Developing Critical Loads for Atmospheric Deposition of Inorganic Nitrogen to High Alpine Lakes: Preliminary Results

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Introduction

Excessive nitrogen from atmospheric deposition is an important component of eutrophication in many ecosystems. Nitrogen limitation of alpine lakes makes alpine ecosystems especially sensitive to additional inputs of atmospheric nitrogen because they have adapted to an oligotrophic environment and may have lower capacity to utilize additional inputs. Previous work at Rocky Mountain National Park in Colorado showed that nitrogen deposition at levels greater than 1.5 kg/ha-yr was sufficient to alter trophic state in high alpine systems (Baron, 2006). The objective of this study is to determine if lakes within Mount Rainier (MORA), North Cascades (NOCA), and Olympic (OLYM) National Parks are receiving atmospheric nitrogen deposition at rates sufficient to alter their trophic state. If lakes show signs of nutrient enrichment, USGS will identify the "critical load", or deposition rate when trophic state began to change. Monitoring in other regions, as well as conceptual models of atmospheric deposition, indicate that deposition of nitrogen at higher elevations is greater than at lower elevations because of higher precipitation rates, yet little precipitation data for high elevations are available for these parks. The relation between the bulk deposition of atmospheric nitrogen and the water quality of high-elevation lakes will be examined to: (1) determine the spatial distribution of nitrogen deposition at park lakes and compare this deposition to lowland sites of the National Atmospheric Deposition Program and (2) determine the relation between atmospheric deposition, lake quality, and ecological effects in these alpine lakes.

Approach

This study will be conducted in four phases; (1) 12 lakes were selected and atmospheric deposition was estimated from July to October 2008; (2) cores from each lake will be collected to determine if diatom communities have been significantly altered and if these changes are related to nitrogen deposition and water quality; (3) an intensive study will be done during the summer in 2010 at three lakes to examine the relation between water quality and atmospheric deposition over biweekly-scale intervals; (4) the relations of lake trophic state and watershed vulnerability with atmospheric deposition will be evaluated.

Site Selection

Site selection was based on previous work at these lakes and on the following hypothesis:

- Elevation is important; high elevation lakes have less alkalinity in general, and are more susceptible to the effects of nitrogen deposition.
- Location in the park is important; some areas get more deposition than others. Therefore, a good spatial distribution will capture a range in nitrogen deposition.
- Lakes in basins with significant amounts of red alder should be avoided; nitrogen fixing plants will make interpretation of nitrogen deposition data difficult. Alder are less likely at high elevation sites.

From this information, the following list of site selection criteria was established:

- Elevation above 4,000 feet
- Above tree line, or minimal forested area around lake
- Depth greater than 5 meters
- Area smaller than 25 hectare
- Oligotrophic status
- Low Acid Neutralizing Capacity /conductivity lakes preferred
- No fish (low densities are acceptable)
- No major influences from wildlife (e.g., minimize disturbance of lake sediment)
- Talus slope preferred for resin collectors deployment
- Aspect—if possible, select south facing basin instead of north facing basins due to differences in solar radiation, temperature, melting, and other factors
- Try to overlap with existing park projects (for additional data and possible coordination of field efforts)
- Try to minimize popular visitor sites
- Within each park:
    - Lakes should span a gradient of elevation
    - Lakes should have good spatial representation

Study Sites

Four lakes from each of the three National Parks (see figure 1) in Washington State were selected for this project based on the previously outlined selection criteria. Lakes with a good range of elevation and spatial coverage within each park were selected. A summary of physical characteristics for each lake are listed in table 1. NOCA has the largest elevation gradient at about 2,200 feet, with OLYM having the smallest at about 600 feet. NOCA also contains the largest and deepest of lakes studied.

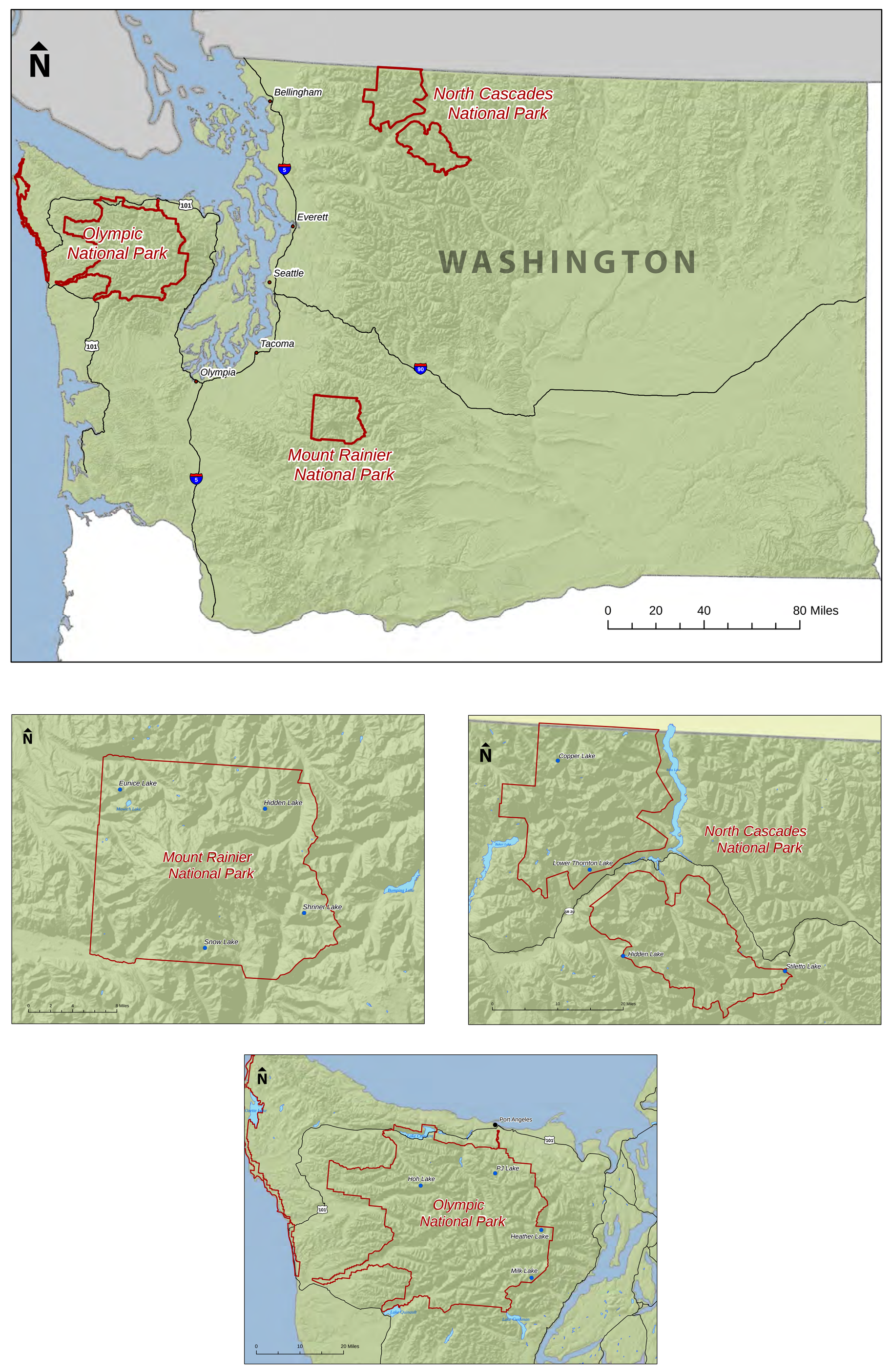

Figure 1. Location of study lakes in the three National Parks in Washington State.

Table 1. Physical properties of study lakes.

Study lake	Park	Elevation (feet)	Area (hectare)	Maximum depth (feet)
Eunice Lake	MORA	5,380	5.3	10
Hidden Lake	MORA	5,970	5.2	23
Shriner Lake	MORA	4,820	1.7	11
Snow Lake	MORA	4,720	2.4	32
Copper Lake	NOCA	5,250	5.1	69
Hidden Lake	NOCA	6,020	25.0	202
Stiletto Lake	NOCA	6,780	0.03	85
Thornton Lake	NOCA	4,540	22.7	104
Heather Lake	OLYM	5,215	0.4	23
Hoh Lake	OLYM	4,380	7.4	49
Milk Lake	OLYM	4,708	1.1	39
PJ Lake	OLYM	4,581	0.8	21

Background Chemistry

A review of existing data from the National Parks was used to characterize each study lake in terms of important water quality parameters (table 2). All of the study lakes generally have low levels of nitrogen and phosphorus. The DIN:TP ratio is a good indicator of nutrient limitation for phytoplankton (Sickman and others, 2003) with values less than 0.5 indicating N-limitation, values between 0.5 and 4.0 indicating co-limitation of N and P, and values greater than 4.0 indicating P-limitation (Morris and Lewis, 1988). Based on these criteria, OLYM lakes tend to be N-limited, MORA lakes range from co-limitation of N and P to P-limitation, and NOCA lakes indicate P-limitation. The nutrient status determined for these lakes should be taken with caution, however, because of inconsistencies in historical data used.

Table 2. Historical data collected at study lakes (number in parentheses indicates number of samples).

Study lake	Park	Data date range	NH3 (µg/L)	NO3- NO2 (µg/L)	DIN (µg/L)	TP (µg/L)	DIN:TP
Eunice Lake	MORA	2003–2006	8 (20)	4 (20)	12 (20)	20 (20)	5.3 (20)
Hidden Lake	MORA	1989–2004	7 (5)	1 (5)	8 (5)	8 (5)	1.0 (5)
Shriner Lake	MORA	1993–2004	14 (7)	4.5 (7)	16 (7)	4 (7)	3.7 (7)
Snow Lake	MORA	1993–2004	6 (9)	9 (9)	15 (9)	4.3 (9)	4.8 (9)
Copper Lake	NOCA	1976–1997	10 (2)	–	25 (2)	5 (2)	5.0 (2)
Hidden Lake	NOCA	1972–1985	10 (1)	–	–	–	–
Stiletto Lake	NOCA	1976–1997	8 (1)	–	25 (1)	5 (1)	5.0 (1)
Thornton Lake	NOCA	1971–1998	9.5 (2)	–	25.5 (2)	2 (2)	12.8 (2)
Heather Lake	OLYM	2007	10 (3)	7 (3)	15 (2)	4.0 (2)	0.4 (2)
Hoh Lake	OLYM	2007	10 (6)	<0.5 (5)	17 (3)	4.3 (3)	0.4 (3)
Milk Lake	OLYM	2007	0.5 (2)	<0.5 (2)	10 (1)	5.0 (1)	0.2 (1)
PJ Lake	OLYM	2007	–	–	–	–	–

Measurement of Atmospheric Deposition

During summer 2008, atmospheric deposition of nitrogen was determined at each lake using an ion exchange resin collector (Fenn and others, 2002). We installed five bulk deposition collectors were installed at each lake, and rainwater was collected in a collapsible bag attached to the outlet of the resin column at three of the five collectors (figure 2). Approximate rain volumes were measured in October 2008 and are shown in table 3. Rain volumes will be used to test the hypothesis that higher precipitation amounts will lead to higher nitrogen deposition. At NOCA, the precipitation pattern between east side (Stiletto) and west side (Hidden) lakes are evident.

Figure 2. Bulk deposition collector being installed at Stiletto Lake NOCA.

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Table 3. Precipitation volumes at study lakes during summer 2008 (number in parentheses indicates number of samples).

Study lake	Park	Elevation (feet)	Location in Park	Data start date	Collection end date	Average precipitation volume (inches)
Eunice Lake	MORA	5,380	NW	07-31-08	10-15-08	9.6 (3)
Hidden Lake	MORA	5,970	NE	07-23-08	10-16-08	4.8 (3)
Shriner Lake	MORA	4,820	SE	07-23-08	10-17-08	–
Snow Lake	MORA	4,720	S	07-22-08	10-01-08	8.4 (3)
Copper Lake	NOCA	5,250	W	08-12-08	10-10-08	9.3 (3)
Hidden Lake	NOCA	6,020	W	07-30-08	10-10-08	12.3 (1)
Stiletto Lake	NOCA	6,780	E	08-03-08	10-10-08	5.8 (3)
Thornton Lake	NOCA	4,540	W	07-30-08	10-09-08	14.2 (3)
Heather Lake	OLYM	5,215	W	08-18-08	10-22-08	7.6 (3)
Hoh Lake	OLYM	4,380	NE	08-23-08	10-22-08	12.9 (3)
Milk Lake	OLYM	4,708	SW	08-12-08	10-19-08	12.9 (3)
PJ Lake	OLYM	4,581	NW	08-05-08	10-24-08	6.4 (2)

Future Plans

In spring through fall 2009, each lake will be visited to collect sediment cores and water for surface chemistry. Water will be collected at the surface and in the deepest part of each lake for nutrients, major ions, chlorophyll-a, and conventional water-quality parameters.

- At each lake, a sediment core will be sectioned into 0.5 cm intervals for the upper 10 cm, and then at 1 cm intervals to 20–30 cm.
- From each core, the top and bottom sections will be analyzed for diatom taxonomy to assess those lakes that indicate a shift in diatom community structure.
- During fiscal year 2010, an intensive study on three lakes will be conducted. Three sediment cores will be dated, and complete diatom analysis conducted.
- Snow sampling for nitrogen will take place in spring 2010, followed by as many as five trips through the fall to each lake targeted for intensive study.
- Final products from this project will include a journal article, a fact sheet, and a USGS data series report.

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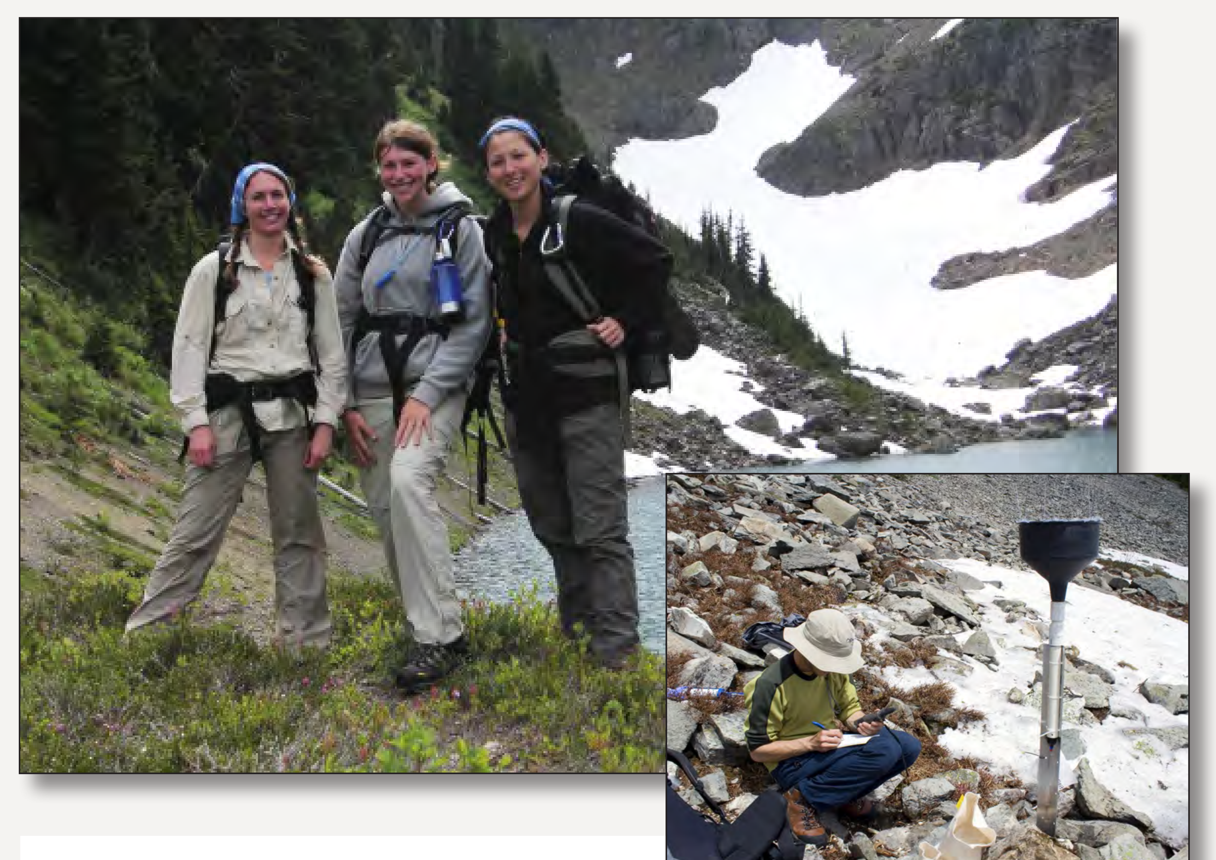

Contacts

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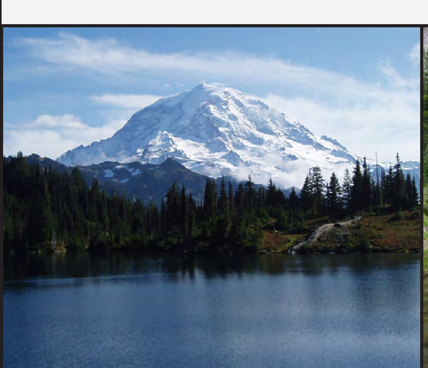
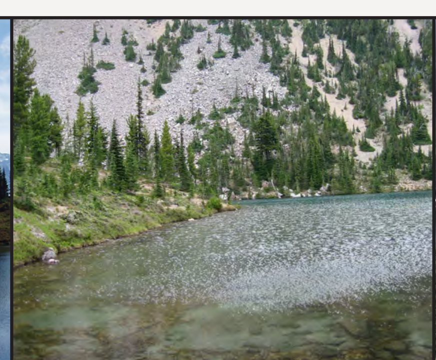
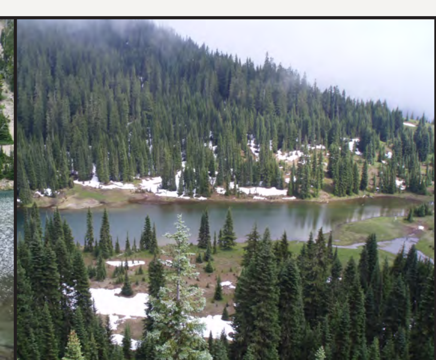


Eunice Lake MORA



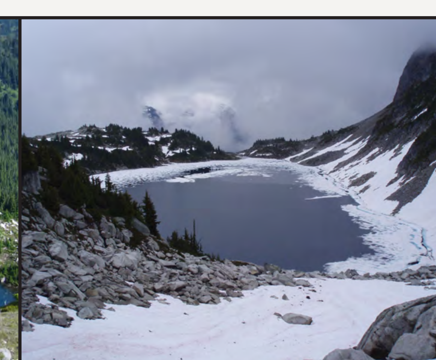
Hidden Lake MORA



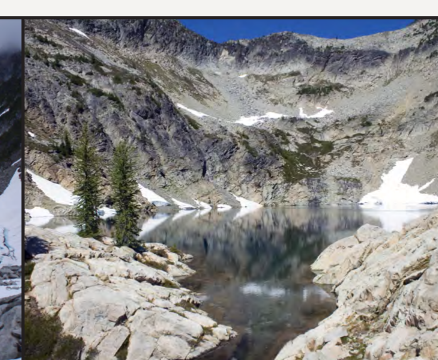
Shriner Lake MORA

Snow Lake MORA

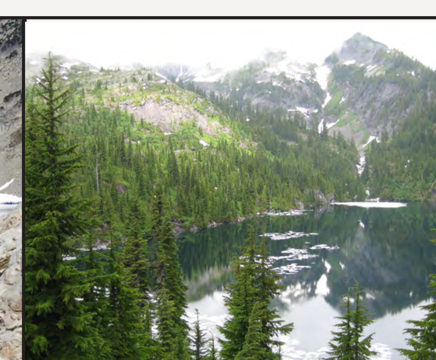
Copper Lake NOCA



Hidden Lake NOCA



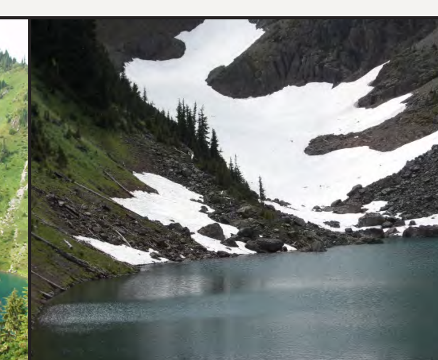
Stiletto Lake NOCA



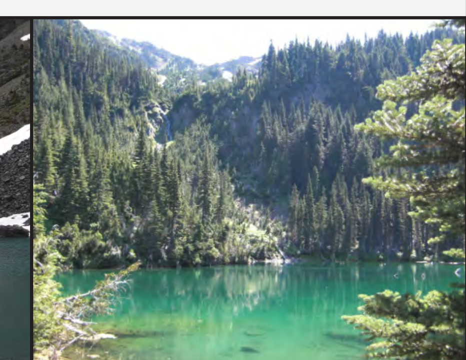
Thornton Lake NOCA

Heather Lake OLYM

Hoh Lake OLYM



Milk Lake OLYM



PJ Lake OLYM