Community-specific biogeochemical responses to atmospheric nitrogen deposition in subalpine ecosystems of the Cascades

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Abstract

The capacity of subalpine vegetation communities to assimilate atmospheric nitrogen (N) deposition (N_{dep}) during snowmelt remains unknown, particularly with climate-induced snowpack loss. This study uses a synergistic modeling and experimental approach to determine community-specific impacts of elevated N_{dep} on biogeochemical processes in the lush-herbaceous, heath-shrub, and wet sedge communities at Mount Rainier National Park. Here we present preliminary results which indicate that fluxes of soil nitrous oxide (N_2O) emissions are highest in the wet sedge community at ambient levels of N_{dep} and compare these data to model output. Future research will evaluate the sensitivity of the Regional Hydro-Ecologic Simulation System (RHESSys) model to changes in N_{dep} by comparing parameterized model output to field measurements. Ultimately, this study will provide insight to policymakers and land managers on how N_{dep} and climate change affect ecosystem services in wilderness areas.

Introduction and Approach

In subalpine ecosystems, winter snowpack acts as a reservoir for N_{dep} (Bowman, 1992). Rapid snowmelt may cause a sudden flux of N_{dep} into saturated soils, which could negate the ability of subalpine communities to assimilate N_{dep} (Daly, 1997; Clow et al., 2008). At higher N_{dep} inputs, subalpine ecosystem become saturated with N, causing ecosystem N loss through emissions of nitrous oxide (N_2O), a potent greenhouse gas, or through leaching into montane watersheds. Chronic N_{dep} can also lead to decreases in plant and microbial biodiversity and productivity (Fig. 1)(Aber et al., 1989; Neff et al., 1994; Mack et al., 2004).

To evaluate the impacts of N_{dep} on subalpine ecosystems, this study uses biogeochemical modeling to inform field research design, the results of which will parameterize the final model scenarios. Preliminary modeling was conducted in 2012 using the DayCent model, which guided the field research performed in 2013 at Mount Rainier National Park (Fig. 2). These field results are currently being implemented into RHESSys model parameterization and development.

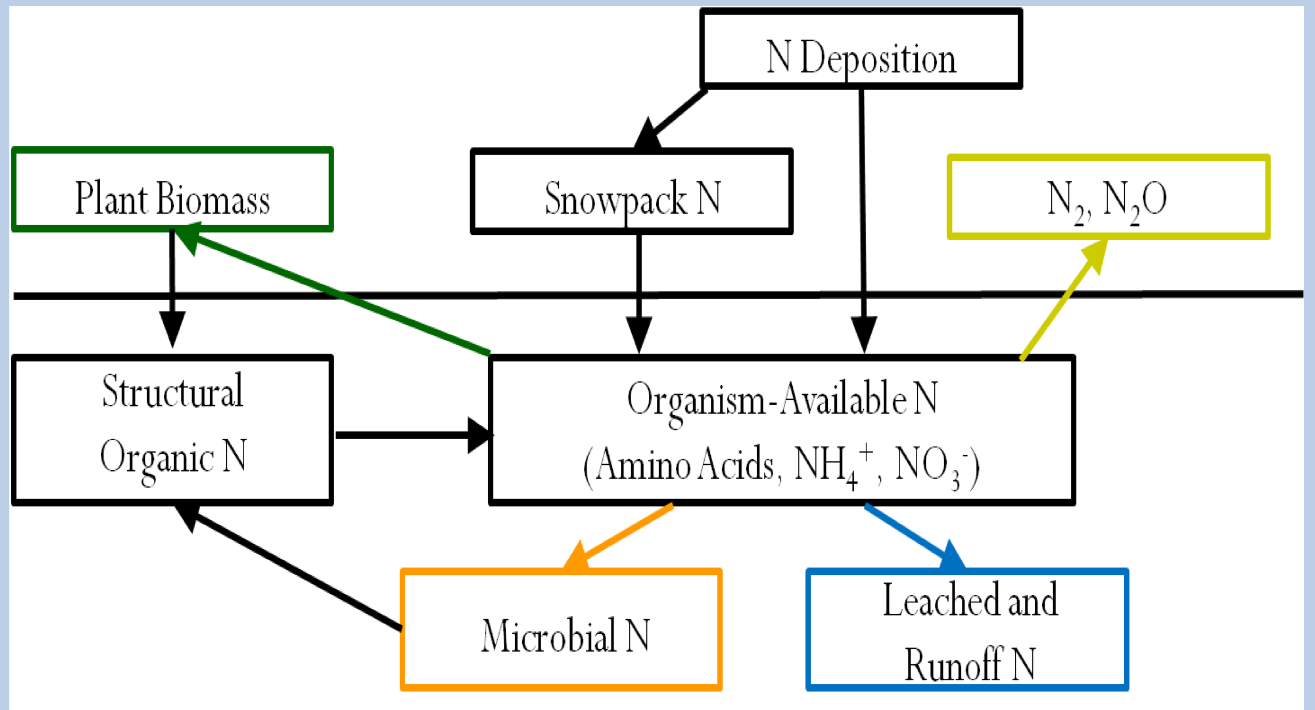

Figure 1. Atmospheric N deposition increases the soil organism-available N pool, elevating N availability for plant uptake and microbial immobilization. High N_{dep} rates can cause saturation and ecosystem N loss by increasing inorganic N leaching and soil N emissions.

DayCent Model Simulations

DayCent is a modified version of the CENTURY model that calculates biogeochemical fluxes on a daily timestep (Parton et al., 1987). Preliminary DayCent simulations were parameterized to the soil, plant communities, and climate of the subalpine meadows of Mt. Rainier at ambient (4 kg N ha^{-1} yr^{-1}) N and elevated (9, 14, and 34 kg N ha^{-1} $year^{-1}$) deposition rates using values from primary literature (Henderson, 1973; Douglass and Bliss, 1977). These simulation results indicated that elevated N_{dep} increases soil NO_3^- leaching rates, N_2O emissions, microbial immobilization, and plant N uptake, with the greatest biogeochemical activity occurring during snowmelt (Fig. 3).

Figure 2. The study location is in the subalpine ecosystem of Paradise in Mount Rainier National Park. A plot frame, used in plant monitoring, and a gas chamber, used to measure soil emissions, are in the foreground.

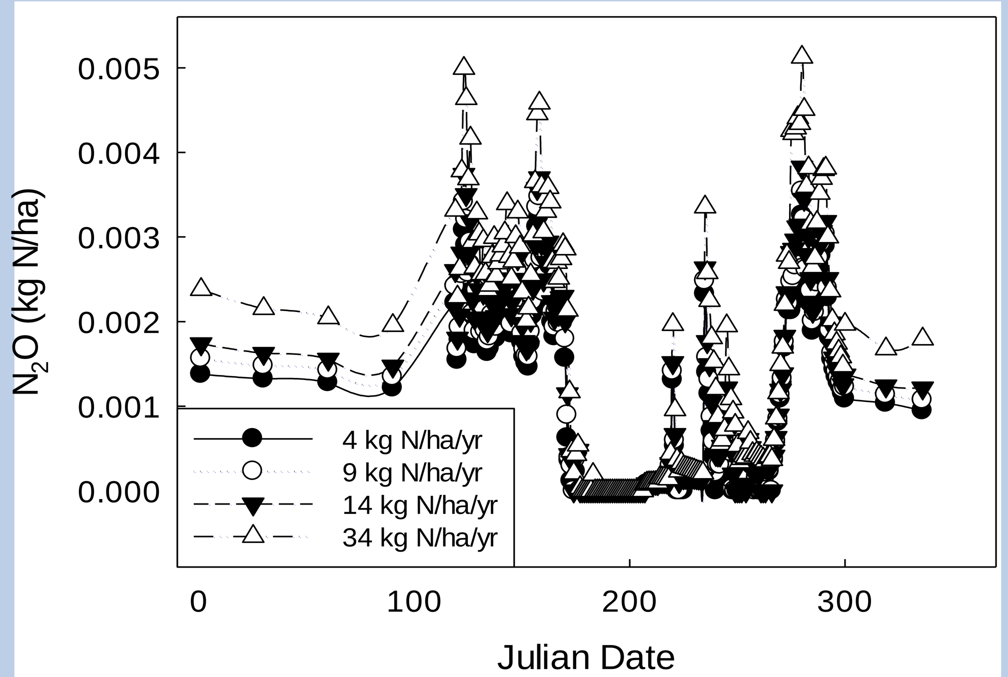

Figure 3. DayCent simulations indicated that soil N_2O emissions increase with elevated rates of N_{dep} (9, 14, and 34 kg N ha^{-1} yr^{-1}) and that snowmelt (150 to 190 days) may be a biogeochemical hot moment.

Model Performance against Field Results

In 2013, field research was conducted to measure changes in N pool and flux sizes between soil NO_3^- leaching, soil N_2O emissions, microbial immobilization, and plant N uptake (Fig. 4). Additionally, soil carbon (C) and N, bulk density, temperature and moisture, and plant biomass were measured to inform the N flux results and parameterize the modeling efforts. These field measurements were used to update the parameterization of the DayCent model. Model simulations were performed using local meteorological data for 2013 under ambient N_{dep} rates to compare model performance to field results (Figs. 4-6).

A repeated measures analysis of variance (RM ANOVA) of the field results indicated that there are marginally significant differences in the magnitude of field soil N_2O emissions between subalpine vegetation communities for each sampling period ($p=0.076$). The peaks and troughs of N_2O emissions in each community are dynamic and fluctuate with soil temperature and moisture. In contrast, the model output showed little change throughout the growing season, with the wet sedge community remaining particularly stable. These differences may be due to dissimilarities between static model output of soil moisture against the extremely variable field conditions.

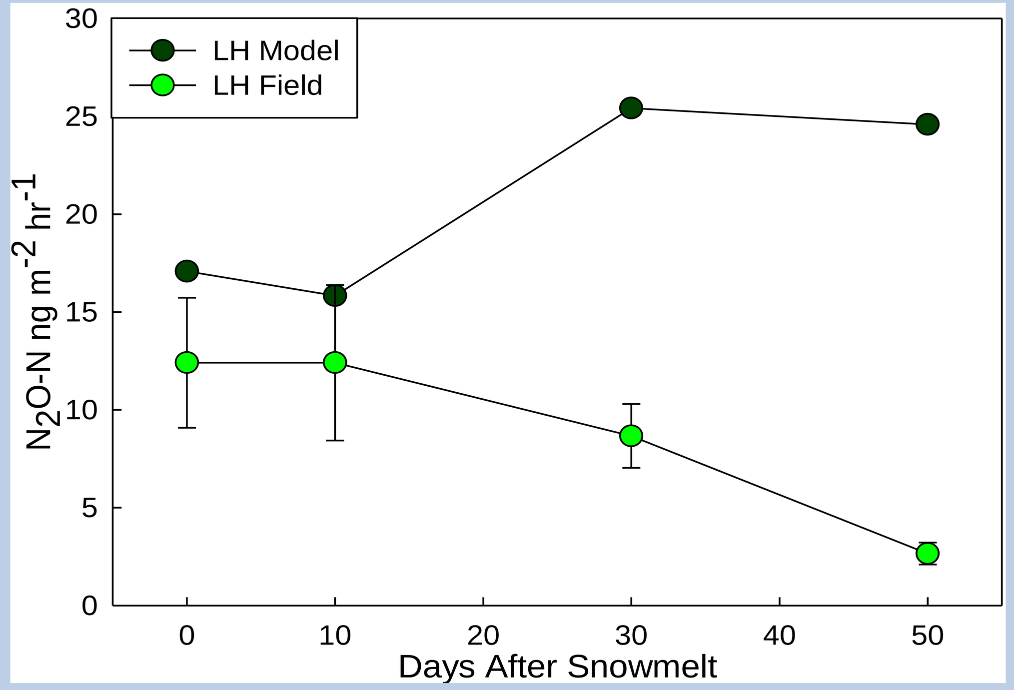

Figure 4. Peak emissions occurred in the first 10 days following snowmelt in the field measurements of the lush-herbaceous (LH Field) community. The modeled results (LH Model) were consistently higher than the field, peaking at 30 days after snowmelt.

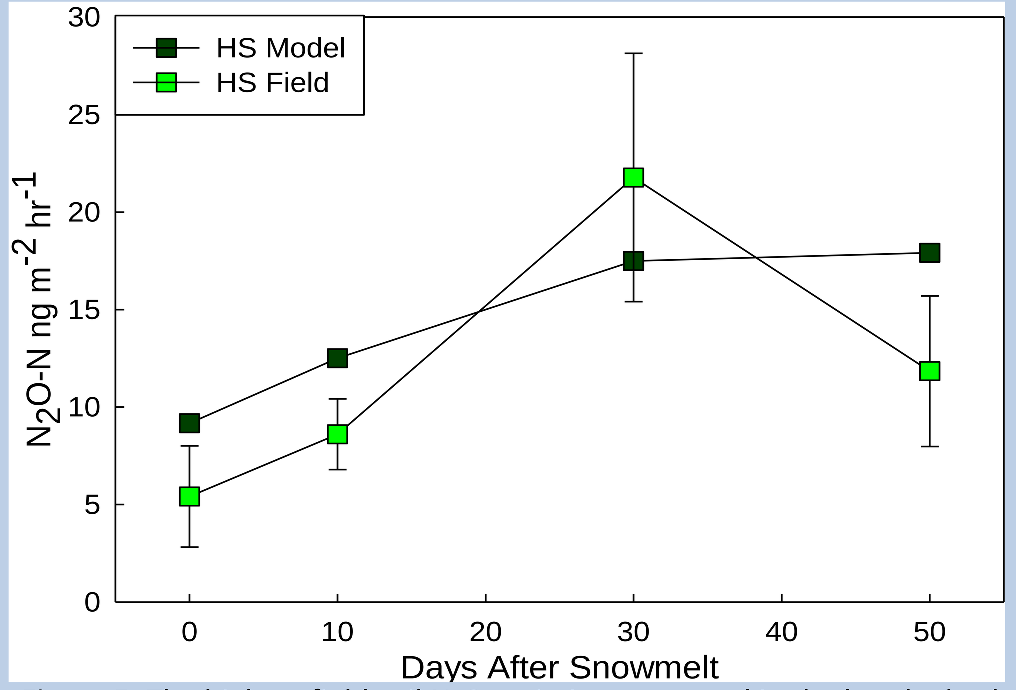

Figure 5. The highest field soil N_2O emissions occurred in the heath-shrub (HS Field) 30 days after snowmelt was complete in each community. The modeled N_2O fluxes (HS Model) generally followed the same trend but remaining more consistent throughout the growing season.

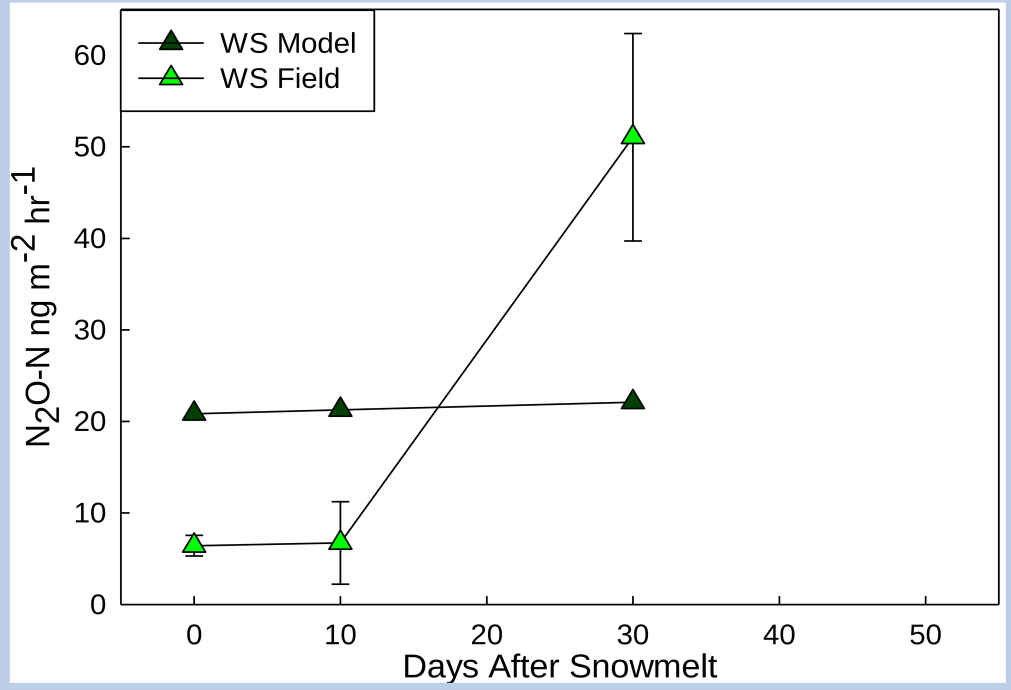

Figure 6. The wet sedge community (WS Field) had the highest N_2O fluxes of the field season, peaking 30 days after snowmelt. The model (HS Model) was unable to capture this variability, potentially due to the stability of modeled soil moisture compared to field conditions.

Future Research

- Ongoing laboratory measurements of field samples will be used to establish predictive relationships of N fluxes with other ecological variables (e.g. soil temperature, vegetation functional type) in subalpine ecosystems.
- In 2014, experimentally manipulated N_{dep} rates (0, 3, 5, and 10 kg N ha^{-1} yr^{-1}) will be applied as mixture of NH_4^+ and NO_3^- to evaluate changes in measurements of soil nitrous oxide (N_2O) emissions, soil nitrate (NO_3^-) leaching, microbial immobilization, and plant N uptake in order to determine a potential N_{dep} threshold for ecosystem N loss in subalpine communities.
- The RHESSys model has recently been adapted to include production of soil N_2O emissions from nitrification and denitrification. Preliminary simulations of ecosystem N partitioning using RHESSys parameterized with field measurements are in progress. Future simulations will evaluate the impacts of climate change and elevated N_{dep} on the provision of subalpine ecosystem services across the Cascade Range. Through collaboration with the National Park Service, these results will be used to inform land managers, policymakers, and the public of the impacts of elevated N_{dep} to high-elevation wilderness areas (Fig. 7).

Figure 7. Class 1 wilderness areas, such as North Cascade National Park, are at the greatest risk of damage by elevated rates of N_{dep}. Policymakers land managers, and scientists need to collaborate to mitigate the impacts of N_{dep} and protect these fragile ecosystems.

Materials and Methods

The study location is in the subalpine ecosystem of Paradise Park in Mount Rainier National Park at an elevation of 1930 m (N 46°47, W 121°43). The three subalpine vegetation communities that are being investigated are the lush-herbaceous type characterized by *Valeriana* spp., wet-sedge type dominated by *Carex nigricans*, and heath-shrub type characterized by *Phyllodoce* spp. and *Vaccinium deliciosum*. Soil N_2O emissions were measured throughout the growing season using a static chamber approach. Gas samples were collected at multiple intervals from the chamber, stored in an air-tight vial, and analyzed on a Shimadzu gas chromatograph. Model simulations were performed using DayCent version 4.5 and National Climatic Data Center (NCDC) meteorological data from the Paradise ranger station (GHCND:USS0021C35S) between January, 1980 to October, 2013.

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