AN ELEVATIONAL GRADIENT IN SNOWPACK CHEMICAL LOADING AT GLACIER NATIONAL PARK, MONTANA: IMPLICATIONS FOR ECOSYSTEM PROCESSES

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ABSTRACT: The accumulation and melting of mountain snowpacks are major drivers of ecosystem processes in the Rocky Mountains. These include the influence of snow water equivalent (SWE) timing and amount of release on soil moisture for annual tree growth, and alpine stream discharge and temperature that control aquatic biota life histories. Snowfall also brings with it atmospheric deposition. Snowpacks will hold as much as 8 months of atmospheric deposition for release into mountain ecosystems during the spring melt. These pulses of chemicals influence soil microbiota and biogeochemical processes affecting mountain vegetation growth. Increased atmospheric nitrogen inputs recently have been documented in remote parts of Colorado's mountain systems but no baseline data exist for the Northern Rockies. We examined patterns of SWE and snow chemistry in an elevational gradient stretching from west to east over the continental divide in Glacier National Park in March 1999 and 2000. Sites ranged from 1080m to 2192m at Swiftcurrent Pass. At each site, two vertically-integrated columns of snow were sampled from snowpits up to 600cm deep and analyzed for major cations and anions. Minor differences in snow chemistry, on a volumetric basis, existed over the elevational gradient. Snowpack chemical loading estimates were calculated for NH4, SO4 and NO3 and closely followed elevational increases in SWE. NO3 (in microequivalents/ square meter) ranged from 1,000 ueq/m^2 at low elevation sites to 8,000+ ueq/m^2 for high elevation sites. Western slopes received greater amounts of SWE and chemical loads for all tested compounds.

KEYWORDS: atmospheric deposition, nutrient loading, ecosystems, snowpack variability

1. INTRODUCTION

Snow is a significant factor in the structure and function of mountain ecosystems in the Rocky Mountain landscapes of the western United States. Snowpacks influence the establishment and survival of trees in meadows and at treeline (Peterson 1998), determine the timing and abundance of stream flows during spring and summer (Fagre et al. 1997, Hauer et al. 1997), and restrict the movements of many animals during winter. Snow and rain bring various chemicals from the atmosphere to mountain ecosystems throughout the year (Fenn et al. 1998). Because mountain snowpacks accumulate as much as 8 months of atmospheric deposition over the cold months and then release it over a relatively short time during late spring, large fluxes in chemicals occur where there are large snowpacks (Campbell et al. 2000).

Humans have altered the biosphere's nitrogen cycle and have doubled the rate of nitrogen entering the land-based nitrogen cycle (Vitousek et al. 1997). As a consequence, atmospheric deposition of nitrogen and other nutrients also has increased in many areas. Excess nitrogen from the atmosphere has been shown to have adverse effects and alter ecological relationships (Stoddard 1995). The accumulation and release by large snowpacks magnify the impact of increased atmospheric deposition in mountains (Baron et al. 2000, Sievering et al. 1996). Additionally, many alpine plants and soil biota are naturally nitrogen-limited and therefore particularly sensitive to these snow-mediated nitrogen pulses (Bowman et al. 1993).

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Glacier National Park encompasses a relatively unaltered mountain ecosystem where "background" (i.e. regional) levels of atmospheric deposition to snowpacks can be determined without regard to local sources. Glacier Park has steep elevational and climatic gradients in its mountain topography that potentially increase its vulnerability to climate change. Relatively greater changes in the timing and amount of snowpack accumulation and snowmelt will occur in these mountains than in flatter terrain elsewhere. These snowpack changes could drive large changes in nutrient pulses.

We examined snowpack chemistry along an elevational transect in Glacier Park to establish baseline values with which to detect future changes in atmospheric deposition, to contrast with other mountain ecosystems in the U.S., and to determine whether high elevations were receiving more deposition than lower elevations.

2. STUDY AREA

Our study took place in the Lake McDonald and St. Mary watersheds of Glacier National Park, a 4,500km^2 preserve that straddles the Continental Divide in northwestern Montana, U.S.A. (Figure1).

Figure 1: Location of Glacier National Park, Montana

Approximately 90% of the park is designated and managed as proposed wilderness. Only one road, the Going-to-the-Sun Road, traverses the park. The elevational transect began in the valley bottom (1080m) of the Lake McDonald watershed on the western side of the Northern Rocky Mountains, continued to the continental divide at Swiftcurrent Pass (2192m) and ended in the valley bottom (1393m) of the St. Mary watershed. The mountains of Glacier National Park are uplifted beds of sedimentary rock which have been shaped by glaciers into U-shaped valleys, serrated ridges and pyramidal peaks. Approximately 37 small, alpine glaciers remain in the park and snow covers much of the landscape for at least half of each year. Coniferous forests cover about 75% of the park and alpine treeline is between 1900-2300m. The western side of the Continental Divide is dominated by Pacific maritime climate patterns and the eastern side is influenced more by a continental climate.

3. METHODS

Field sampling and laboratory analysis of major cations and anions generally followed the protocol of Ingersoll (1995). Field sample collection was timed to occur near the estimated maximum seasonal snow accumulation for the elevational transect. The Apgar site was a single snowpit sample collected once annually from 1996-2000 as part of a Rocky Mountain Regional study. It provided a measure of interannual variability in solute concentration and snow water equivalence. For the elevational transect, snow was collected on both sides of the continental divide simultaneously by separate field crews (Figure 2).

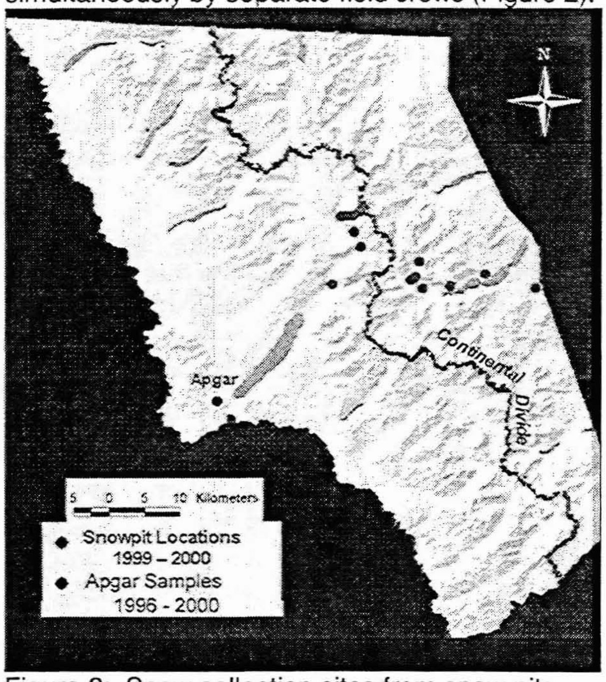


Figure 2: Snow collection sites from snow pits, and location of Apgar, Glacier National Park, Montana

Snow collection sites were chosen every 100-200m in elevation based on several criteria. These criteria included relatively flat areas not under tree canopies, no disturbance to the snowpack (e.g. avalanche debris, skier activity), protected from wind deposition or scouring and in a safe location for conducting work. At each collection site a snow pit was dug to the ground and one wall of the pit, facing away from the sun, was prepared for collection. Snow scoops, snow density cutters, and snow shovels were pre-rinsed with deionized water and transported in pre-rinsed plastic bags to the site. Field personnel used disposable latex laboratory gloves during snow collection. Snow samples were immediately sealed in pre-rinsed plastic bags and kept frozen during transport. Duplicate vertical columns of snow, representing the entire stratum of the snowpack, were collected from each snow pit except for the top 5 cm and bottom 10 cm. These latter precautions were to avoid contamination by incidental excavation activities (top) or forest litter and soils (bottom). Snow density and temperature were recorded every 10 cm and snow structural characteristics were noted. After transport by overnight delivery service to the U.S. Geological Survey Regional Research Laboratory in Boulder, Colorado, snow samples were stored at -20°C until analysis. Snow samples were melted and analyzed for conductivity, pH, alkalinity and major cations and anions using inductively coupled plasma, atomic absorption and ion chromatography (Ingersoll 1995). Quality control involved analysis of deionized-water blanks, standard reference samples, comparing results from the duplicate snow column samples.

4. RESULTS

The major ion concentrations from the Apgar site over 5 years (Figure 3) demonstrate that considerable variability exists from year to year.

Snow chemistry at Apgar Lookout
microequivalents per liter (μeq/L)

Date	Snow depth cm	pH	H	NH_4	Ca	Mg	Na	K	Cl	NO_3	SO_4
3/19/96	160	5.53	3.0	1.9	0.5	0.0	4.1	3.8	0.9	2.5	5.2
4/4/97	255	5.01	9.8	2.3	1.8	0.7	1.6	0.0	1.4	5.2	4.9
3/5/98	144	4.99	10.2	6.1	2.5	0.8	2.2	0.0	1.4	6.9	6
3/25/99	182	5.28	5.3	5.5	2.5	0.8	2.1	0.6	1.4	5.2	4.7
3/6/00	181	-	-	4.6	1.5	0.8	1.2	0.4	0.3	6.5	5.4

Figure 3: Apgar Lookout major ion data, 1996-2000. A single collection from a snow pit was made each year.

There was 3 times more ammonium (NH4) per liter, for instance, in the 1998 snowpack than there was in the 1996 snowpack. At a regional scale, however, the Apgar site and other sites in northwestern Montana have lower nitrogen concentrations than Colorado.

The relationship between snow water equivalence (SWE) and snow depth is compared in Figure 4 for the 1999 and 2000 elevational transects.

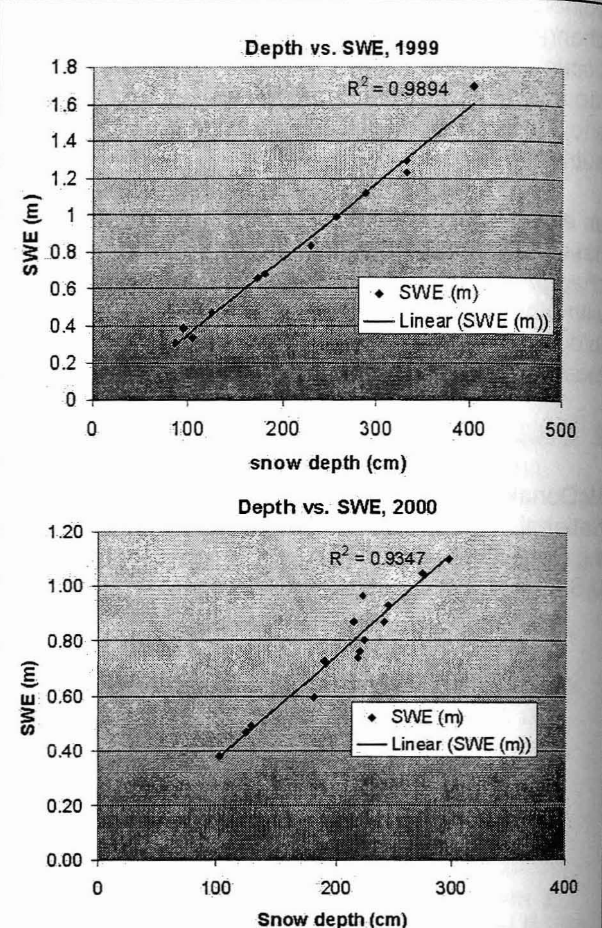


Figure 4: Snow Water Equivalent (SWE) vs Snow depth in Glacier National Park for 1999 – 2000. Data collected at maximum accumulation for annual snowpack.

The greater variability in the relationship between SWE and depth in 2000 reflects the settling of the snow from repeated freeze/thaw cycles and rain-on-snow events that occurred prior to our collection. These weather events affected the upper portions of the snowpack but not the lower portions. Thus, there was no loss of solutes from the snowpack despite the transitional nature of the snow.

A general elevational gradient in SWE existed for both sides of the continental divide for both years (Figure 5). At any given elevation, SWE was greater on the western side of the continental divide because most moisture-laden winter storms

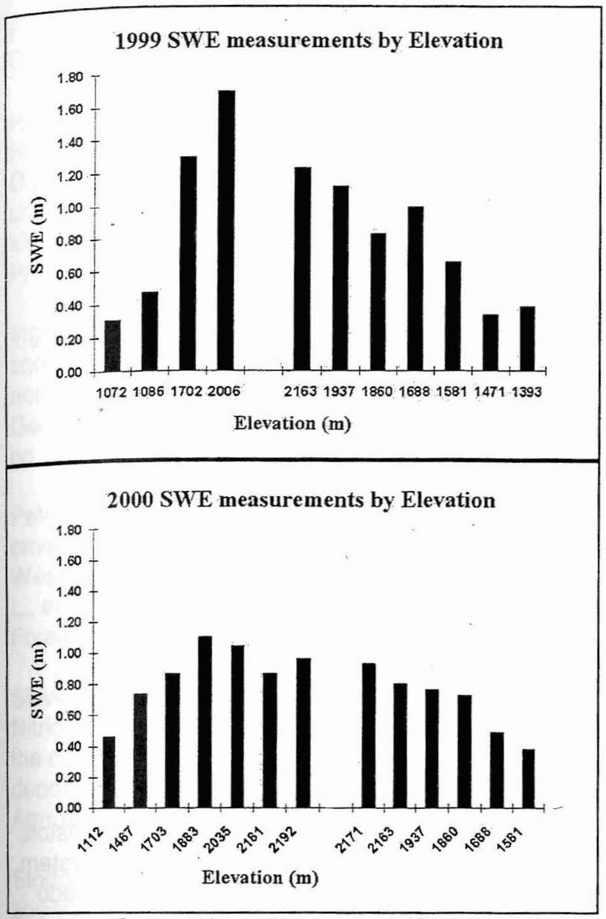
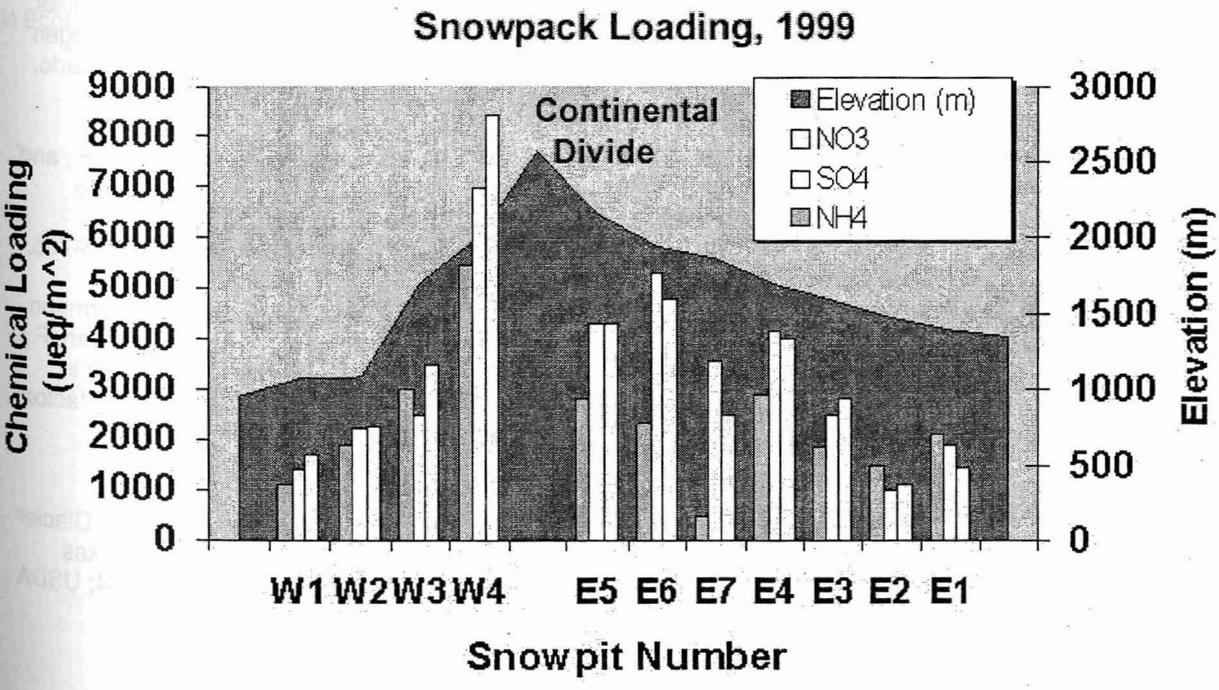


Figure 5: Snow Water Equivalent (SWE) of snow collected at different elevations on western side of Continental Divide (left bars) and eastern side of the divide (right bars) for 1999 and 2000 in Glacier National Park, Montana.

approach the Northern Rocky Mountains from the west (Finklin 1986). In 2000, we sampled higher elevation sites than in 1999 and found that SWE on the western side did not continue to increase with elevation. These higher elevation sites were at or above treeline and it was not possible to find a site adequately protected from the wind. The prevailing westerly winds drive much of the higher elevation snow over the Continental Divide (Finklin 1986), reducing the SWE on the western side and adding it to the eastern side.

Although major ion concentrations varied annually in the snowpack at Apgar (Figure 3), there was little variation in the snow samples by elevation within each of the 1999 and 2000 sampling periods. However, multiplying the ion concentration by the SWE gives an ecologically more appropriate measure of the total potential nutrient inputs from spring snowmelt. In 1999, the nutrient "loading" at each site (Figure 6) increases consistently as a function of both elevation and SWE. This general trend is evident for the 2000 data except for the higher elevations where nutrient loading declines near the Continental Divide. This latter trend reflects the reduction in SWE caused by wind redistribution of snow.



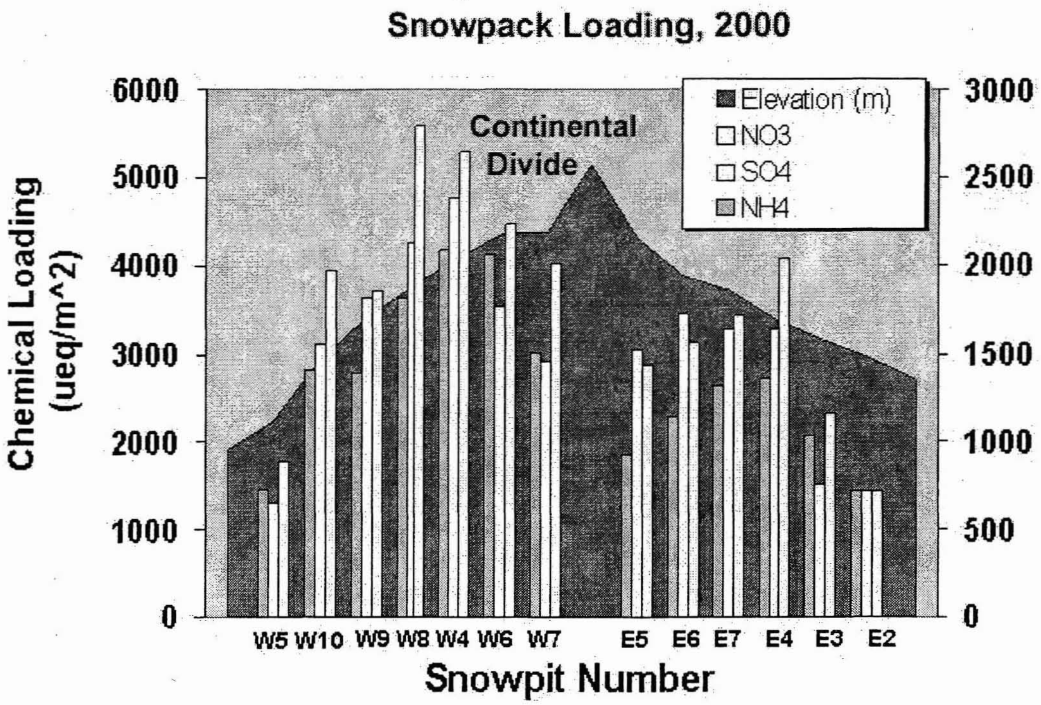


Figure 6: Profile of snowpack chemical loading along elevational gradient in Glacier National Park, Montana, 1999 and 2000.

5. SUMMARY

This study established baseline values for major ion concentrations in seasonal snowpacks in Glacier National Park. These major ion concentrations in snow potentially can affect soil and vegetation dynamics during spring snowmelt when they create a nutrient pulse. The year-to-year variation in SWE and ion concentration at the Apgar site suggests that the strength of the annual nutrient pulse will be variable for the larger ecosystem. The results from the elevational transects in 1999 and 2000 indicate that greater nutrient loading, and potential spring nutrient pulses, generally increase with elevation except near the continental divide. Loading is the solute concentration multiplied by the snowpack's snow water equivalent. Because higher elevation alpine plant communities seem more responsive to variation in nutrients such as nitrogen, the greater loading at these elevations is potentially significant. Overall, nutrient loading in Glacier Park's mountains is low compared to alpine areas in Colorado but the spatial and temporal variability established in this study suggests that some effects could occur with potential future increases in atmospheric deposition and/or snowfall.

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