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Nitrogen Contents and Fluxes in Sierra Nevada Forests of California

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Introduction

Nitrogen (N) is an essential nutrient for vegetation, but in excess it can be a stressor to vegetation, cause acidification of soils and water, and water eutrophication. Thus it is important to understand the N budget (inputs, storage, and outputs) to evalutate forest health and recommend management options. N content and fluxes in mixed conifer forests are being studied at the Kings River Experimental Watersheds (KREW). Soon the effect of prescribed fire and tree harvesting on N in various components of the ecosystem will be evaluated.

Until recently, little was known regarding the thresholds at which various ecosystems in California are impacted by chronic N deposition. Fenn et al. (2010) report the current understanding of the empirical critical loads (CLs) of N deposition at which undesirable effects are observed for mixed conifer forests in California: 17 kg N ha^{-1} yr^{-1} for leaching to water and 3 to 5 kg ha^{-1} yr^{-1} for lichen responses. They conclude that Mediterranean forests are less prone to NO_3^- leaching than temperate catchments. Management options for relieving N stress on forests are prescribed fire at repeated intervals in combination with reduced N deposition.

Study Area

KREW is an integrated ecosystem study that measures physical, chemical, and biological attributes. It was established in 2000 and consists of eight instrumented watersheds between 1,500 and 2,500 meters (Figure 1). The perennial, headwater streams are small with narrow riparian areas (Figure 2) and are located in steep topography with granite derived soils (Figure 3). Precipitation is about the same at both sites, but the Providence site is at the rain-snow transition zone and the Bull site is snow dominated.

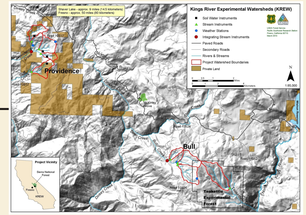


Figure 1. The Kings River Experimental Watersheds (KREW) is located on headwater tributaries of the Kings River in the Sierra Nevada Mountains of California. KREW consists of two sites approximately 15 km apart: Providence Creek and Bull Creek watershed clusters.

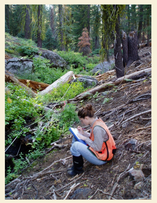


Figure 2. Headwater stream located in Teakettle Creek watershed.

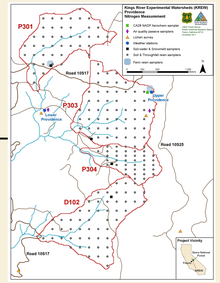


Figure 4. Nitrogen measurement instrument locations in the Providence Creek site.

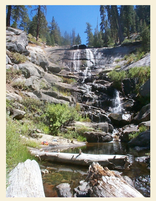
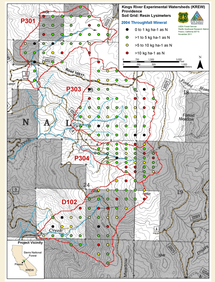


Figure 3. Waterfall on B204 stream located in the Bull Creek site.

Figure 5. Nitrogen measurement instruments (left to right): air quality passive sampler, NADP aerochem sampler, Fenn resin sampler and Snowmelt sampler.

Methods

We are measuring N deposition and fluxes using different techniques in an effort to compare methods and accurately quantify amounts in this area of steep terrain and dense forests (Figure 4). Air concentrations are measured using passive samplers at 2-week intervals (Bytnerowicz 2005). Wet deposition is measured with the National Atmospheric Deposition Network's aerochem sampler every week. Bulk throughfall is measured annually with two types of above-ground resin collectors: short columns that sit on the ground at 470 points and longer columns (Fenn) mounted above ground in two clusters at the Providence site. Snowmelt collectors provide bulk throughfall samples every two weeks. Soil water fluxes are sampled annually with resin collectors in the shallow mineral soil at 470 points and at 2-week intervals during the wet season with vacuum lysimeters at four locations. Lichens are a sensitive indicator of air pollution; a one-time lichen survey was conducted.



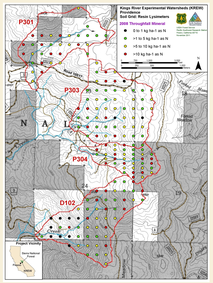
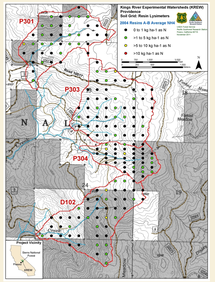


Figure 6. Comparison of 2004 and 2008 total N throughfall in Providence Creek site. Annual throughfall in 2004 is predominately in the 1 to 5 kg range with many locations receiving more than 5 kg per ha.



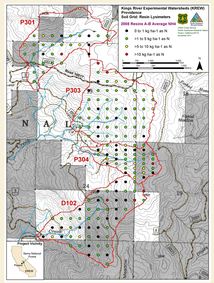
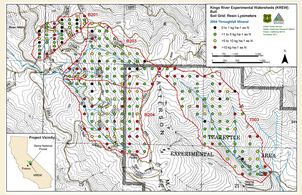


Figure 8. Comparison of 2004 and 2008 NH4-N flux to mineral soils in Providence Creek site.



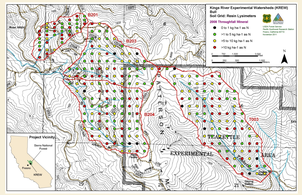
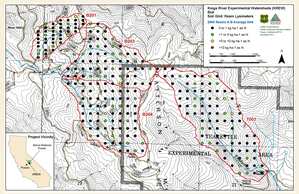


Figure 7. Comparison of 2004 and 2008 total N throughfall in Bull Creek site.

Annual throughfall for total N (NO3-N + NH4-N) in Providence (Figure 6) is lower than in Bull (Figure 7). As detected with the Fenn resins in Providence (Figure 11), throughfall values were substantially higher in 2008 at both sites. NH4-N flux to mineral soils (13 cm) is mostly < 1 kg with a few points at > 5 kg (Figures 8 and 9). Like throughfall, the flux to mineral soils significantly increased in 2008. Total precipitation in 2004 was average at 95 cm while 2008 precipitation was slightly higher at 115 cm. There is no obvious pattern or landscape-attribute correlation for high values across the watersheds.



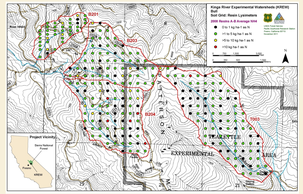


Figure 9. Comparison of 2004 and 2008 NH4-N flux to mineral soils at 13 cm in Bull Creek site.

Results

Five years of using passive samplers during the summer months show that the concentration of N components in air is moderate to moderately high (Figure 10). The Providence site usually experiences higher levels of both HNO3 and NH3 (summer averages 2.4 and 4.3 µg m^{-3}) than the Bull site (1.2 and 4.2 µg m^{-3}). Background levels of HNO3 in summer should not exceed 0.4 µg m^{-3}, while those for NH3 in remote mountain locations in North America should be less than 1 µg m^{-3}. Above-ground ion-exchange resin columns (2006-2009) show that total inorganic N deposition under the forest canopy at Providence ranged from 5.6 to 11.3 kg ha^{-1} (Figure 11). Under the forest canopy N deposition is significantly higher than in the open; open areas are receiving more NH4-N than NO3-N. A smaller type of resin collector, placed on the ground at a grid spacing of 150 m (470 locations), provides spatial resolution to N fluxes (Figures 6 to 9). These resins measured annual inorganic N deposition ranging from 5 to 11 kg ha^{-1} yr^{-1} during the 2004-2008 sampling period in the Bull watersheds and from 3 to 10 kg $ha^{-1}yr^{-1}$ in the Providence watersheds. Fluxes of inorganic N in the shallow mineral soil varied considerably by year, ranging from 2-3 kg ha^{-1} yr^{-1} in both Bull and Providence watersheds in 2004 to 6-16 and 6-20 kg ha^{-1} yr^{-1} in the Providence and Bull watersheds, respectively, in 2008. Reasons for the large inter-annual variation are still under investigation, but point to the need for good controls and background data in order to properly assess treatment effects. Johnson et al. (2011) report nutrient hot spots at both the sub-meter and 2-m distances; we also see them at the 150-m scale (Figures 8 and 9).

Although atmospheric deposition is moderately high, it is not close to the empirical critical load that can cause N leaching to water (17 kg N ha^{-1} yr^{-1}). Water quality of the streams is quite good as one would expect from mountain headwaters where no new land disturbance has occurred for years. Nitrogen is seldom above the detection level (0.05 mg L^{-1}) in the Bull site, and the Providence site has streams with a small spring nitrate pulse. Inorganic N is also not detected very often in the water collected from snow melt.

Pathways of streamflow were determined for KREW using geochemical tracers (Ca^{2+}, Mg^{2+}, K^+, and Cl^-) and endmember mixing analysis. Three endmembers were determined: near-surface runoff from snowpack and spring rainstorms, fall rainstorm runoff, and baseflow. Near-surface runoff contributed more than 50% of streamflow on average at six catchments, whereas baseflow made up greater than 60% of streamflow at the other two catchments. Fall rainstorm runoff contributed less than 6% on average. This information about hydrologic processes should assist in understanding both water yield and nutrient processing after land treatments.

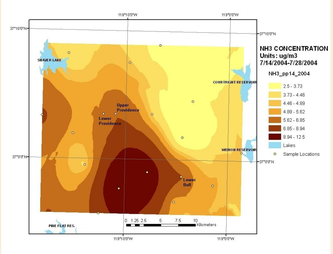


Figure 10. Summer ammonia concentrations from air quality passive samplers located in the research area (Hunsaker 2007).

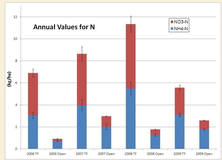


Figure 11. Nitrogen deposition measured by Fenn resin samplers located in the Providence site.

Collaborators

M. Fenn and A. Bytnerowicz, Pacific Southwest Research Station, Riverside. This study area is also the National Science Foundation's Southern Sierra Critical Zone Observatory and will be part of their National Ecological Observatory Network.

On the Web

KREW: http://www.fs.fed.us/psw/programs/snrc/water/kingsriver

Southern Sierra Critical Zone Observatory: https://snri.ucmerced.edu/CZO

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