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Wildfire effects on forest carbon and nutrient budgets

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ABSTRACT

A wildfire burned through previously established research plots, allowing comparisons of pre- and post-fire nutrient pools and fluxes. The Gondola fire resulted in the loss of 30.9 mg ha^{-1} of C and 510 kg ha^{-1} of N, mostly by the combustion of forest floor and vegetation. Mineral N leaching was accelerated for 3 years after the fire, but accounted for only 19 kg ha^{-1} of the total N loss. Potential inputs of P by ash were small relative to soil extractable pools and no significant changes in soil extractable P were noted. No changes in exchangeable K^{+} were noted, even though inputs by ash could have been detected, suggesting that K was lost either during or after the fire. Similarly, decreases in soil exchangeable Mg^{2+} were noted even though ash inputs should have caused notable increases, suggesting Mg loss either during or after the fire. The increases in soil-exchangeable Ca^{2+} were large, but only marginally significant ($P = 0.09$) and fell within the error bounds of what could have been input from ash. Comparisons with a nearby site that burned >20 years previously suggest that ecosystem C pools will not be made up for until trees are re-established at the Gondola fire, whereas N losses could be more than made up for within 20 years if N-fixing vegetation colonized the site.

1. Introduction

Wildfire has substantial and lasting effects on the nutrient budgets of forest ecosystems (e.g., Baird et al., 1999; Dyrness et al., 1989; Grier, 1975; Johnson et al., 1998, 2005; Neary et al., 1999; Rasion et al., 1985; Trabaud, 1994). Because of its low volatilization temperature, most nitrogen (N) in fuels that burn is lost to the atmosphere (Neary et al., 1999; Rasion et al., 1985), and simple calculations reveal that even infrequent fire can have large impacts on the long-term N budgets of forest ecosystems (Johnson et al., 2004). Volatilization temperatures of S, P, and K are somewhat higher, and varying amounts of these elements are lost via volatilization depending upon fire severity. Volatilization temperatures for Ca and Mg, on the other hand, are sufficiently high that they are usually not volatilized and are either left behind in ash or lost by convective or particulate transport (Neary et al., 1999).

While there are many studies of the effects of prescribed fire on nutrient budgets (Belillas and Feller, 1998; Caldwell et al., 2002; Neary et al., 1999; Certini, 2005), nutrient budgets for wildfire are rare because of the lack of suitable comparable control sites and/or lack of pre-fire data. Hence, the effects of wildfire on nutrient budgets are usually assessed after the fact using nearby forests as controls (e.g., Baird et al., 1999; Dyrness et al., 1989; Grier, 1975; Johnson et al., 1998, 2005; Neary et al., 1999; Rasion et al., 1985; Trabaud, 1994).

We had the opportunity to directly measure the nutrient changes due to wildfire when the Gondola fire burned through approximately half (7 of 16) of a set of plots that we had previously established in the Lake Tahoe basin near Stateline, Nevada, USA. This allowed us to study the before and after effects of a wildfire, including unburned control plots. In a previous paper on this site (Murphy et al., 2006), we reported on the effects of this wildfire on forest floor C and nutri-

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ent contents, soil leaching, and soil chemistry. In this paper, we combine the soil nutrient concentrations and forest floor losses reported by Murphy et al. (2006) with previously unreported data on soil bulk density to calculate changes in soil C and nutrient contents as well as changes in the C and nutrient contents of vegetation and downed woody debris as a result of the fire. We have also measured N and P leaching from soils with resin lysimeters, allowing the calculation of a complete budget including soluble losses of these nutrients for the Gondola wildfire. We compare these results to those published in the literature for other wildfires, which in most cases do not include pre- and post-fire collections as we have in this study.

2. Site

The Gondola wildfire site is located on the southeastern portion of the Lake Tahoe basin in Nevada just north of the Nevada-California state line. The site ranges in elevation from approximately 1950 m to 2100 m and receives 87 cm of average annual precipitation, most of which occurs as snow during winter and spring precipitation. Overstory vegetation is characteristic of a typical Sierra Nevada mixed conifer forest type consisting of Jeffrey pine (*Pinus jeffreyi* [Grev. and Balf.]), white fir (*Abies concolor* [Gord. and Glend.] Lindl.), and a scattered distribution of sugar pine (*Pinus lambertiana* [Dougl.]) and incense-cedar (*Calocedrus decurrens* [Endl.]). Understory vegetation consists primarily of green leaf manzanita (*Arctostaphylos patula* [Green]) and ceanothus (*Ceanothus velutinus* [Dougl.]). Soils are the Cagwin Series, coarse, loamy sand, mixed Typic Cryosamments derived from granite.

3. Methods

Sixteen 400 m^2 research plots were established in the fall of 2001 and baseline sampling was initiated the following spring. A wildfire occurred in July of 2002, completely burning five plots and partially burning four others. All of the five completely burned plots and two of the four partially burned plots had been previously sampled for forest floor and soil nutrients. In this analysis, we report the results from the five completely burned plots only.

3.1. Vegetation biomass and nutrient content

Tree biomass was estimated from measurements of diameter at breast height (dbh, or 137 cm) within each plot and applying the regression equations provided by Gholz et al. (1979). Counts of saplings (>1.37 m tall to ≤10.1 cm dbh) and seedlings (≤1.37 cm tall) by species were made in 54 m^2 and 40 m^2 subplots, respectively. Biomass of seedlings and saplings was estimated by the count of trees in the subplot and average biomass by component (foliage, branch, bole) of nine sample trees encompassing a range of diameters and multiplying this value by the total count. The biomass of saplings and seedlings before the fire was less than 1% of total vegetation biomass. The 54 m^2 subplots were also used for mapping of shrub and herbaceous understory species, permitting expression of the prevalence of individual species on a percent ground cover basis. In order to also express their prevalence on a dry weight basis, five samples of known ground cover area were collected from random locations for each species, dried and weighed. For shrub species, each sample consisted of all tissues occupying a ground area of 0.093 m^2, while 0.01 m^2 was used for herbaceous species. Total herbaceous and shrub biomass before the fire accounted for less than 1% of total vegetation biomass.

Tree nutrient contents were calculated from concentrations measured on foliage, branch, and boles of samples from live trees taken before the burn. Samples were ground in a Wiley Mini-Mill (Thomas Scientific, Swedesboro, NJ) and analyzed using a Jarrell Ash ion coupled plasma spectrophotometer (Thermo Jarrell Ash Corp., Franklin, MA) after microwave digestion via a nitric acid hydrogen peroxide mixture at A&L Western Agricultural Laboratories (Modesto, CA). Total C and N were analyzed using a dry combustion C and N analyzer (LECO, St. Joseph, MI) at the Oklahoma State.

3.2. Forest floor and large woody debris sampling

Prior to the fire, forest floor samples were collected from five random locations in each study plot from a litter ring of 0.07 m^2 in area (Murphy et al., 2006). Samples were taken according to horizon (Oi, Oe, and Oa), and non-foliar up to 2.54 cm in diameter material was placed into the category of "other". Post-burn samples were taken 1 m north of pre-burn sample locations within the burned plots. We did not resample the forest floor in the control area after the fire, assuming that net changes in it would be minor. Pre-burn Oe and Oa samples were floated in water to remove mineral material. Post-burn Oe and Oa samples were not floated in water due to the possible dissolution of any remaining ash and organic material that did not undergo complete combustion. Instead a 0.84 mm standard testing sieve was used to separate the mineral from the organic fraction in the post-burn samples. This size sieve proved to be sufficient in allowing smaller diameter material to pass through the sieve while retaining the organic fraction and larger diameter mineral material, which was subsequently removed by hand.

Large woody litter was inventoried by the methods of Pyne (1996). For 100 h (>2.54 to <7.6 cm diameter), and 1000 h (>7.6 cm diameter) fuels, a single 4 m^2 and a single 54 m^2 subplot (respectively) were established in the center of each 400 m^2 plot. 100 h fuels within the 4 m^2 plots were collected, dried to a constant weight, and later returned to the plot, minus a small subsample for nutrient analysis. For the 1000 h fuels, notation was made as to whether each piece was sound or decayed, and then lengths and mid-point diameters were recorded for calculation of the volume according to the Huber formula (Avery and Burkhart, 2002). Collection of 10 log sections from random locations, measuring their dimensions, and then drying and weighing them provided a density constant for use in converting volume to weight. Pre-burn samples were taken during May and June of 2002 and post-burn samples taken during September of 2002.

All forest floor samples were oven dried at 55 °C, weighed separately, and then bulked together in the laboratory by