his own early work Ottmar determined that the proportion of the forest f oor reduction is inf uenced by lower forest f oor moisture content and pre-burn depth. The relationship holds as long as the relative humidity is less than 40 percent. That’s when the surface layer is dry enough to carry f re and sustain combustion hot enough to ignite the lower layers. This project was the chance to sort out the details and feed it all into a predictive model that would dovetail into Consume.

Flames converge on the Taylor Highway as fire/research teams retreat. Fires burning along major highways gave scientists unprecedented access.

Forest f oor consumption was measured at 24 black spruce and white spruce sites during eight wildf res in 2003 and 2004. During the 2003 f re season, efforts were concentrated on the Erickson Creek wildf re along the Dalton Highway 50 miles northwest of Fairbanks; the Chena Lakes wildf re 10 miles east of Fairbanks; and the Black Hills wildf re, 50 miles east of Tok. During the 2004 f re season the researchers concentrated their efforts on f ve f res—the Chicken, Porcupine, Wall Street, Kings Creek, and Gardiner wildf res 50 to 100 miles north and east of Tok (see map on page 4).

To measure forest f oor consumption, 9 to 18 plots were staked out at each f re site. Within each plot, 16 forest f oor pins were inserted 1.5 feet apart into the forest f oor. Organic layer depths were measured and samples collected for drying and weighing to determine pre-burn fuel moistures. Moisture contents of the upper duff layer ranged from 236 percent during the Erickson Creek wildf re in early July, to 60 percent on the Gardiner wildf re in late August. The lower duff moisture content ranged from 319 percent on the Wall Street wildf re late in June to around 60 percent on the Porcupine and Gardiner f res in mid-July and late August. Pre-burn forest f oor depths ranged from 5 to nearly 11 inches. Forest f oor consumption generally increased as moisture content decreased and forest f oor depth increased. Forest f oor reduction ranged from 7 inches on the Porcupine wildf re in late August to 2.27 inches on the Wall Street wildf re in late June 2004.

To measure emissions and consumption rates, crews from the Fire Chemistry Project lead by Dr. Steve Baker used their f re atmosphere sampling system (FASS). FASS towers were set up a few hours ahead of the f aming front.

The 2003 fire season served as a dress rehearsal for the researchers allowing them to take full advantage of the record setting fires of 2004. This map shows the location of the 2003 wildfires sampled (Erickson, Chena, and Blackhills) and the 2004 wildfires sampled (Porcupine, Chicken, Wall Street, Kings Creeks, and Gardener).

Instrument boxes were set in shallow depressions made on a wet surface and covered with fire shelter material. Canisters of background air were collected at each tower before the fire came through. As the flaming front passed they collected more samples and recorded temperatures, wind speed, carbon monoxide and carbon dioxide. Ambient air and smoke were drawn into pressurized canisters from the top of the 30-foot high towers. Anemometers mounted just below the sample head measured airflow from three directions. Sampling times were set for 5 minutes during the flaming phase, 7 minutes during the intermediate phase and 10 minutes during smoldering. The sample towers were directly in the path of the fire as it burned and the high intensity crown fire tested the heat resistance of the sample towers and ground packages. They captured a series of "instantaneous" consumption rates measured over time for the smoldering fuel to calculate the overall consumption rate and the amount of fuel consumed. Baker's team also employed a portable sampling chamber to collect ground level emission emitted during the smoldering phase. Following the passage of the flaming front, four to six plots were identified as potential smoldering sources. Each plot was revisited in the same order each time at intervals of 1 to 4 hours. Background samples of the ambient air were collected periodically as well.

A researcher measures post-fire depth of the organic layer to determine how much was consumed.

Measuring smoldering and residual emissions.

Optimal conditions reap optimal results

These ground-sampling emissions data are the f rst to be collected during active wildf res in the Alaska boreal region and will be important in future smoke production and carbon release calculation. The new forest f oor consumption equation and emission factors have been implemented into Consume 3.0, and the user's guide and tutorials have been upgraded. Ottmar highly recommends that managers, scientists, and State regulatory agencies use the program because it now provides the best science and most up-to-date ability to predict fuel consumption and emissions for f re effects in boreal ecosystems.

Ottmar warns that the forest f oor equation resulting from this study still has some limitations and should be used only under the conditions under which it was developed. If it rains within a few hours of ignition and the smoldering stage is terminated prematurely the model will most likely over-predict forest f oor consumption. This is because the total consumption f gure ends up being determined more by the rain than by lower forest f oor moisture content and pre-burn forest f oor depth. He also adds that when sustained surface winds are greater than 10 miles per hour, more forest f oor is consumed than can be accounted for by lower forest f oor moisture content and pre-burn depth. Other factors like relative humidity, surface moisture, wind speed and upper duff moisture are also likely to inf uence how much of the forest f oor burns and Ottmar says that the predictive capability of the model will be further improved by including these variables in future analysis.

Ottmar would like to collect more information down the road to build a validation dataset, but he doesn't expect to be granted another optimal Alaska f re season full of perfect measurement conditions like he experienced in 2004. "I haven't seen anything like it since. Not even close," he concludes. "We inventoried about 27 plot areas and 24 of them burned through which is amazing in Alaska. The opportunities presented in 2004 were unbelievable. We had everything in place to take good advantage of it all and it worked out very well for us."

Management Implications

- This research makes Consume 3.0 and other fuel consumption, fire effects, and smoke production models more robust by accounting for boreal forest fuel bed types, thereby aiding managers, planners, and researchers in developing environmentally, socially, and legally responsible land management plans.
- This knowledge enables a more effective and informed use of emission production and wildfire/prescribed fire trade-off models which provide improved wildland fire emissions and carbon accounting in the Alaska boreal forest types.
- Flaming emission factors during the passage of the fire front for wildfires sampled in 2004 can be considered representative crown fire emission factors for Alaska and other boreal forest sites where emission factors are required as model inputs.
- Pre-burn measurements of forest floor depth and moisture content are required.
- Using these predictions, resource managers can determine when and where to conduct a prescribed burn or plan for a wildland fire for use to achieve desired objectives while reducing impacts on other resources.

Further Information: Publications and Web Resources

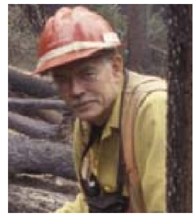
Consume web site: http://www.fs.fed.us/pnw/fera/products/consume.html

Forest Floor Consumption and Smoke Characterization in Boreal Forest Fuelbed Types of Alaska. JFSP Project 03-1-3-08. http://www.f rescience.gov/JFSP_Search_Results_Detail.cfm?jdbid=%23%27%3A%238%0A

Ottmar, R.D. and D.V. Sandberg. 2003. Predicting forest f oor consumption from wildland f re in boreal forests of Alaska – preliminary results. In: Galley, K.E.M., R.C. Klinger, N.G. Sugihara (eds). Proceedings of Fire Conference 2000: The First National Congress on Fire Ecology, Prevention, and Management. Misc. Pub. 13. Tallahassee, FL: Tall Timbers Research Station: 218-224.

Web-based self-paced tutorial, instructor's guide and student workbook for Consume 3.0 including boreal forest fuel consumption and emission factors: http://www.fs.fed.us/pnw/fera/research/tutorials/consume.shtml

Scientist Profiles



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Results presented in JFSP Final Reports may not have been peer-reviewed and should be interpreted as tentative until published in a peer-reviewed source.

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