Ecological Implications of Fire in Greater Yellowstone, 1996

Consequences of Fire on Aquatic Nitrate and Phosphate Dynamics in Yellowstone National Park

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Abstract. Airborne remotely sensed data were collected and analyzed during and following the 1988 Greater Yellowstone Ecosystem (GYE) fires in order to characterize the fire front movements, burn intensities and various vegetative components of selected watersheds. Remotely sensed data were used to categorize the burn intensities as: severely burned, moderately burned, mixed burn, lightly burned, and unburned. Water samples were then collected in six streams, under various burn conditions, for the next five years. Those samples, collected twice a day, for the summer months following snow melt, were analyzed with a Dionex ion chromatograph in order to determine the chemical concentrations of nitrates (NO_3) and phosphates (PO_4)in the streams. Those nitrate and phosphate levels were compared to a reference stream (unburned) in order to determine the change in chemical concentrations under various burning conditions. Our results indicate that stream nitrate remains high, even after five years of ecosystem recovery. Nitrate levels, found in various burn conditions, ranged from 2.6 to 33 times greater than our reference, unburned stream concentrations. Phosphate concentrations exhibited similar conditions with levels 2.0 to 29 times greater than background levels. These results indicate that burn intensities regulate stream water nitrate and phosphate concentrations; that aquatic ecosystem alterations are of much longer duration than previously thought; and that remotely sensed data can be used effectively to predict burn intensities which relate to watershed chemical changes that will affect aquatic conditions.

Keywords: Remote sensing; Nitrate; Phosphate; Burn intensities; Water chemistry; Yellowstone National Park; Greater Yellowstone Ecosystem (GYE).

Introduction

The Greater Yellowstone Ecosystem (GYE) fires of 1988 provided a dramatic natural experiment of fire impacts on both terrestrial and aquatic environments. Fires affect the biotic community by altering soil chemistry, mobilizing nutrients, removing the soil cover, and changing the stand composition of vegetative components. Streams and water bodies are also severely altered by the sudden influx (through runoff) of nutrients and debris during and following a fire. The application of ammonium phosphate fire retardants can also significantly alter the nutrient levels following fires. This issue was investigated and no retardant was in use in the Park near our sampled streams during the fire suppression activities (Despain 1995). Spencer and Hauer (1991), provided experimental evidence to support their hypothesis that increased phosphate concentrations in streams (monitored during a wildland fire in Montana) were the cumulative result of entrapment of smoke in watersheds. They theorized that the concentrations would decrease as the fire decreased and that phosphate levels would return to normal background levels in a short period of time (weeks to months).Their field analysis during and following the burn provided supporting evidence of their hypothesis. Riggan et al. (1985), has shown that the stream nitrate and phosphate concentrations measured after controlled burns in a Mediterranean ecosystem (chaparral) in Southern California exhibited increases for extended periods of time. Those authors theorized that concentrations may remain elevated for periods up to five years. Experiments conducted in Canadian pine forests (Cofer et al. 1988), and Brazilian grass/woodlands (Riggan et al. 1993) also support the conclusion that burn intensities and emission factors control nitrate loss and are a major long-term input to stream chemical composition changes. Those results have led us to hypothesize that nitrate and phosphate concentrations are tied more directly to the intensity of the burn and less directly to the vegetation being consumed during the fire.

In Yellowstone, remote sensing and water chemistry analysis were used to document pre- and post-fire aquatic system conditions. The objectives were to determine the severity of burning condition on montaine forest watersheds utilizing remote sensing instrumentation and to determine the rate of nitrate and phosphate concentrations in downstream flows from watersheds experiencing various burn intensities. We hypothesize that nitrate and phosphate inputs from watersheds experiencing various burn intensities will exhibit short-term peaks (2-5 years) after fires. We expected that as regrowth occurs, nutrient-rich runoffs will diminish and subsequent inputs to streams will diminish. Therefore, following the wildfires of 1988, water sampling and chemistry analysis of six streams within Yellowstone National Park were performed in order to determine the effects of fire in Lodgepole pine (*Pinus contorta*) dominated, montaine forest ecosystems. Various burn intensities for the stream watershed areas were determined from the airborne Daedalus multispectral Thematic Mapper Simulator (TMS) scanner data and used to quantify nitrate and phosphate changes. We provide evidence that nutrient pulse trajectories vary with burn intensity.

Methodology

Remote Sensing Collection and Analysis

Various burn intensities for Yellowstone National Park were determined from digital and photographic data collected from the NASA high altitude ER-2 aircraft. Digital data was collected by the Daedalus AADS1268 multispectral Thematic Mapper Simulator (TMS) scanner. The Daedalus instrument collects information in 12 distinct bandpass regions of the electro-magnetic spectrum, (Table 1). Given the system IFOV of 1.25 milliradians (mrad), at nominal ER-2 altitude, spatial resolution is approximately 24.5 meters at sea level.

The TMS data was analyzed using a standard image processing software package (IDIMS). The TMS data, collected 15 September 1988, during the waning days of the fires were used to determine burn severity of various watershed complexes (Table 2). Similar data collection

Table 1. Spectral wavelength regions of the Daedalus AADS1268 multispectral Thematic Mapper Simulator (TMS) scanner and corresponding bands of Landsat Thematic Mapper (TM).

Daedalus Channel	Wavelength (μm)	Spectral Region	TM Equivalent
1	.42 - .45	Blue	TM-1
2	.45 - .60	Blue/Green	
3	.52 - .60	Green	TM-2
4	.60 - .62	Green/Red	
5	.63 - .69	Red	TM-3
6	.68 - .75	Red	
7	.76 - .90	Near Infrared	TM-4
8	.91 - 1.05	Infrared	
9	1.55 - 1.75	Short Wave IR	TM-5
10	2.08 - 2.35	Short Wave IR	TM-7
11	10.4 - 12.5	Thermal (Low Gain)	TM-6
12	10.4 - 12.5	Thermal (High Gain)	TM-6

systems available on the NASA-Ames C-130B Earth Resources Aircraft were also utilized for discrimination of burn intensities. The C-130B airframe supports the NS-001 scanner, a Thematic Mapper Simulator developed at NASA-Ames Research Center. Data from that scanning system was also used in post-fire analysis to assist in determining the vegetation recovery rate in the park for a period of a few years following the fires of 1988. The method for determining fire intensity closely follows that described by Riggan et al (1993), and involves determining the ash composition at longer wavelengths. The temperature of the ash layer can remain as high as 345° Kelvin (K) under solar heating. This allows for subtle discrimination in burn efficiencies using mid-infrared, or longer wavelengths to determine ash temperatures. The color of the ash in infrared wavelengths also assist in discriminating burn efficiencies. An intense wildfire, burning at very high temperatures will effectively remove living vegetative matter completely, leaving a white/gray ash color. Lower efficiency fires will leave more carbon on the soil surface, contributing a darker color to the ash layer (Ambrosia and Brass 1988). These two factors, combined with the analysis of similar phenomenon on aerial, infrared photography collected after the fires allowed the discrimination of discrete burn intensities.

Burn intensities were divided into five categories based upon analysis of the imagery: (Severely burned, Moderately burned, Mixed burning, Lightly burned, and Unburned). The analysis focused on selecting burned watersheds dominated by dense stands of Lodgepole pine on moderate/steep slopes (Cache Creek), mixed stands of Lodgepole pine and grammenoid communities on relatively flat, gentle terrain (Blacktail Deer Creek and Soda Butte Creek), and mixed burning and mixed vegetation watersheds dominated by major stream/river systems (Snake River and Lamar River). An unburned watershed, with similar topographic and vegetative characteristics was also selected as a reference stream in order to allow comparative analysis of stream chemistry compositions. That watershed, Amphitheater Creek, is dominated by dense stands of Lodgepole pine on moderate to steep slopes. The Amphitheatre Creek watershed is adjacent to the Cache Creek drainage.

Stream Data Collection and Analysis

Six stream watersheds were chosen for nitrate and phosphate analysis in the park following the 1988 wildfires. The six streams were selected in the late spring of 1989 based on numerous factors. Those factors included: the existing burn intensities for the area, vegetation composition, and previous long-term stream monitoring by both the National Park Service (NPS) and the U.S. Geological Survey (USGS), Water Resources Division. Three of the streams chosen for sampling were coinciden-

Table 2. NASA ER-2 and C-130B flights and data collection over the Greater Yellowstone Ecosystem (GYE). Flight numbers are reference for Flight Summary Reports (FSR) available from NASA-Ames Research Center.

Aircraft Type	Flight Number	Mission Date	Data Collection Photography	Scanner
ER-2	88-123	2 Sep. 1988	—	yes
ER-2	88-125	6 Sep. 1988	yes	yes
ER-2	88-126	9 Sep 1988	—	yes
ER-2	88-129	15 Sep. 1988	yes	yes
ER-2	88-149	29 Sep. 1988	yes	—
ER-2	89-005	6 Oct. 1988	yes	—
ER-2	89-158	30 Aug 1989	yes	—
ER-2	89-159	1 Sep. 1989	yes	—
C-130B	91-009-04	9 Aug. 1991	yes	yes
C-130B	91-010-15	20 Sep. 1991	yes	yes

tally monitored by the USGS: Blacktail Deer Creek, Soda Butte Creek, and the Lamar River near the junction with the Yellowstone River (M. K. White 1993). Five of the watersheds were located in the north/northeastern section of the park, with the sixth, the Snake River, being monitored at the southern boundary of the Park. The Snake River was included in the area covered by the Snake River Complex and the Huck Complex fires of 1988. Cache Creek, Soda Butte Creek, and the Lamar River were included in the Clover-Mist Complex, and Blacktail Deer Creek was part of the Wolf Lake Complex. Elevation ranges for all the stream sampling stations were similar, with point sampling elevations ranging from 6000 feet ASL (Lamar River) to 6905 feet ASL (Amphitheatre Creek).

Stream water sampling in Yellowstone National Park was undertaken using ISCO waste water samplers. The ISCO samplers were programmed to collect one litre of water twice in a 24-hour period. Each sampler contains 28 bottles, enough for two samples a day for fourteen days of sampling. During collection and servicing, at the end of the two-week period, the samples are removed, transferred to sterile 100ml bottles, labeled for time/date of collection, packaged and sent to the U.S.F.S. Riverside Fire Lab, California for analysis.

Nitrate and phosphate analyses were performed using a Dionex Series 4000i ion chromatograph. The absorption column separates chemical ions in a carrier solution into distinct bands based on their affinity for the absorbant. Concentrations of individual ions are determined using an electrical conductivity detector and comparing the areas under their curves on the chromatogram with those of a calibration curve. Results are expressed as PPM (mg/L) of NO_3 and PO_4. QA/QC data were analyzed and a report generated. The QA/QC procedures consisted of generating a calibration curve using six calibration standards at the beginning of the run and drift correcting against the single highest standard at the end of the run. A normal run contains approximately 50 samples, two pair of duplicated samples and two in-house standard reference material samples, one at the beginning of the run and one at the end. Lab protocol dictates that duplicates and SRM's be in tolerance of less than 10% for means greater than .50 mg/L; 5% for means less than .50 mg/L or the run is not valid. In actuality, the error rates for the Yellowstone samples were far less. The 1989 data was not available at the time of this paper preparation because the data had not been sufficiently transferred to the computer for analysis.

Results

Nitrate and phosphate levels on the reference stream, Amphitheatre Creek remained constant throughout the recording periods (June - September). Due to the stable nature of the concentrations on Amphitheatre Creek, sampling was discontinued after the 1991 season, although the data provided a baseline to relate the other stream concentrations to our reference. Nitrate concentrations on Amphitheatre Creek averaged 0.3 mg/L during June/July 1990 and 1.0 mg/L during August/September 1990. Phosphate concentrations peaked at 0.3 mg/L during precipitation events in late August and late September of 1990, and again in late July of 1991. Phosphate concentrations remained relatively stable at, or under, 0.15 mg/L during the remainder of the recording period.

Blacktail Deer Creek, an intensily burned watershed, exhibited nitrate concentration averages 4 to 10 times greater than Amphitheatre Creek with short-term concentrations 20 to 30 times the average for Amphitheatre. The short-term, elevated concentrations, generally coincided with precipitation events. The phosphate concentrations for Blacktail Deer Creek exhibited average levels of approximately 0.3 mg/L, with peaks over 2.0 mg/L. These phosphate levels are 2 to 10 higher than Amphitheatre concentrations. Both nitrate and phosphate concentrations for Blacktail Deer Creek were highest during 1992, although individual peak concentrations were highest during the 1991 period.

Cache Creek, a severely burned watershed, exhibited high nitrate concentrations during the whole monitoring period. Average concentrations from 1990-1993 were 3.5 mg/L with short-term peak concentrations well above 10.0 mg/L. These levels are 10-33 times greater than on Amphitheatre Creek. The highest average nitrate concentration occurred during 1992. Phosphate concentrations averaged 0.4 mg/L during recording periods, with one peak occurring 13 August 1990 (3.2 mg/L) and another occurring 18 June 1993 (8.74 mg/L). These levels are 2.7-29 times greater than our reference watershed.

The Lamar River, a mixed burned composition watershed above our sampling station, exhibited nitrate concentrations of 1.5 mg/L with numerous peak levels at or near 8.0 mg/L. For the 1990-1993 period, concentrations were consistently higher during early June, decreasing at a constant level through late September. Nitrate levels were 5 times higher on average while peak concentrations were 8 times higher on average than peak concentrations occurring on Amphitheatre Creek. The Lamar River phosphate concentrations averaged 0.2 mg/L, with the highest average occurring in 1990. The highest peak concentration occurred 12 June 1992 (12.66 mg/L). These concentrations are 1.3 times higher than our reference average, although peak concentrations are 42 times higher than peak concentrations in Amphitheatre Creek.

The Snake River, a moderately burned watershed above our sampler, exhibited pronounced nitrate pulses related to snow melt and precipitation events. Concentrations averaged 1.5 mg/L with peaks of 5.0-5.2 mg/L. These levels are 5 times greater than the Amphitheatre average, while peak concentrations were 5.2 times greater than peak Amphitheatre concentrations. The Snake River phosphate concentrations were very low during our recording periods, although peak concentrations occurred during precipitation cycles and were from 0.1-0.8 mg/L. The average phosphate concentration was below that of Amphitheatre Creek, although peak concentrations following precipitation events were 2.6 times greater. Due to the size of the Snake watershed and the degree of mixed burning above our sampling station, the values for the Snake may be no different than occurred in normal years before fires.

Soda Butte Creek, a lightly burned watershed, exhibited uncommon nitrate concentration patterns. Concentrations remained low, averaging approximately 0.8 mg/L, although frequent peaks occurred between 4-8 mg/L. The highest peak concentration occurred on 15 September 1992, when nitrate concentrations were measured at 27.09 mg/L. These average levels are 2.6 times greater than Amphitheatre, while peaks were 4-27 times greater. Phosphate concentrations exhibited similar characteristics. Averages were similar to Amphitheatre Creek, although periodic peak concentrations were 8.4-11.8 times greater. All stream nitrate and phosphate concentrations are summarized in Table 3.

Conclusions

The Greater Yellowstone Ecosystem fires of 1988 allowed us the unique opportunity of analyzing the effects of various burn intensities on stream NO_3 and PO_4 dynamics. We analyzed infrared and thermal digital scanner data collected both during and following the fires to determine the intensity of burning in watersheds dominated by old-growth Lodgepole pine communities. Subsequent data collection missions were undertaken in order to monitor the ecosystem recovery effort. We chose six watersheds with varying burn intensities for further stream analysis. Burn intensities were in those watersheds were grouped as severe, moderate, mixed, lightly burned and unburned. In those streams, both nitrate and phosphate concentrations were measured to determine the influence of burn intensities on NO_3 and PO_4 concentrations. Previous studies by Riggan et al. (1985) in southern California (chaparral community), have indicated stream nitrate changes in severely burned watersheds are 10 to 60 times greater than from unburned watersheds, and 7 to 8 times greater than from moderately burned watersheds. We found similar results in our studies in Yellowstone. Unburned watersheds exhibit little or no change in their stream chemical makeup.

In Yellowstone, we recorded nitrate concentrations that were 4 to 33 times greater on average than reference levels, while peak levels were 10 to 33 times greater. As expected, concentrations in moderately burned watersheds were lower, averaging 5 to 8 times higher than our control stream. Soda Butte Creek, a lightly burned watershed, exhibited nitrate concentrations 2 to 6 times greater than levels recorded on Amphitheatre Creek, while peak concentrations were 4 to 27 times greater. For all streams, higher concentrations (than Amphitheatre) were recorded for all five years of the study. The short-term peak levels suggested by Spencer and Hauer (days to weeks), following major watershed fires, may be consistent with our findings, although our sampling of burned watersheds did not occur until the following spring season, eight months after the fires. Our research suggests that the concentrations may persist for longer periods of time than Spencer and Hauer suggest.

Table 3. Nitrate and phosphate concentration levels in Yellowstone National Park watersheds under various burn intensities as compared to the control stream, Amphitheatre Creek. The ranges relate to the peak concentration conditions encountered.

Stream Watershed	Burn Condition	Nitrate Levels	Phosphate Levels
Amphitheatre Creek	Unburned Reference	0.3 - 1.0 mg/L	0.1 - 0.3mg/L
Soda Butte Creek	Lightly Burned	2.6 times Greater	0 - 11.8 times greater
Lamar River	Mixed Burn	5.0 times greater	1.3 times greater
Snake River	Mixed Burn	5.2 times greater	2.6 times greater
Blacktail Deer Creek	Moderately Burned	4 to 10 times greater	2 to 10 times greater
Cache Creek	Severe Burn	10 to 33 times greater	2.7 - 29 times greater

Phosphate concentrations in severely burned watersheds exhibited a 2 to 29 time increase over Amphitheatre Creek concentrations. Phosphate concentrations were 1 to 2 times greater in moderately burned watersheds than our unburned watershed. Peak concentrations were up to 42 times greater, although most peaks, following precipitation events were 2 to 3 times greater. We documented significantly lower phosphate concentrations in our lightly burned watershed, Soda Butte Creek. Concentrations were on par with Amphitheatre Creek, although peak discharges were measured at 8 to 12 times greater than peak discharges on Amphitheatre Creek.

Results of our field and lab investigations strongly suggests that fire intensity, temperature and fire duration play a dominant role in determining downstream NO_3 and PO_4 composition. Our results also indicate that the duration of stream nitrate and phosphate concentrations are long-term, possibly affecting watersheds in excess of five years. The nitrate and phosphate levels in our monitored watersheds were consistently elevated above the levels recorded for the unburned watershed. Peak concentrations, coinciding with periodic precipitation events, were highly elevated above both Amphitheatre Creek as well as above the levels on the individual burned watersheds. This suggests that the burn severity controls the runoff potential (leaching) of the nitrates and phosphates by regulating the entrapment power of remaining or new biomass material. We suggest that peak concentrations on severely burned watersheds were much more elevated because of the increased runoff from those sites, where little or no biomass material on or above the soil structure impeded increased erosion flows. Conversely, the less severe burn areas retained more biomass, thereby restricting runoff, erosion, and nutrient transport into the stream ecosystem.

The authors conclude that burn severity can be modeled from remotely sensed data, that the severity of burning contributes to increased erosion and runoff, and that increased erosion and runoff help regulate the nitrate and phosphate nutrient influxes in streams and water bodies. NO_3 and PO_4 concentrations remain at an enhanced level for extended periods of time, and receive periodic pulses immediately following precipitation events. Our continual monitoring of the recovering Yellowstone National Park watersheds should enhance our knowledge of long-term environmental and aquatic alterations following major conflagrations.

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Postscript

The material presented at the 1993 Second Biennial Conference on the Greater Yellowstone Ecosystem: The Ecological Implications of Fire in Greater Yellowstone, September 19-21,1993 and in this proceedings paper are a summation of the researchers ongoing efforts in Yellowstone National Park. Similar material, data and results were presented at another venue, The Second Thematic Conference on Remote Sensing for Marine and Coastal Environments. Portions of this paper are derived, with consent, from an article prepared by V.G. Ambrosia, et al. entitled, "Long-Term Dynamic Stream Nitrate And Phosphate Changes Following Watershed Wildfires." The sole intent of this article is to consolidate materials presented at the Yellowstone Conference and to provide a summation of the research to a different readership.

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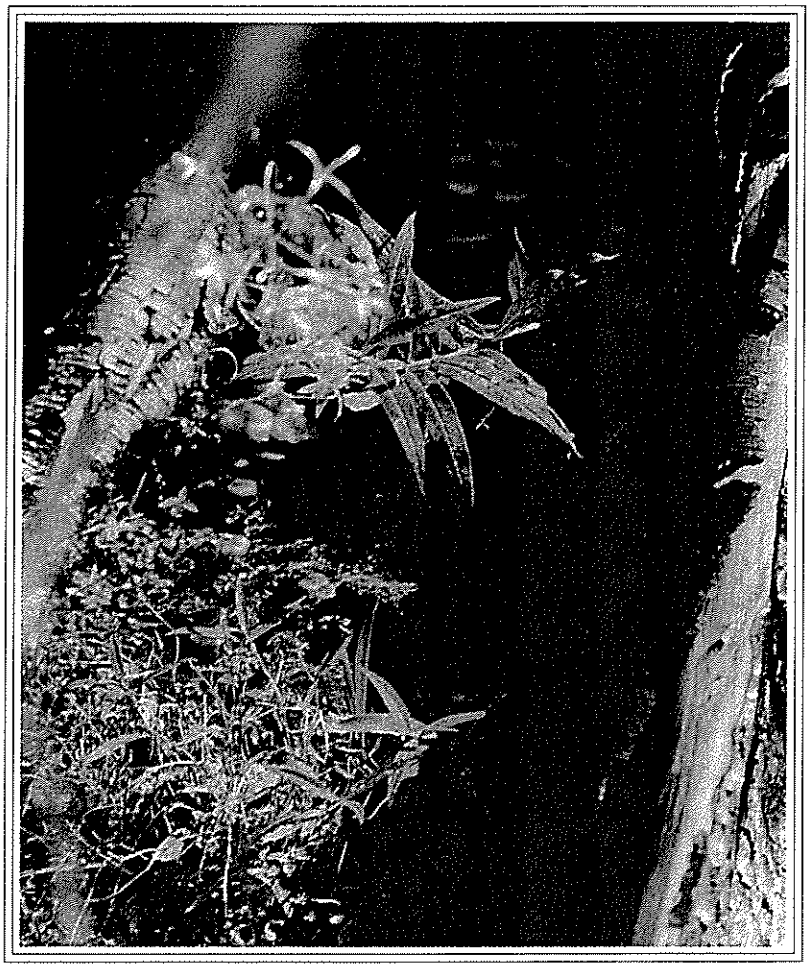

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