Final Completion Report
Project Title: **Critical loads of atmospheric N deposition in alpine vegetation in Rocky Mountain and Glacier National Parks**
PMIS #105919
Contact: William D. Bowman, University of Colorado

Project summary
The purpose of this project was to establish critical N loads for alpine vegetation response (changes in species abundance, diversity) as well as soil chemical responses (inorganic N, extractable cation, and soil pH) using *in-situ* experiments with low-level N additions, 5, 10, and 30 kg N/ha/yr. The research provides a list of indicator plant species (albeit rather short, a single species) for terrestrial vegetation responses to N deposition within the focal plant communities. In addition, to the degree the park managers will allow, permanent monitoring plots were established in ROMO for future evaluation of vegetation change to N deposition and other environmental stressors. Due to problems with loss of replicate plots in GLAC, the majority of the summary results pertain to ROMO.

Critical loads for alpine dry meadows at Chapin Pass in ROMO were estimated at 3 kg N/ha/yr, based on changes in plant species composition. Soil inorganic N pools increased with increasing N inputs, indicating a limitation in ecosystem sequestration for N at relatively low levels, and a potential for future acidification of soils. However, at this time (2009), neither soil pH nor extractable base cations have changed, although there was a tendency toward lower extractable Ca^{2+} and Mg^{2+} in the highest N addition treatment. Aboveground biomass did not vary significantly among the N treatments. Estimates of plant N uptake are still pending chemical analyses of the plant tissues. These results, taken together, reinforce the concern that N critical loads for alpine ecosystems are low, and that the potential for future soil acidification is high.

Project Purpose and Objectives

Emissions and deposition of anthropogenic N are increasing throughout the western U.S. due to increases in fossil fuel consumption and agricultural development. Atmospheric deposition of N has been linked to ecosystem eutrophication (greater growth of plants and algae), loss of diversity, and acidification of soils (Galloway et al. 2008). Ecological impacts due to N deposition are particularly acute in the Front Range of the southern Rocky Mountains (Fenn et al. 2003). Of particular concern are the high elevation Class I protected regions, including Rocky Mountain National Park (ROMO) and the Indian Peaks Wilderness. Biota in alpine lakes in ROMO have been altered in conjunction with elevated N deposition (Baron et al. 2000), and changes in vegetation composition have also been noted at nearby Niwot Ridge (Bowman et al. 2006).

To better protect the resources of ROMO and Glacier National Park (GLAC), an effort was initiated in 2005 to establish empirical estimates of N critical loads, i.e. the level of N input that elicits a negative ecosystem response (Porter et al. 2005). The experiments were established in alpine dry meadows due to the sensitivity of alpine vegetation to variation in N availability (Bowman et al. 2006), is considered an important scenic resource, and because it provides significant ecosystem services (water quality and retention), the experiments were established in alpine dry meadows. The sites were located ca. 2 km ENE of Chapin Pass in ROMO, and in the upper Appistoki Valley in GLAC. Experimental N additions (0, 5, 10, and 30 Kg N per ha) were added to 5 replicate 1 m x 1.5 m plots each at each site. Nitrogen was added as NH_4NO_3 in solution, sprayed onto the plots 3 times during the growing season. Control plots received an equivalent amount of water (4 L/plot/ application).

Vascular plant species were recorded annually in 100 points of every experimental plot. Aboveground production was estimated by clip harvesting vegetation in 3 0.04 m^2 subplots within each of the larger 1.5 m^2 plots. Soils in the plots were analyzed for extractable cations, C:N of the organic matter, and inorganic N (resin bags and soil lysimeters). At each site, two soil samples (4 cm diameter x 15 cm deep) were collected from each plot and composited, sieved, and extracted with $BaCl_2$ for analysis of extractable cations, or analyzed for pH (water extraction).

Sampling of the plots in GLAC was compromised by loss of 6 plots in 2008 due to corner stakes and identification tags being pulled out, presumably by bighorn sheep. Animals were observed near the plots, and some identification tags were recovered that had been chewed by the animals. One entire block of plots was lost. Replicate plots for some of the treatments decreased to 3.

The project personnel who participated in field work and lab analyses included John Murgel and the PI. We received occasional volunteer help from other researchers, undergraduate students, and family members.

Overall species richness of vascular plants was 40 in the GLAC site, and 43 for the ROMO site, and did not change with treatment or time, nor did the Shannon-Wiener diversity, which incorporate both the richness and evenness of species. Plant species composition changed little in response to the N additions at GLAC, but significant changes occurred at the ROMO site. Increases in *Carex rupestris* (Fig. 1), observed in plots on Niwot Ridge, were used to estimate a N critical load of 4 kg/ha/yr for that location (Bowman et al. 2006). Using the rate of change in cover with increasing N inputs, a baseline N deposition rate of 4 kg/ha/yr (Baron 2006), and assuming that the change in *C. rupestris* cover was due only to N deposition, we estimated a critical load for Chapin Passof 3 kg N/ha/yr (Fig. 2). similar Thus, nitrogen deposition at the Chapin Pass site is currently at or exceeding the estimated critical load.
, a finding suggested for the east side of the continental divide by Baron (2006).

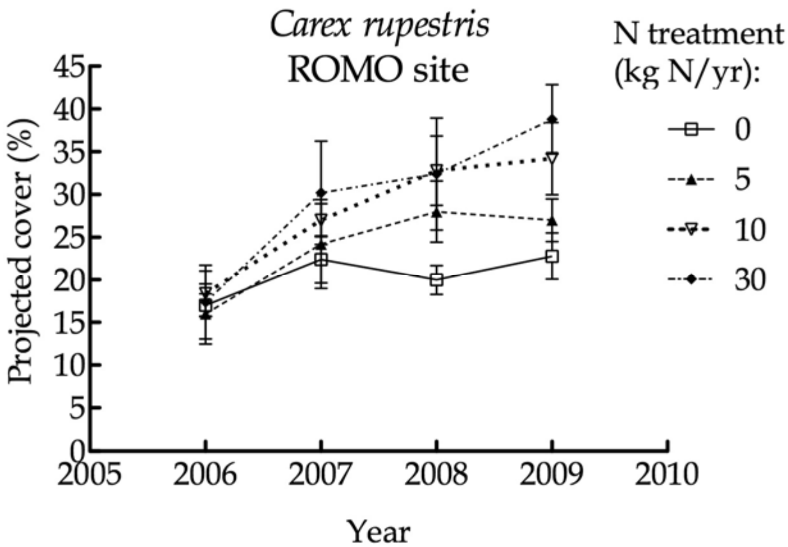

Fig. 1. Change in the cover of Carex rupestris *in plots treated with 0 (control), 5, 10 and 30 kg N/ha/yr, at Chapin Pass in Rocky Mountain National Park.*

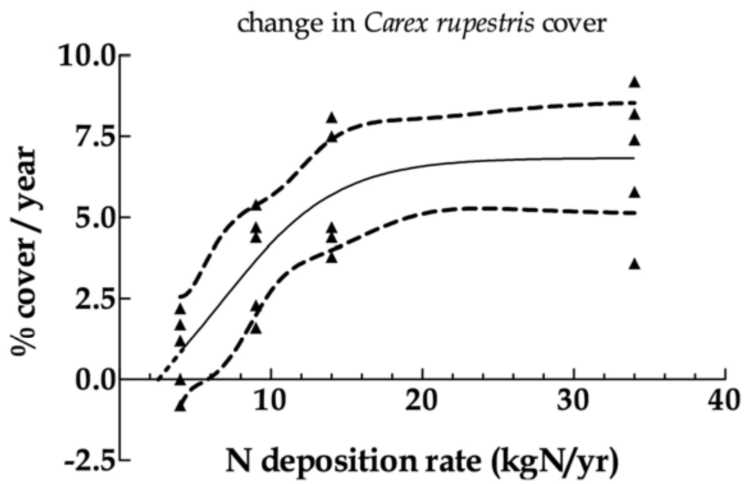

Fig. 2. Rate of change in the cover of Carex rupestris *in plots treated with 0 (control), 5, 10 and 30 kg N/ha/yr, at Chapin Pass in Rocky Mountain National Park over a 4 year study period (2006-2009). Back projection of the function to a rate of change = zero provides an estimate of the critical load, 3 kg N/ha/yr. Dotted lines represent the 95% confidence intervals for the fit of the data (sigmoidal dose response function).*

Aboveground biomass did not increase significantly at either site, although a general trend toward increasing biomass was noted at the GLAC site (74 $\pm$ 10 g/m^2 in control plots, 116 $\pm$ 18 g/m^2 in plots with 30 Kg N/ha/yr), but the loss of replicate plots lowered the statistical power of the tests to determine if this trend was significant (P < 0.09). Biomass of non-*Kobresia* (dominant species) graminoids increased significantly (P < 0.01) in the ROMO plots (Fig. 3), due largely to the increase in *Carex rupestris* cover.

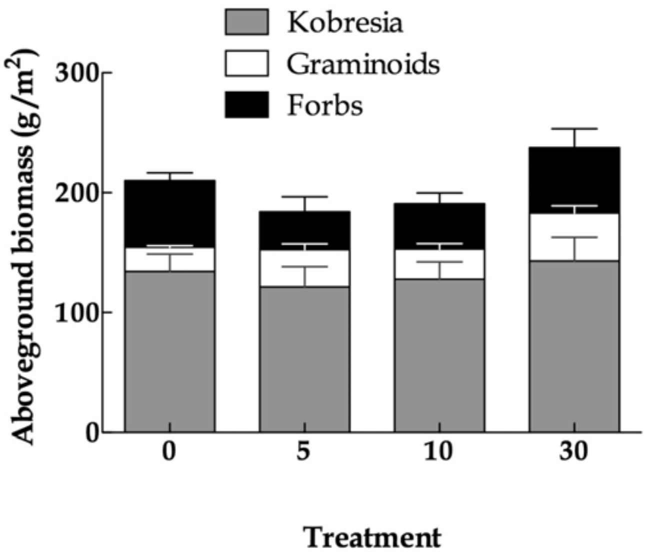

Fig. 3. Change in the aboveground biomass of dry meadow vegetation in plots treated with 0 (control), 5, 10 and 30 kg N/ha/yr, at Chapin Pass in Rocky Mountain National Park.

Soil solution inorganic N increased with increasing N inputs, as estimated using both ion exchange resin bags, buried at a 15 cm depth, which provide an integrated measure for a year, and microlysimeters, which provide a short-term estimate (Fig. 4). Thus, any increase in biological and soil sequestration of N was not sufficient to take up the greater supply. Greater inorganic N in soil solution can potentially lead to soil acidification and loss of base cations.

Soil pH values averaged 6.04 $\pm$ 0.03 (2006) and 5.94 $\pm$ 0.08 (2008) for the GLAC site, and 5.75 $\pm$ 0.05 (2006) and 5.83 $\pm$ 0.06 (2008) for the ROMO site, and did not vary with treatment at either site. Initial soil C:N ratios were 13.4 + 0.1 at ROMO and 13.7 + 0.2 at GLAC. The dominant cations at both sites were Ca^{2+} and Mg^{2+}, and did not vary among the treatments, although there was a trend towards lower values at the highest N inputs. Extractable Al^{3+}, a toxic element to many organisms, did not change with increasing N input.

Conclusions

This research has demonstrated a low N input threshold for changes in plant species composition in alpine dry meadows. Because changes in plant species composition are an undesired consequence of N deposition in national parks, and serve as early warning indicators of more detrimental impacts to ecosystems such as soil acidification and loss of nutrient cations, this threshold, 3 kg N/ha/yr, serves as a reasonable N critical load for the alpine of Rocky Mountain National Park.

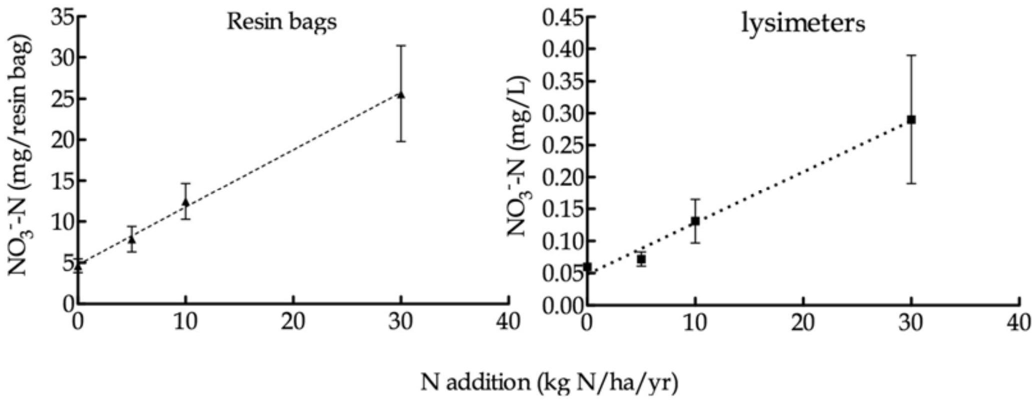

Fig. 4. Estimates of soil inorganic N pools from ion exchange resin bags placed at 15 cm depth for one year (June 2008-May 2009), and microlysimeters sampled in June 2009 in plots treated with 0 (control), 5, 10 and 30 kg N/ha/yr, at Chapin Pass in Rocky Mountain National Park.

References

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