Joint Fire Science Program
Fire Science Brief
RESEARCH SUPPORTING SOUND DECISIONS

An unburned mid-altitude site in April of 2003, on an intermittent tributary to Squaw Creek in Idaho. Showing fuel accumulation in a riparian zone, this site is located close to the site of one of the test burns. Credit: Kirsten Stephan.

# After the Fire, Follow the Nitrogen


## *Summary*

Nitrogen availability in soils, streams and associated terrestrial and aquatic vegetation can be influenced by both wildfires and prescribed burns, though typically not to the same degree. Extensive research was done on post-fire nitrogen dynamics at several mid-altitude coniferous National Forest sites in Idaho. Sites included both wildfire locations and prescribed burn projects. By measurement of both ammonium ($NH_4$) and nitrate ($NO_3$) levels, researchers documented over time the effects of both high-intensity wildfires and lower-intensity prescribed burns on nitrogen transformation processes in soil levels, and nitrogen levels in various ecosystem components.

Field measurements demonstrated that the soil, water and foliage nitrogen effects of low-intensity spring prescribed fires are quite different from the nitrogen dynamics of wildfires. Wildfires in these western forests produced significant (three year plus) pulses of nitrogen to aquatic systems, compared to very limited pulses from spring prescribed burns.

### *Key Findings*

- Elevated nitrogen levels in soils and vegetation of riparian forests were far more pronounced following high-intensity wildfires compared to low-intensity spring prescribed fires.
- The moderately elevated nitrogen pulse in soils and terrestrial plants from spring prescribed fires had typically disappeared by the end of the first growing season.
- In most cases the brief nitrogen pulse in soil after spring prescribed fires was completely contained within the terrestrial ecosystem and did not reach adjacent streams.
- High-intensity wildfires appear to output inorganic nitrogen, usually as nitrate, into adjacent streams. This output can persist for several years.

## Nitrogen transport after the fire

Nitrogen is a key element for plant growth, and fire alters the availability of inorganic nitrogen. Significant fire in an upland forest causes changes in soil chemistry and related plant growth. Questions come up, "Exactly how do forest fires affect soil chemistry, and specifically nitrogen levels and nitrogen transport characteristics? Do such fires result in a long-term increase of nitrogen in the soil, into vegetation and into surrounding watersheds? How does the nitrogen output from spring prescribed burns compare to that from major wildfires? What are the respective trends of each type of fire on ammonium and nitrate nitrogen concentrations?"

In many headwater streams of central Idaho, growth of aquatic organisms is limited by availability of nitrogen, which in most cases is quite low. These low levels may be attributable to several reasons, including low nitrate levels in adjacent soil water, diminished numbers of anadromous fish which normally died after spawning and contributed to stream nitrogen levels, and control over wildfires which in the past freed up nitrogen from plants which infiltrated to stream waters. Forest and stream managers need more information on possible contributions of both wildfires and prescribed fires on stream water nitrogen levels.

The Idaho projects developed methodologies for evaluating and comparing nitrogen dynamics from both prescribed burn projects and from more intense wildfires. Measurements were taken at several fire sites. Researchers simultaneously measured nitrogen concentrations and production rates in soils, terrestrial plant foliage, stream water, and stream plant life following such events.

Research indicated that soil ammonium and nitrate concentrations substantially increased immediately after all fires. Elevated nitrogen concentrations in soil persisted from one to four months following spring prescribed burns compared to unburned watersheds. These concentrations were significantly lower than those initially observed after higher-intensity wildfires, and elevated nitrogen levels from prescribed burns disappeared after a far shorter period of time. This indicated a correlation between fire severity and longer-term soil inorganic nitrogen levels.

Plants that re-sprouted after prescribed burns retained foliar nitrogen concentrations at levels similar to those observed after wildfires. However initial raised nitrate concentrations in plant foliage persisted for less than a year after prescribed burning, and only very modest and short-term increases in nitrogen in stream water were measured. Resource managers who are trying to achieve a longer-term nitrogen pulse in stream water need to aim for higher burn severity than that provided by typical prescribed spring burns. Higher intensity fires which more completely reduce fuel loads can stimulate persistent nitrogen cycling in streams.

## Prescribed burns and the nitrogen cycle

Spring prescribed burns have commonly been used for fuel reduction, with the goal of reducing the risk of wildfires, and to modify the characteristics of forest lands. Such fires can eliminate or reduce dominance of some undesired species. In some cases where periodic low-intensity fires were historically the norm, prescribed burns can help return forest lands to their approximate characteristics before European settlement.

Managers have expressed interest in the effects of fires, and especially prescribed burns, on forest soil, plants, and watershed chemistry. Fire does release nitrogen in various forms much more quickly than natural decomposition. A major pulse of nitrogen as both ammonium and nitrate is quickly released following a high intensity wildfire. Researchers from the University of Idaho initiated research to determine the dynamics and duration of this nitrogen release. Particular attention was given to comparing the nitrogen dynamics of lower-intensity prescribed burns with the releases from wildfires.

The principal investigator for these projects, which were funded by the Joint Fire Science Program, was Dr. Kathleen Kavanagh, from the Department of Forest Resources of the University of Idaho. Other investigators were Dr. Wayne Minshall from the Department of Biology of Idaho State University, and Neil Bosworth from the Forest Service, Boise National Forest. In addition, graduate students Aki Koyama and Kirsten Stephen from the University of Idaho played major roles in structuring and conducting the research and evaluating and publishing the research results. Major elements of the research are currently being prepared for publication in peer-reviewed journals.

Goals of the research were to document nitrogen dynamics both on sites of wildfires and on sites where prescribed fires had occurred. especially on riparian sites and in adjacent streams. Riparian areas are defined as "three dimensional zones of direct physical and biotic interactions between terrestrial and aquatic ecosystems." Riparian forest areas represent an important links between these two ecosystems.

Researchers noted that in the past, most post-fire nitrogen research was on upland sites and did not include nitrogen effects on adjacent stream water. Since riparian areas often differ from other upland areas in terms of microclimate, moisture availability, and species composition, the resulting different fuel loads and fuel moistures might lead to differing fire intensities and severities. Researchers also had a interest in the actual effects of the fires on stream water chemistry and stream biota.

## Filling a knowledge gap

Because of a lack of data, forest managers have traditionally taken a conservative approach and have avoided prescribed burning in these riparian areas in many National Forests. As a result, fuel stocks have often risen to levels that could support extensive, high-intensity wildfires. A goal of this research was to fill this knowledge gap and allow better-informed decisions in these areas.

In the cases of both the wildfire sites and the prescribed burn sites, the study involved taking measurements over time of ammonium and nitrate in soils in the fire areas, in foliage of plants that sprouted after the fires, in stream water in adjacent streams, and in aquatic life adjacent to and in those streams. The riparian zone was defined as those areas within 30 meters (m) of a stream. Measurements were taken over periods of up to three years and were compared to control measurements in areas with similar characteristics but which were unaffected by fire.

## Taking nitrogen's pulse after wildfire

The project studying the dynamic of nitrogen following wildfires in riparian forests began on four mid-altitude forest sites in central Idaho in 2004. The sites chosen had experienced high-intensity wildfires one year previously. These sites previously had coniferous forest cover over the generally mineral soils. Nearly all vegetation cover had been killed or consumed by the fires. Because the research program was established after the fires, researchers also carefully selected comparable unburned sites for controls.

Criteria for fire site selection were: (1) severely burned stands with all the dominant conifers killed and organic matter consumed on the forest floor, (2) enough space to set up 30 m by 30 m plots, and (3) nearby control forest sites with no fire effects. On the four fire sites, soil cores at random locations were taken, documented, preserved and transported to a laboratory for analysis using accepted techniques. These analyses indicated that inorganic nitrogen levels in these soils was significantly elevated even after the passage of two years.

This verified earlier observations that without fire, cycling of nitrogen in soil and plants is complex and closely linked with the plant growing cycle, soil microbial activity, and carbon reserves in the soils. In typical mid-altitude coniferous forest areas, microbial nitrogen production rates are high, but are often offset by matching microbial nitrogen uptake, so net available nitrogen to soil water is low.

After five years, a wildfire site is showing vigorous re-growth, and nitrogen levels are returning to levels similar to unburned areas. Credit: Kirsten Stephan.

With high-intensity wildfire, both organic and inorganic nitrogen in the vegetation and the forest floor material is released, both to the atmosphere and in the form of oxidized mineral to the soil. Researchers found that both ammonium and nitrate nitrogen levels in the soils were elevated and microbial uptake was lower, compared to similar unburned forest areas. Available soil nitrogen levels for plant growth and for transport to adjacent streams were much higher. Sampling of soil, terrestrial plant foliage, stream water and aquatic plant growth in these wildfire areas and the related control areas continued for three years during the growing seasons.

Trends in concentration of ammonium ($NH_4$+) and nitrate ($NO_2$-) in the soil and stream water sampled followed differential patterns when comparing burned vs. the unburned sites. Ammonium levels in soil in the burned areas studied were much higher during the first growing season after fire, but thereafter returned to levels not statistically different from unburned area soils. Nitrate in the soil returned to levels comparable to control sites within three years. Nitrate in stream water was more persistent and still elevated three years after wildfires.

Foliar concentrations of nitrogen in terrestrial plants were significantly higher in burned relative to control sites the first growing season after the fire, slightly higher in the second season, and unchanged in the third season. Aquatic mosses mirrored stream water nitrate levels in that nitrogen concentration of moss leaves were significantly elevated without a decreasing trend over the study period. Researchers expect that stream water nitrate levels and moss nitrogen levels will start to decline by the fourth or fifth years after the fire.

## Prescribed burn studies

Simultaneously to the wildfire project, researchers measured nitrogen concentrations in headwater watersheds of three low-intensity spring prescribed burns and one higher-intensity spring test burn for two post-fire years. Again they looked at soil, understory plant foliage, stream water, and aquatic biota. The low intensity fires, conducted in April of 2004, had involved understory vegetation and some downed dead timber, but not standing timber. Most forest floor materials were not extensively consumed.

In all cases, results were compared with unburned control sites with similar characteristics. Researchers compared the results of this study to those of the companion study on higher-severity wildfires. Sampling techniques were the same as those used for the wildfire burns, and began the summer following the spring prescribed burns.

A typical low-intensity prescribed burn site a few weeks after the fire. Credit: Kirsten Stephan.

As with the wildfire soil samples, both ammonium and nitrate levels in the soils were elevated in the first summer following the fires. Ammonium and nitrate levels from the one higher-intensity test burn, not surprisingly, were roughly similar to those from the wildfires. However, in the case of the three lower-intensity prescribed burn areas, both the ammonium and nitrate levels did not reach the magnitude of the wildfires or the higher-intensity test burn, and dropped to levels comparable to those in the control plots by the end of the first summer.

Sampling of total nitrogen in terrestrial foliage which re-grew on the prescribed burn sites showed a level elevated approximately 50 percent above the control plots the first year, but by the following summer, these foliar nitrogen levels were essentially the same as at the control sites. Nitrogen levels in aquatic moss in the prescribed burn areas did not increase above control levels in any of the sampling seasons after the prescribed burns.

Aquatic moss in headwater streams near prescribed burns did not increase in nitrogen levels after the fires. Credit: Kirsten Stephan.

Stream water nitrate levels adjacent to prescribed burn areas were only briefly and modestly elevated above those in unburned control areas but far below levels experienced with wildfire areas. The slightly elevated levels occurred only in the second spring after the burns, but by the third summer, levels were indistinguishable from the control sites. In contrast, in wildfire areas high nitrate levels in stream water had persisted through the third summer and beyond, and at levels more than an order of magnitude higher than those from prescribed burns.

## Nitrogen transport mechanisms

Nitrogen moves between ecosystem components, from its state of being tied up within vegetation, forest floor material and soil, via its conversion to inorganic forms through microbial decomposition and fire, to subsequent re-inclusion in growing plant materials or transport through soil water and stream water. Nitrogen can also leave an ecosystem via combustion or due to stream flow.

Research demonstrated a strong seasonality to the nitrogen cycle, with changing temperatures, freezing, precipitation and spring snowmelt. According to Kathleen Kavanagh, the most significant delivery of inorganic soil nitrogen into the streams in wildfire areas appears to take place as the snow is melting in the spring. She points out, "Given that the main flush of inorganic N occurs during spring snowmelt (when the plants are dormant), I would have to say that any N released by low-intensity spring burns is quickly sequestered by microbes and plants. That amount is low enough that it does not hang around until the following spring, when it would be flushed with the snowmelt." Researchers indicate that more work is needed in understanding the winter transformation of nitrogen to help understand the spring flush of nitrates into streams. This is particularly important in the seasons after a wildfire event.

Fires release the nitrogen that has been tied up in growing or dead plants and in microbial life. Much is lost to the atmosphere, but net available inorganic nitrogen in the soil increases and becomes available to new microbial or vascular plant life. If not incorporated in plant life, it can be carried in solution in ground water to surface streams. Researchers found that ammonium peaks quickly and nitrate is more persistent, especially after wildfires.

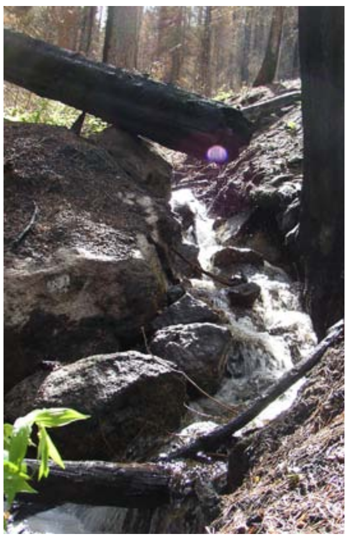
Kavanagh notes that ammonium is largely converted to nitrate, by microbial activity. She explains, "The subsequent conversion of nitrate and ammonium into organic compounds occurs in the plants and microbes as they convert the inorganic form to amino acids and proteins. Some organisms prefer one form or another but this was not part of our study."

## It depends on fire intensity

This research encompassed both low intensity prescribed fires and high-intensity wildfire sites, where virtually all the trees were killed. Differences in nitrogen dynamics between these two situations are significant. Kavanagh emphasizes, "We definitely see a strong relationship between the intensity of the fire and the nitrogen pulse through the soil into the adjacent stream water. If your goal is to supply nitrogen to the stream, you'll need a hotter fire than the typical spring prescribed burn."

Kavanagh explains why transfer of nitrogen from terrestrial ecosystems to stream water through low-intensity prescribed burns does not appear to be significant. “Most prescribed burns are conducted to limit consumption of forest floor duff and to minimize tree mortality. Therefore, they do not release much nitrogen above the levels that can be used by terrestrial plants and microbial life immediately following the burn.”

With higher-intensity wildfires, the capacity of microbial organisms and plant to incorporate nitrogen into their biomass is reduced and levels of inorganic nitrogen released are greater, so researchers saw elevated stream water levels for three years and longer. In these headwater streams, Kavanagh does not feel increased levels of nitrogen will be a problem and will in fact increase the biological productivity of the streams. She notes that “Our results indicate that given the low levels of nitrogen in these headwaters streams, the likelihood of ‘over-nitrification’ is very low.” She and her colleagues and students are continuing to do research on the wide range of processes involved in forest nitrogen dynamics.



A year after a wildfire, this Idaho headwater stream shows elevated levels of nitrogen, which have been demonstrated to persist for 3 to 5 years. Credit: Kirsten Stephan.

According to Kavanagh, the results of these studies are already being incorporated in classroom instruction and discussion, and the experiences in the research work are being extended into other research areas. She says, “Students are learning that fire can be a significant and positive source of available inorganic nitrogen both to the forest land and to adjacent stream waters.

A related ongoing project is experimental placement of anadromous fish carcasses along similar stream banks to evaluate this as another source of stream water nitrogen. The results to date indicate a significant nitrogen pulse in the water, and a corresponding increase in the biological productivity of the streams.

Kavanagh concludes, “We’re telling people that it’s okay to do prescribed burns, even in areas adjacent to headwaters streams. And in doing rehabilitation after a wildfire, remember to take advantage of the increased forest and stream productivity that will likely occur.” She suggests that manager should consider as a benchmark, how the nitrogen cycle worked in this area in the past. The cycle is complex and not yet completely mapped, but significant knowledge has been accumulated that will help managers make better decisions.

### *Management Implications*

- By controlling the intensity of prescribed burns in upland forests, it is possible to limit the levels of inorganic nitrogen that will flush through to stream water and aquatic biota.
- The inorganic nitrogen output from a high-intensity wildfire will persist in soil and in adjacent streams and aquatic biota for several years.
- In many Western streams, these elevated levels of nitrogen in stream water from wildfires may somewhat enhance growth of aquatic organisms, but will not be generally detrimental to stream water quality.
- The most important seasonal period for nitrogen flushing in mid-altitude Western forest soils is during the spring snowmelt process.
- The inorganic nitrogen output from low-intensity spring prescribed burns appears to be entirely taken up by plants and soil microorganisms during that growing season.
- Resource managers who are trying to achieve a longer-term nitrogen pulse in stream water need to aim for higher burn severity than that provided by typical spring prescribed burns. Higher intensity fires which more completely reduce fuel loads can stimulate nitrogen cycling in streams.

## Further Information: Publications and Web Resources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## *Scientist Profiles*

**Dr. Kathleen Kavanagh** is an Associate Professor of Forest Ecosystem Science at the University of Idaho. Her research, which focuses on the impact of change on forest ecosystem processes such as water and nitrogen cycling. Change can occur in many ways, however fire, climate and harvesting are common themes in Dr. Kavanagh's research. This research is supported by the Joint Fire Science Program and the National Science Foundation.

*Kathleen Kavanagh* can be reached at:
Forest Resources Department
University of Idaho
PO Box 441133, Moscow, ID 83844-1133
Phone: 208-885-2552
Email: katyk@uidaho.edu

**Aki Koyama** has just finished his two-year postdoctoral fellowship at Washington State University, where he investigated how elevated carbon dioxide level in atmosphere affects carbon and nitrogen cycle in desert soils. He is currently writing and revising manuscripts of his past studies.

*Aki Koyama* can be reached at:
Washington State University
Pullman, WA 99164
Phone: 509-335-3564
Email: akoyama@wsu.edu

**Kirsten Stephan** finished her doctoral research in 2007. She is now Assistant Professor of Biology at Lincoln University in Missouri. While her main focus is on teaching plant biology courses, she also continues research on the effects of long-term prescribed burning on nutrient cycling and vegetation composition in the Missouri Ozark Mountains.

*Kirsten Stephan* can be reached at:
Lincoln University
Department of Life and Physical Sciences
131 Founder's Hall
820 Chestnut St, Jefferson City, MO 65101
Phone: 573-681-5116
Email: stephank@lincolnu.edu

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John Cissel
Program Manager
208-387-5349
National Interagency Fire Center
3833 S. Development Ave.
Boise, ID 83705-5354

Tim Swedberg
Communication Director
*Timothy_Swedberg@nifc.blm.gov*
208-387-5865

Writer
Jake Delwiche
*jakedelwiche@earthlink.net*

Design and Layout
RED, Inc. Communications
*red@redinc.com*
208-528-0051