*ISRO, OLYM,
ROMO, NOAT

Long-term Ecosystem Studies in Isle Royale, Olympic, and Rocky Mountain National Parks; Noatak National Preserve, and Fraser Experimental Forest

Robert Stottlemyer
USGS BRD MESC
240 W. Prospect Rd.,
Ft. Collins, CO 80526
(970) 498-1017

Jill Baron
USGS BRD MESC
NREL
Colorado State University
Ft. Collins, CO 80523

Robert Edmonds
Forest Resources
University of Washington
Seattle, WA 98195

Laura Scherbarth
Ecology Program
Colorado State University
Ft. Collins, CO 80523

Heidi Steltzer
Forest Sciences
Colorado State University
Ft. Collins, CO 80523

U.S. Geological Survey
Biological Resources Division

Mid-Continent Ecological
Science Center

2001 Annual Report
(Res. Rept. No. 95)

March 2002

Long-term Ecosystem Studies in Isle Royale, Olympic, and Rocky Mountain National Parks; Noatak National Preserve, and Fraser Experimental Forest

Robert Stottlemyer
USGS BRD MESC
240 W. Prospect Rd.,
Ft. Collins, CO 80526
(970) 498-1017

Jill Baron
USGS BRD MESC
NREL
Colorado State University
Ft. Collins, CO 80523

Robert Edmonds
Forest Resources
University of Washington
Seattle, WA 98195

Laura Scherbarth
Ecology Program
Colorado State University
Ft. Collins, CO 80523

Heidi Steltzer
Forest Sciences
Colorado State University
Ft. Collins, CO 80523

U.S. Geological Survey
Biological Resources Division

Mid-Continent Ecological
Science Center

2001 Annual Report
(Res. Rept. No. 95)

March 2002

TABLE OF CONTENTS

SUMMARY

Here we summarize FY01research results from the five-site network where a common set of longer-term, ecosystem-level studies and monitoring are underway on protected Federal lands. Continuous systematic studies began on most sites in 1982.

In establishing the network, the conceptual model for monitoring and research was designed to 1) best detect incipient change as possibly caused by human or non-human stress, 2) quantify the magnitude of change, and 3) statistically separate the human-induced component. The published literature suggests when searching for early change in terrestrial ecosystems, one studies processes such as production, decomposition, and nutrient cycling. In the aquatic ecosystem, community structure and species are perhaps the best components to study.

Network studies initially emphasized obtaining a basic understanding of the structure and function of these diverse ecosystems. Early attention was devoted to quantifying the effects of atmospheric sulfur, especially as sulfate (SO_4^{2-}), on terrestrial nutrient leaching and acidification of surface water. Owing to the nature of the long-term research design, we next were able to focus on terrestrial ecosystem responses to atmospheric nitrogen (N) deposition. Atmospheric N inputs, principally as nitrate (NO_3^-), ammonium (NH_4^+), and nitric acid, provide the needed nutrients to aquatic and terrestrial ecosystems. However, some species more than others readily take advantage of this added N which subsequently changes ecosystem biodiversity. Ecosystem N and carbon (C) cycles are interconnected, and change in N availability alters the C budget and subsequently basic ecosystem functioning.

At present, network studies focus on other aspects of global change, in particular climate and its interaction with atmospheric N inputs and the C cycle. Climate change, especially temperature, has a marked effect on the rate of below-ground processes such as the mineralization of C and N from organic pools. Mineralization rates frequently show pronounced increases with warming soil temperatures which, in turn, accelerates green house gas production, as carbon dioxide (CO_2), and available N as $NO_3^-$and NH_4^+. Generally, >99% of the terrestrial ecosystem's biodiversity is below-ground. Soil microbiota respond rapidly to changes in temperature, moisture, and nutrient availability, altering their biodiversity and function. The soil microbial community regulates the quality and quantity of nutrients and some energy available to the above-ground biomass. In time, change in below-ground biodiversity is reflected throughout the ecosystem.

In our network of sites, the Asik watershed in the Noatak National Preserve, Alaska, has the lowest level of atmospheric contaminant inputs with about <10% the loading to Isle Royale National Park, the site with highest inputs. The current research emphasis at the Asik site is on measuring the effect of rapid climate warming on terrestrial production of C and N, dissolved organic carbon (DOC) and nitrogen (DON) export to the aquatic ecosystem, and the relationships between change in basic soil properties and processes with observed changes in treeline location. Change in the terrestrial production of usable organic C and N can have a pronounced effect on the productivity and biodiversity of boreal and treeline aquatic ecosystems.

West Twin Creek in Olympic National Park has the next lowest level of inputs, but has the highest precipitation amounts in the network. This relatively clean site has permitted basic research on the structure and function of old-growth mixed conifer forests in a region with few long-term study sites. The role of natural disturbance, as debris flows and high stream discharge, is also under investigation. Other current questions being addressed are the role of riparian red alder on stream production and suitability for anadromous fish, and the source and ramifications of periodic significant increases in atmospheric N loading to the ecosystem.

The two Colorado sites have low to moderate levels of atmospheric contaminant inputs. On the East Slope of the Continental Divide at Loch Vale in Rocky Mountain National Park, the recent research focus has been on the effects of atmospheric N inputs to the terrestrial and aquatic ecosystems in proximity to Colorado's urban Front Range. The general research themes are quantifying the long-term trends in climate and biogeochemical fluxes, ecosystem/atmospheric responses to N deposition, and the effects of global change on mountain ecosystems.

At the Fraser Experimental Forest, Colorado, nine alpine and subalpine watersheds are routinely monitored along with six meteorological stations. The research emphasis in recent years has been on summarizing long-term studies on the effect of canopy removal on snowpack chemistry and subsurface flow and nutrient export. Such data are in demand by the Forest Service to address questions associated with development such as ski areas.

Isle Royale National Park, Michigan, receives the highest atmospheric loadings in this network of sites. It is one of three long-term study sites located near the southern extent of the boreal biome in North America. Because of its geographical location, most of the current research emphasizes the effects of warming temperatures and change in moisture and nutrient availability on soil production and export of organic C and N to the aquatic ecosystem, and the subsequent effects on the physical and chemical properties and biological diversity of the aquatic ecosystem.

INTRODUCTION

The Long-term Ecosystem Studies program, established by the National Park Service as the Small Watershed Research Program in 1982, consists of sites in Rocky Mountain National Park (Loch Vale watershed), Olympic National Park (West Twin Creek watershed), Isle Royale National Park (Wallace Lake watershed), the Noatak National Preserve (Asik watershed), and the Fraser Experimental Forest, a cooperative U. S. Forest Service research site. Each site within the network also has studies underway funded by other programs including the USGS Global Change Program the results of which are summarized elsewhere (Stottlemyer et al., 2001).

The program objectives initially were to 1) gain understanding of ecosystem structure and function in little-studied systems, and 2) assess the long-term effects of atmospheric inputs of hydrogen (H^+), nitrogen (mainly NO_3^- and NH_4^+), and sulfur (SO_4^{2-}) in National Park ecosystems receiving a gradient of atmospheric deposition. In recent years the research objectives have shifted to examine the broader ramifications of global change, in particular the relationships between atmospheric N inputs, ecosystem C and N cycles, and below-ground microbial functional diversity.

The parks studied are representative of major portions of the land area under Park Service management. At each network site, both terrestrial and aquatic ecosystems are under study. To better detect incipient change and improve the statistical separation of human- and non-human induced stress in ecosystems, in the terrestrial system the study of processes (production, decomposition, nutrient cycling) is generally emphasized, while in the aquatic ecosystem change in community composition is quite sensitive (Schindler, 1986). A particular network research emphasis has been on linkages between the systems especially how terrestrial processes might alter the availability of nutrients and energy to the aquatic ecosystem.

This network is also paired with complementary Global Change Research sites at two additional National Parks: the Noland Divide watershed, Great Smoky Mountains National Park, and the Pine Canyon watershed, Big Bend National Park. The design permits comparison of findings between the Great Smoky Mountains site (high precipitation and high N deposition) with Olympic (high precipitation, low N deposition); Big Bend (warm desert) and Asik (cold desert); Asik (northern boreal ecotone) with Isle Royale National Park (southern boreal ecotone); and Rocky Mountain National Park (high elevation, east slope, lower precipitation amount) and the Fraser Experimental Forest (high elevation, west slope, high precipitation amount). Such contrasts in physical factors have a profound effect in regulating the rate and relative importance of ecosystem processes.

This annual report summarizes the activities in the site network during FY 2001. The field activities this FY indicate both the routine monitoring underway and related research. The FY 2001 publications, reports, and presentations summarize the type of research continuing or completed by both site investigators funded by the USGS-BRD and others working on the sites or datasets from the network.

OLYMPIC WEST TWIN CREEK

Investigators:

Robert L. Edmonds, Stephanie A. McAfee, and Carol J. Volk,
College of Forest Resources, University of Washington, Box 352100, Seattle, WA 98195

Project History:

This report covers research conducted in Olympic National Park (ONP), which provides an excellent location for gathering valuable baseline data from a pollution free site to evaluate the effects of anthropogenic atmospheric inputs and global change on ecosystems. In 1984 we initiated a long-term small watershed research program in West Twin Creek watershed within the Hoh River Valley, Olympic National Park, Washington. This program includes basic monitoring of vegetation, precipitation, throughfall, stemflow, soil solution, stream chemistry, hydrology, annual litterfall, and litter decomposition. Tree health, growth, and mortality have also been monitored every five years since 1985. Data accumulated over the past 16 years are a valuable resource for analyzing the effects of global change on pristine old-growth watersheds. The long-term objectives of the study are to: 1) Establish a long-term monitoring site in a pristine environment. Data sets for precipitation chemistry and elemental cycling in unpolluted ecosystems provide a baseline for comparison to other sites around the country that are atmospherically impacted; and 2) Obtain baseline information regarding the structure and function of terrestrial and aquatic components in the West Twin Creek Watershed. We are primarily interested in determining the influence of plant, soil, and stream components on the chemistry of solutions flowing through these ecosystems.

The specific objectives for 2001 were to:

1. Continue monitoring precipitation, throughfall, and stream chemistry and hydrology in the West Twin Creek Watershed with the specific evaluation of long term and seasonal water chemistry trends, and effects of the December 1999 debris flow on water chemistry and biotic communities.
2. Install automatic water samplers on West Twin and Lindner Creeks to investigate the effect of storm precipitation on stream chemistry.
3. Collect and analyze samples for stable isotopes from alder and coniferous streams.
4. Begin monthly monitoring of Hoh River water chemistry.
5. Measure soil nitrogen (N) mineralization, respiration, pH, and moisture on a quarterly basis, and soil functional ecology biannually.
6. Investigate the role of buried coarse woody debris in retaining N in upland soils in the West Twin Creek watershed.
7. Collect litterfall seasonally on two of the six permanent sampling plots in the West Twin Creek Watershed; one at 342 m and one at 586 m.
8. Collect and maintain databases for precipitation, throughfall, stemflow, stream chemistry, hydrology, and microclimate data: air, soil, and stream temperature; soil moisture; and photosynthetically active radiation (PAR).
9. Continue monitoring the surface and ground water chemistry, litterfall inputs, periphyton, aquatic invertebrates, and amphibian communities in West Twin, Snider, Twin, Alder, Canyon,

and Lindner Creeks to compare the stream food webs of red alder and conifer-dominated riparian corridors.

10. Share findings through presentations and submission of research papers and reports.

Study Sites:

WEST TWIN CREEK

The 58-hectare West Twin Creek watershed is located in the Hoh River Valley on the western side of the Olympic Mountains. Elevations in the watershed range between 180 and 850 m and slopes vary between 30 and 85%. Mean January and July air temperatures are 4 and 16°C, respectively, at the Hoh Ranger Station. Soil temperatures do not fall below 0°C and rarely exceed 20°C. Soils are classified as Typic Dystrocrepts, and forest floor depth ranges from 5 to 10 cm. Coarse woody debris is an important structural feature in these forests, and large portions of the forest floor are composed of decaying wood. Annual rainfall averages 350 cm and is strongly seasonal with most falling between October and May. Snow rarely falls in the lower elevations and usually lasts only a few days when it does occur. However, a weak snowpack may develop above 600 m.

ADDITIONAL HOH STREAMS

In the summer of 2000 five streams in the Hoh River Valley were added to expand the West Twin-Lindner Creek riparian comparison. In addition to West Twin, Twin and Snider Creeks within Olympic National Park were added to replicate old-growth forested streams. On Department of Natural Resources (DNR) land just outside of ONP, Canyon, Alder, and Tower (sampled only Fall 2000) Creeks were added to the study to replicate the red alder-dominated streams.

Progress during FY 2001:

The basic monitoring program continued at West Twin Creek in 2001. Precipitation and stream chemistry data have been collected since 1984, and hydrology and microclimate data are also available for the same time period. Highlights of this year are:

1. Completion of a manuscript on long-term and seasonal trends in the water chemistry of West Twin Creek.
2. Investigation of the impacts of the December 1999 debris flow on the temporal patterns of ammonium (NH_4^+) concentration in West Twin Creek.
3. Collection of biota (vegetation, invertebrate, and amphibian) for ^{13}C and ^{15}N stable isotope analyses in alder and conifer dominated streams.
4. Determination whether siltstone exposed in stream channels is a potential N source to stream water.
5. Installation of automated water samplers on West Twin and Lindner Creeks.
6. Initiation of a study investigating the N retention of buried coarse woody debris.
7. Continued study of the effect of riparian vegetation on stream water chemistry and associated food webs.
8. Continued investigation of carbon (C) and N cycling in upland soils.

Key Findings To Date:

WEST TWIN CREEK WATER CHEMISTRY

Long-term and Seasonal Trends

Long-term monitoring of stream chemistry can provide useful insights into stream health and the influence of anthropogenic activities. It has been assumed coastal streams in the western United States and Canada are relatively pristine because they are far from sources of pollution. However, atmospheric N over Asia is expected to increase due to increased fossil fuel combustion and fertilizer use (Galloway et al., 1995) and air masses rich in N move from Asia over the North Pacific Ocean (Talbot et al., 1996, Gregory et al., 1997). Asian air masses are known to reach the Washington coast (Jafee et al., 1999). Thus N deposition to western North America could be increasing, although it has been reported to be low (Lynch et al., 1995).

Stream chemistry has been monitored for more than 15 years at sites in southern British Columbia (Feller, 1987) and nine years in the western Olympic Peninsula (Edmonds and Blew, 1997). Long-term studies are needed to examine patterns and trends in stream chemistry. The objectives of our research were thus to determine: (1) trends in stream chemistry over a 16-year period from 1985 to 2000 in an old-growth forest watershed on the coastal Olympic Peninsula of Washington, and (2) seasonal patterns in stream chemistry.

Edmonds and Blew (1997) found no trends in the chemistry of West Twin Creek between 1985 and 1993, but significant changes occurred between 1994 and 2001. Our main conclusions are: (1) stream nitrate (NO_3^-) concentrations increased (Figure 1), apparently in relation to an increase in NO_3^- deposition, either due to Asian air pollution or oceanic sources, (2) a strong depression in stream pH occurred between 1993 and 1996, but after 1997 pH increased to near pre 1993 values, (3) alkalinity decreased and the relative amount of alkalinity that can be attributed to carbonate weathering has decreased strongly since 1992, (4) concentrations of potassium (K^+), NH_4^+(Figure 2), and magnesium (Mg^{2+}; Figure 3) increased, but there were no significant long-term trends for EC, phosphate (PO_4^{2-}), chloride (Cl^-), sulfate (SO_4^{2-}), calcium (Ca^{2+}), or sodium (Na^+), and (5) strong seasonal patterns were noted for EC, Ca^{2+}, and Mg^{2+} with the highest concentrations occurring in late summer, just prior to the rainy season. Seasonal patterns in NO_3^- concentrations were also observed with highest concentrations occurring in fall and winter. From 1994 to 1996 the highest peaks were in the winter months perhaps related to atmospheric inputs. Changes in precipitation N inputs appeared to influence stream chemistry during this period, although the cause of the change and the reason for the rapid response are unknown. Further research is needed to quantify the sources of alkalinity, as well as more thoroughly investigating the evidence for N-saturation in the West Twin Creek watershed.

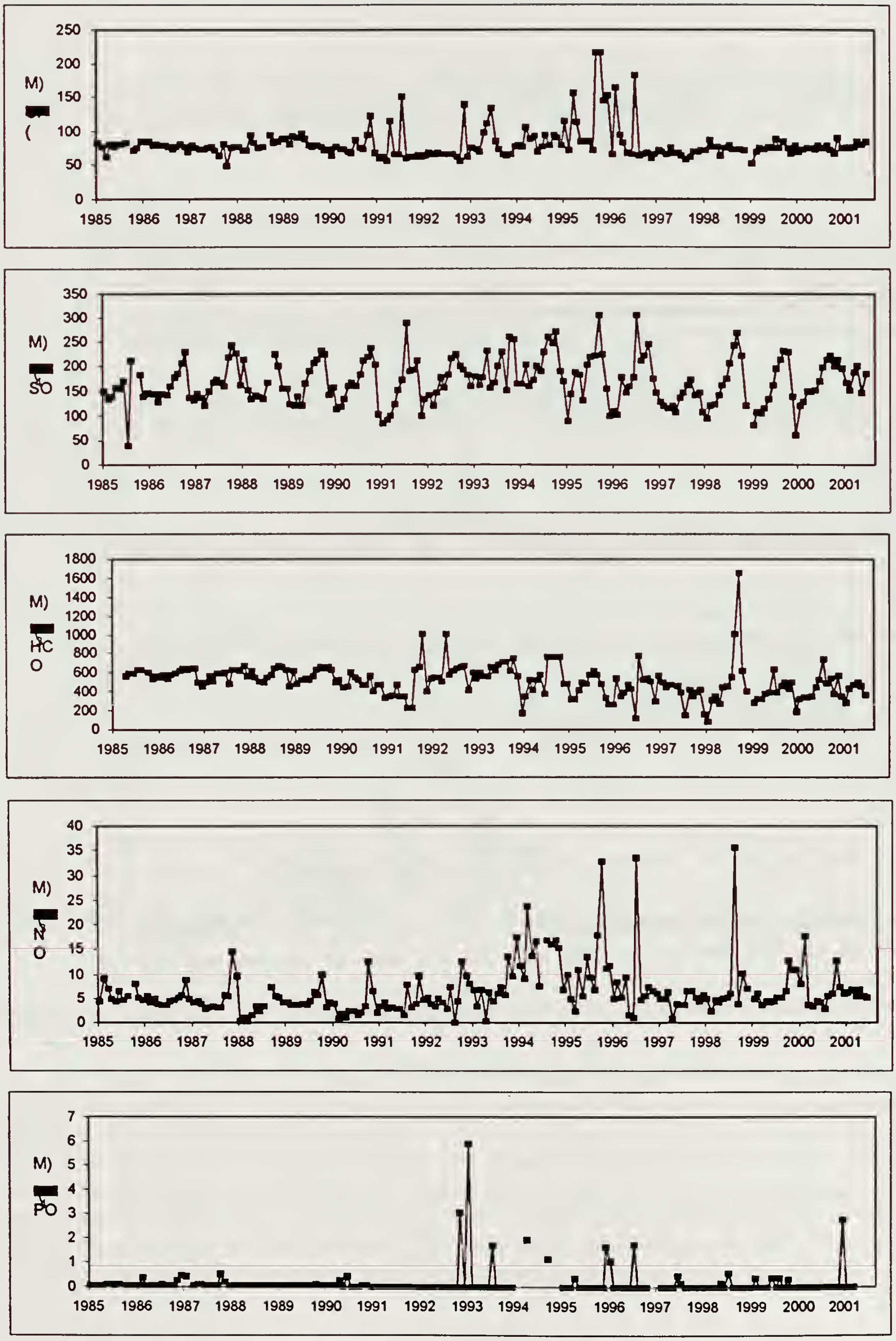


Figure 1. Anion concentrations in µM for West Twin Creek from January 1985 - June 2001.

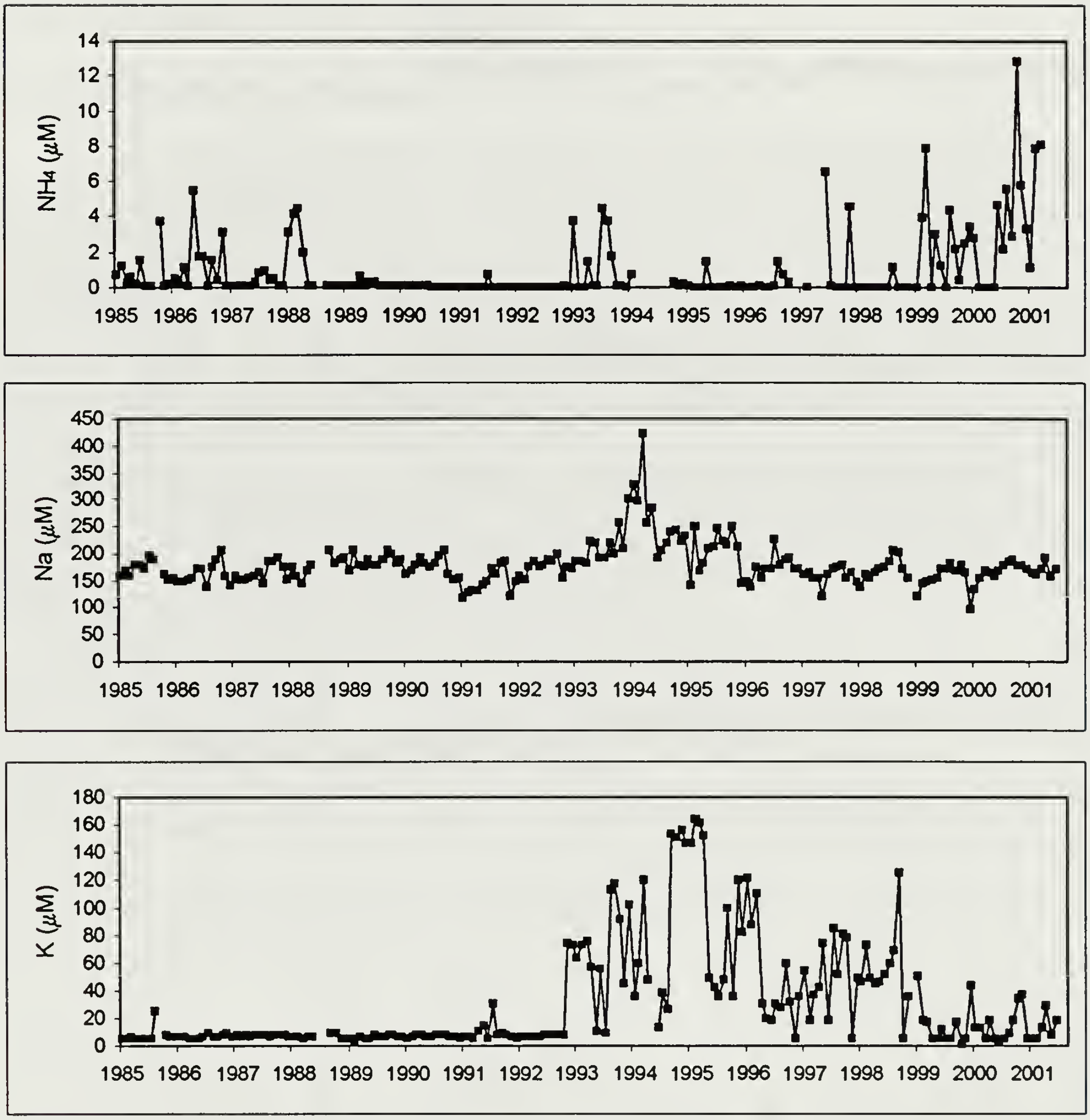


Figure 2. Monovalent cation concentration in µM for West Twin Creek from January 1985 – June 2001.

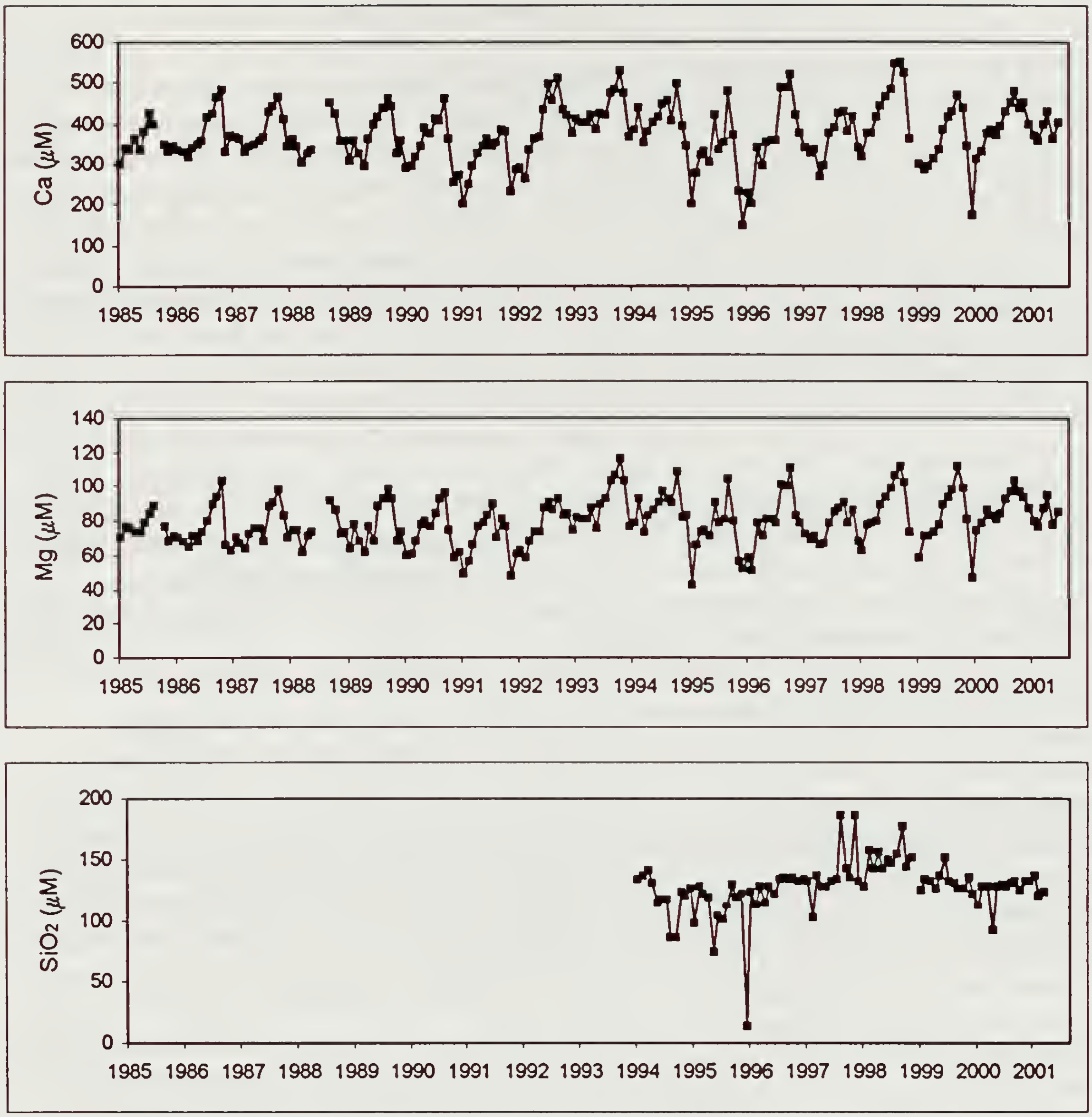


Figure 3. Multivalent cationconcentration in μM for West Twin Creek from January 1985 – June 2001.

Debris-Flow Effects

In steep, mountainous watersheds of temperate regions, floods are a major disturbance shaping the physical (Sidle and Swanston, 1982), chemical (Fisher et al., 1982), and biological attributes of natural ecosystems (Fisher et al., 1982, Lamberti et al., 1989). On occasion, debris flows are associated with large flood events (Benda and Dunne, 1997). Debris flows are mass movements of sediment and debris down stream channels that greatly alter both the streambed and adjacent riparian zone. The recurrence interval of debris flows varies with stream size, land management, climate, and fire frequency (Benda, 1990; Benda and Dunne, 1997; Montgomery et al., 2000). Benda (1990) estimated return intervals for small stream debris flows in old-growth forests to be about 500 years. Studies describing the ecological effects of catastrophic disturbances on natural communities are limited (Turner et al., 1997).

In May of 1999, we began to monitor the temporal dynamics of stream periphyton and insect consumers on artificial substrates in West Twin Creek. A rain on snow event in the winter of 1999 led to the release of a large volume of sediment, water, and wood in the upper reaches of West Twin. During the first two weeks of December 1999 approximately 58 cm of rain fell on West Twin Creek watershed, with 27 cm falling within a 48-hour period (13 December to 15 December). At the time, about 15 cm of snow was on the forest floor. Flooding on the Hoh River peaked on December 15 at 1,171 m^3/s (a peak flow recurrence interval of 2 to 10 years). Pore water pressure in hillslope soils would have risen rapidly during the same time frame, and probably triggered the landslide and subsequent debris flow in West Twin Creek.

Mean daily PAR was about 10% greater after the debris flow compared to before. In addition, mean daily water temperature was significantly warmer (1°C) after the debris flow compared to before. Calcium, NO_3^-, Na^+, Cl^-, SO_4^{2-}, PO_4^{2-}, K^+, and Mg^{2+} were unchanged by the debris flow. The only statistical change in water chemistry was observed for dissolved NH_4^+-N concentration, which was 133% higher after the debris flow compared to before, possibly from the release of nutrients from the landslide area coupled with diminished vegetative uptake. Regardless of the mechanism, light, temperature, and nutrient levels, which are all critical to ecosystem productivity, increased after the debris flow.

We also observed increases in periphyton biomass in 2000 as compared to 1999. Chlorophyll *a* and total periphyton biomass were 100 to 120% greater after the debris flow compared to before. This difference was marginally statistically significant for periphyton ash-free dry mass ($p=0.07$).

The greater availability of food resources may have contributed to the dramatic increase in abundances of select primary consumers found on tile substrata after the debris flow. Averaged across time series, Baetidae abundance was 4350% higher and Chironomidae abundance 360% higher after the disturbance compared to before. We speculate that the abundance of baetids and chironomids increased in response to increased primary production. These two primary consumers, which feed mainly on periphyton, are known to be early colonists of disturbed stream habitats following a major flood (Lamberti et al., 1991; Mackay, 1992). Not all taxa increased in abundance after the debris flow. Abundance of the case-building caddisfly, Glossosomatidae, was 92% lower after the disturbance compared to before. This species has yet to recover to pre-disturbance abundance levels.

From West Twin Creek we have evidence that a relatively infrequent disturbance event within an individual stream reach, a debris flow, profoundly altered stream ecosystem structure and function. We speculate that catastrophic debris flows in streams draining old-growth forests may serve as productivity “hotspots” within the overall drainage network. These hotspots, where density and production of opportunistic insects such as Chironomidae and Baetidae is extremely high, may lead to the export of high quantities of organic matter to downstream mainstem habitats.

GEOLOGIC NITROGEN

The Hoh Lithic Assemblage underlying tributaries to the Hoh River is a complex of sandstone and siltstone/argillite with minor amounts of breccia (Tabor and Cady, 1978). Deposited in a near-shore marine environment, there is great spatial variability in both chemical and textural composition of the bedrock. Siltstone contains approximately 2.5 times as much N (1230 mg kg^{-1}) as sandstone (470 mg kg^{-1}). This translates into pools of 3250 and 1050 kg ha^{-1}, respectively in the upper 20 cm of unweathered rock and represents a significant portion of N storage in the region. We suggest that differences in the N content of siltstone and sandstone, coupled with differences in basin lithology, lead to different stream NO_3^- -N concentrations. Siltstone has significantly more C and N than sandstone, as well as greater Si release rates (Table 1). Geologic N in siltstone is likely to be in one of two forms: incorporated in organic matter or as NH_4^+ replacing K^+ in clays, micas, and zeolites. The low H/C of siltstone (6.8) suggests the organic matter is highly aromatic and, thus, recalcitrant. As a result, N weathering from the rocks should derive primarily from silicates. While Si and N release rates are not necessarily correlative, the probable silicate source for N validates using Si release rate as a proxy for N release. Calculated Si release rates are of the same order of magnitude as those found by Holloway et al. (2001).

Table 1. Measured chemical composition of Hoh Lithic Assemblage rocks and calculated Si release rates. Standard errors are shown in parentheses.

	Siltstone	Sandstone
C (mg kg^{-1})	7280 (517)	995 (84)
N (mg kg^{-1})	1235 (15)	473 (22)
Si release rate	0.0063%	0.0007%

There are two factors that control the autumn NO_3^--N concentration in the streams investigated: amount of red alder in the riparian area and channel percent siltstone. Streams with a significant alder component in the riparian vegetation have much higher stream NO_3^--N concentrations than those surrounded primarily by conifers (Table 2). Overall, the best fits are obtained by using alder percent and channel percent siltstone to estimate streamwater NO_3^--N concentration. The data and model results suggest that geologic N is an important, though previously unmeasured, pool which needs to be considered in future models.

Table 2. Measured stream parameters. Chemical concentrations are the average of October, November, and December 2000 measurements.

	Alder	Canyon	Lindner	West Twin	Snider	Twin
Si –ave (mg L^{-1})	2.74	3.3	2.67	3.36	2.76	3.07
NO_3-N ave (mg L^{-1})	0.236	0.17	0.151	0.109	0.062	0.053
%silt	12.0	4	7	40.0	11.5	26.2
%sand	89.8	5	93	60.0	88.5	73.8
%alder cover	72.5	41.	57	0	8.0	8.0
%silt+%alder	82.7	82.	64	40	19.5	34.2

ISCO AUTOSAMPLER INSTALLATION

Water autosamplers were installed on West Twin and Lindner Creeks in October and November 2001, respectively, to measure changes in stream chemistry and suspended sediments associated with precipitation and hydrologic variation due to storm events. This can be especially important for N and phosphorus(P) in low order streams as most is derived from the terrestrial portion of the watershed (Gosz, 1978). Nitrogen and P concentrations in streams are strongly related to high and low discharge events. These patterns are specific to stream gradient (low vs. high) elevation, land use, and ionic form (NO_3^-, NH_4^+, PO_4^{2-}). In this study we hope to compare the amount of N and P movement through the streams with respect to watershed characteristics, storm events, and resulting discharge variability. This will assist in estimating the transport of N and P from the watershed.

Daily discharge values from the Hoh River were available for 2001 for comparison to West Twin and Lindner Creek water chemistry comparisons. Since daily precipitation data for the Hoh River Valley is not yet available from NADP water chemistry, sediment comparisons were made between streams but not correlated with storm events. Suspended sediments in West Twin are about 10-12 times higher than that found in Lindner Creek. Hoh River discharge is shown for reference to daily discharge until further information is available. Precipitation will be considered in data analysis at a future time.

pH values for Lindner Creek averaged 7.66 and 7.28 for West Twin Creek. Ammonium concentrations were very similar for West Twin and Lindner Creek. TKN and NO_3^- were both higher in Lindner Creek in comparison to West Twin Creek, with NO_3^- being the dominant ion in TKN composition (Figure4a-d). Lindner Creek NO_3^-, TKN, and NH_4^+ were highly variable in November 2001, but due to a sampling error we were unable to collect samples from West Twin Creek for comparison.

STABLE ISOTOPES IN ALDER AND CONIFER STREAMS

The use of C and N isotopes can define structural characteristics (N) of food webs and resource derivation (C). Nitrogen isotope ratios ($^{15}N/^{14}N$) are enriched at successive trophic levels, providing a means for estimation of consumer trophic position (Cabana and Rasmussen, 1996, from VanderZanden and Rasmussen, 2001). Stable C isotope ratios ($^{13}C/^{12}C$) can be used to track the flow of organic matter in ecosystems. Distinct $\delta^{13}C$ values can be used to determine resource derivation, as there is little fractionation of C isotopes from prey to predator (Hecky and Hesslein, 1995).

We have selected a subset of sites from the riparian alder and old-growth stream communities to determine whether stable isotopes could identify different pathways of energy and nutrient flow through food webs in streams with alder or conifer as the dominant riparian vegetation. Stable isotope analysis can also provide insights into food web relationships in headwater streams. Our main objectives of this study were to compare the trophic structures and major C sources of aquatic communities in alder and conifer streams using N and C stable isotopes, respectively. The samples collected in August 2001 were analyzed at the EPA's research laboratory in Corvallis. The EPA donated their time and expertise to the project as they are pursuing similar research.

Preliminary stable isotope analyses show that the vegetation and invertebrate shredders from alder sites had higher ^{15}N content than conifer dominated sites. In addition, the ^{13}C signature of invertebrates (grazer, filter feeder, predator, and aggregate samples) from alder streams was higher compared to West Twin Creek, suggesting differences in invertebrate food source derivation between stream systems. The ^{15}N signature was also different in periphyton and insect consumers in red alder streams compared to conifer-dominated systems.

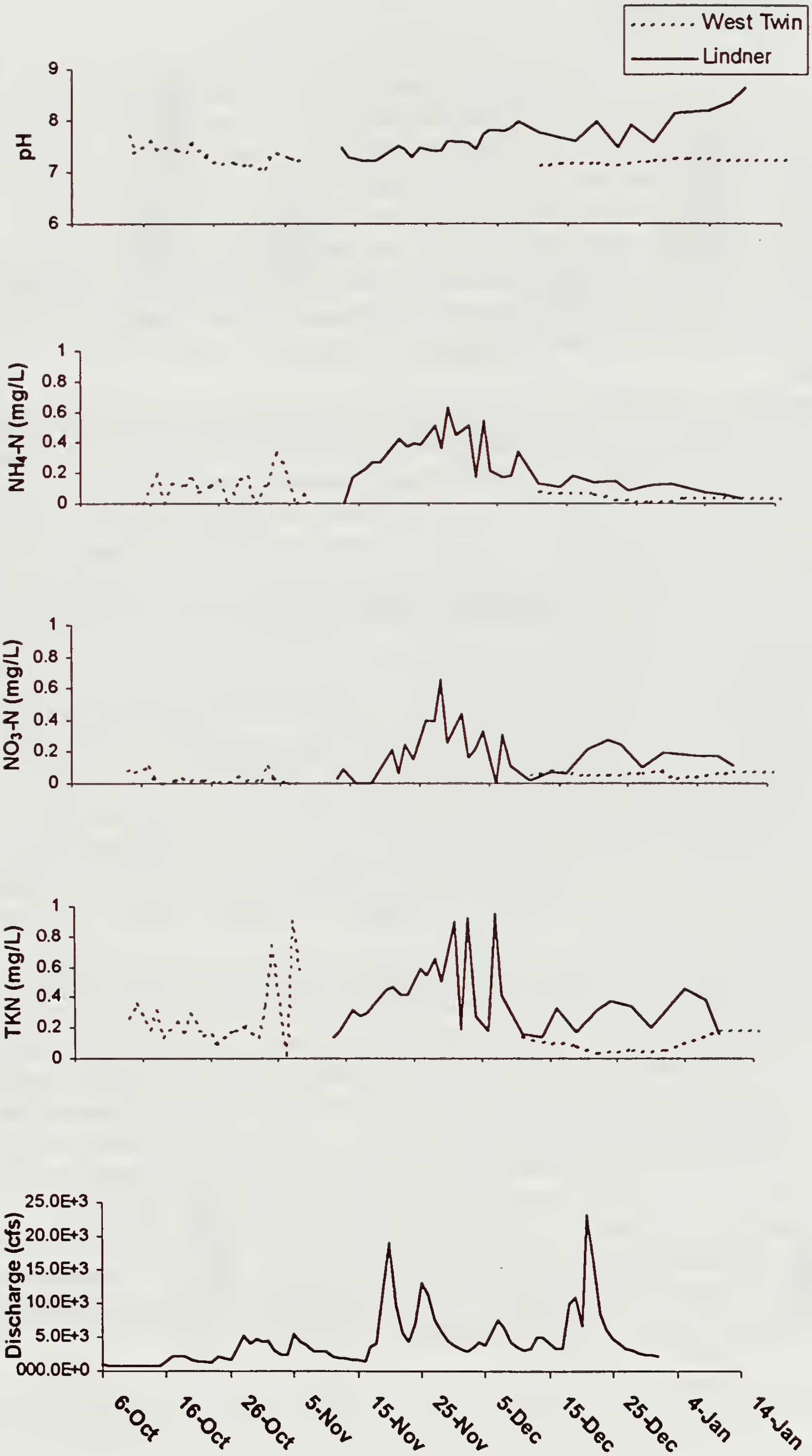


Figure 4. Nutrient analysis of 32 hour ISCO samples (a-d) and (e)Hoh River from USGS gauging station 12041200.

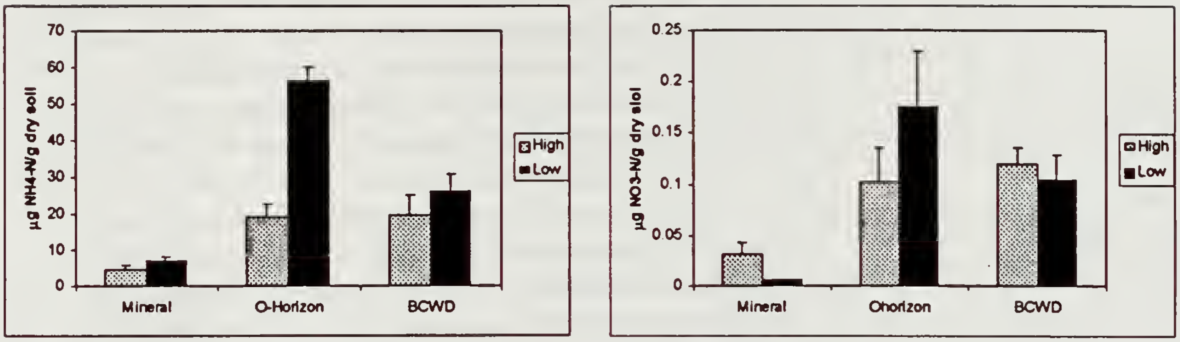
BURIED COARSE WOODY DEBRIS

Between 1993 and 1996, a long-term monitoring study at West Twin Creek measured increased winter NO_3^- concentrations in both bulk precipitation and stream water. The source of this perturbation has yet to be determined. Another component of these forests receiving little attention is the role of buried coarse woody debris (BCWD) in the N cycle. Buried coarse woody debris is decayed woody material covered by at least 2 cm of forest floor and is an important component of the organic horizon in the Hoh rain forest, comprising up to 20% of the forest floor surface. Its distinct chemical structure and potential differences in the microbial community structure both suggest that it would process N differently than mineral soil. Thus, we are attempting to determine potential N immobilization by mineral soil and BCWD in the West Twin Creek watershed.

The study's objectives were to 1) compare pools of available N (NH_4^+ and NO_3^-) in mineral soil, buried coarse woody debris, and the O-horizon just prior to the growing season; 2) measure winter rates of ammonification, nitrification, and N immobilization in the three substrates; and 3) quantify the amount of N immobilized by different mechanisms: microbial uptake vs. physico-chemical reaction. Investigation of these three topics will allow us to more accurately assess the watershed's rapid response to increased NO_3^- deposition between 1993 and 1996. Data were archived until 2000. We currently report physical and chemical differences between the two substrates.

Mineral soil and BCWD can be efficiently differentiated on the basis of color with BCWD being generally darker and redder in hue than mineral soil. Organic material, both the forest floor and BCWD, holds more moisture than mineral soil. The soil in the West Twin area is coarse textured and water leaches through the soil profile rapidly. The difference between substrates may not be very significant during the rainy season, but during the dry summer months BCWD likely provides a steadier moisture source for plants as well as the microbial community. pH is lowest in BCWD, intermediate in the forest floor, and highest in the mineral soil. This is due to a combination of increased organic acids in the organic material and a greater pool of base cations in the mineral soil.

Ammonium pools are approximately one order of magnitude larger than NO_3^- pools, regardless of substrate type (Figure 5), as has been noted in other measurements of extractable inorganic N in this region (Edmonds et al., 1998). There are statistically significant differences between substrate types for both species; mineral soil always contains the smallest pools and the O-horizon the largest. The most significant elevational differences are found in the O-horizon. This is likely to due to the fact that the top-most soil horizon is most affected by environmental factors. Site differences were pronounced at the time of sampling; the upper elevation site was covered by approximately 10 cm of snow. In addition, the lower elevation site had a well-developed understory – lacking at the upper site --which contributed nutrient rich foliar material to the O-horizon. The small available NO_3^- pools found in West Twin soils are not consistent with that of an N-saturated ecosystem (Aber et al., 1998) but are consistent with measurements of soil NO_3^- in pristine old-growth forests of Chile (Perakis and Hedin, 2001).



a

b

Figure 5. Extractable inorganic nitrogen in mineral soil, fine litter and BCWD from near plots 1 and 4 in the West Twin Creek watershed. a shows NH_4-N concentration ±1 se and b NO_3-N concentration.

Upland Soil C and N Cycling

In conjunction with the Unites States Geological Survey (USGS-BRD) study, Comparative Effects of Global Change on Ecosystem Nitrogen and Soil Biogeochemistry in the U.S. National Parks, we began a monitoring project in the summer of 2000 to measure soil chemistry, net N mineralization, soil respiration, and soil functional microbiology. We expect to continue monitoring through 2005.

Ammonium concentrations are larger than NO_3^- pools (Figure 6), as expected. There are two exceptions to this – the very high NH_4^+ measurement in Plot 4 (August) and NO_3^- in Plot 1 (October). The high NH_4 measurement could be due to transformation of NO_3^- to NH_4^+ in the extract. However, we have measured similar NH_4^+ concentrations in buried coarse woody debris from near Plot 4. Thus it is also possible that the August sampling period included woody debris or moss with a high N concentration. In Plot 1, however, it appears that the NH_4^+ pool increases throughout the season, probably due to high net ammonification rates or decreasing plant uptake. Ammonium pools are generally larger in Plot 4, which has a larger accumulation or organic matter.

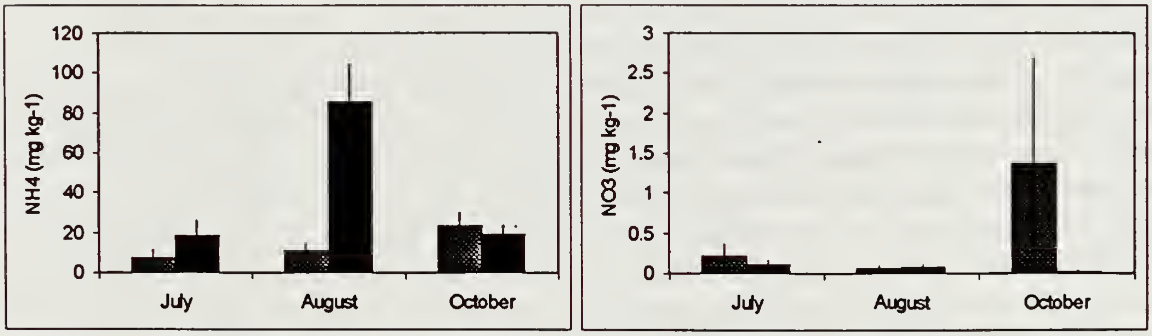


Figure 6. Ammonium and nitrate concentrations. Values are the mean of 6-8 samples, and error bars show the standard error of the mean. Data are from 2000.

There is a statistically insignificant seasonal pattern in soil moisture, with the highest mass percent soil water occurring in the late winter and early spring and the lowest during the summer months. The soil moisture pattern is less pronounced than the seasonal precipitation and discharge trends because the coarse textured mineral soil on the valley walls drains rapidly. Plot 4 is significantly wetter than Plot 1 (p=0.000), and this is likely due to the greater accumulation of organic matter at higher elevations.

pH displays a seasonal cycle that is statistically significant (p=0.000), with low pH values in the spring and high values in the fall. Soil moisture and pH were significantly correlated (p=0.000), yet only 10% of the variation in pH can be explained by variation in soil moisture. There are several possibilities for the spring decrease in pH, including increased dissolution of organic acids, increased root exudation, or increased Al dissolution, all of which are at least partially dependant on soil water content. pH values in plots 1 and 4 are statistically different (p=0.000), and pH in Plot 1 is generally >0.1 units higher. Since the upper soil horizons are influenced primarily by the accumulation of organic matter and activities of the plant community, it is likely that the pH differences are due to differences in the species composition between the two sites.

In general it appears that soil respiration peaks in the late spring with warming temperatures and reduces throughout the summer as soil moisture decreases. It is expected that soil respiration rates would be controlled by the combination of temperature and soil moisture. However, the data collected do not support this hypothesis. During the portion of the year when temperature is the expected limiting factor, respiration at higher elevation (Plot 4) is similar to that at lower elevation (Plot 1). During the dry season, soil respiration is higher in the dry plot (Plot 1). Thus, it appears that other factors such as substrate quality or composition of the soil microbial community, must interact with climatic controls on soil respiration.

West Twin and Lindner Creeks Foodweb Study

In the Northwest, the predominance of red alder in riparian corridors is a consequence of clearcutting and other disturbance events. In the past 100 years, logging has removed natural vegetation and pioneering red alder now dominate riparian banks of streams on Department of Natural Resources (DNR) lands in the Hoh River watershed. Red alder is a pioneer species that has a symbiotic relationship with a N fixing endophyte in its root system. As a result, soil under red alder vegetation has increased concentrations of N in comparison to coniferous forest soils (Binkley et al., 1992; Bormann et al., 1994; Compton, 1997). Research by Tarrant and Miller (1983) has shown red alder to be a significant source of N for terrestrial ecosystems. The physical habitat difference between red alder and coniferous forests is quite pronounced. The deciduous nature of red alder forests opens winter canopies and increases light penetration to the stream, while coniferous forests remain closed throughout the year, providing a stable set of environmental conditions. In addition, red alder has two seasonal inputs, spring catkins and autumn litterfall, while conifers shed the majority of their litter in the fall (Edmonds et al., 1998).

The soil-stream interface is an important control point for nutrient flux (Hedin et al., 1998). Riparian vegetation can also affect streamwater nutrient concentrations, as significant concentrations of N derived from red alder can be carried into aquatic ecosystems (Goldman, 1961). In streams, elevated N levels can greatly increase the production of aquatic biotic components. Algae grown in rich N environments also lowers C:N ratios, constituting a more nutritionally rich diet for primary consumers (Kahlert, 1998). Herbivorous macroinvertebrates and vertebrates will respond to increases in food abundance, although little research has investigated the impact of higher quality food on invertebrate growth and production. The objectives of this study are to: 1) analyze the structure, function, and nutrient content of aquatic food webs using measurements of growth, biomass, and abundance in populations of periphyton, invertebrates, fish, and amphibians, and; 2) compare aquatic community compositions between streams with red alder and coniferous dominated riparian forests.

Stream water chemistry in Lindner Creek was less concentrated in cations and SO_4^{2-} than in West Twin Creek. Lindner Creek did have higher Cl^- levels than West Twin Creek due to its closer proximity to the Pacific Ocean. Contrary to water chemistry in 1999, winter 2000 water indicated the NH_4^+ and TKN were greater in Lindner than West Twin Creek. Increased NO_3^-, NH_4^+, and TKN were also witnessed in Lindner Creek after the first rains in September and October of 2000. Stream water NO_3^- and TKN were almost twice as high in Alder and Canyon Creeks as in Twin and West Twin Creeks, both old-growth coniferous streams. Water samples analyzed for total organic C also showed increased quantities in Lindner Creek.

Seston, organic matter suspended in the water column, biomass was greater in Lindner Creek compared with West Twin Creek. In addition, seston phosphorus content was two times greater in Lindner Creek than West Twin Creek, 3417 ppm (373SE) and 1288 ppm (423SE), respectively). Seston C:N ratios were also higher in Lindner Creek. Low C:N ratios potentially indicates a higher quality resource for stream and terrestrial consumers. The difference in C:N ratios is due to the increased total N concentration in periphyton from alder streams.

Lindner Creek (400 g m^{-2} yr^{-1}) had higher annual litterfall inputs compared to West Twin Creek (150 g m^{-2} yr^{-1}). The N content of red alder leaf litter was approximately 3 times greater than coniferous litter (alder 2.1%N, conifer 0.8%N). This resulted in a lower C:N ratio of red alder litterfall on Lindner Creek. The P content of red alder leaf litter was also significantly greater than the P content of coniferous needles (Table 3). Similar seasonal litter inputs were also documented in the additional Hoh red alder study sites; red alder streams had significantly higher litterfall inputs than coniferous dominated streams.

Table 3. Litterfall nutrients. (mean (1standard error)).

	%C	%N	C:N	P (mg kg^{-1})
West Twin	50.52 (0.35)	0.77(0.06)	65.61	446.84 (45.58)
Lindner	48.2 (0.54)	2.37 (0.18)	20.37	687.55 (41.63)

Both chlorophyll *a* and biomass (ash-free dry mass-AFDM) measurements of periphyton suggest a positive response to red alder. However, an explosion of invertebrate consumers in West Twin confounds these data after the debris flow in December 1999, making site differences difficult to interpret. Nutrient analyses of periphyton suggest Lindner Creek to have higher concentrations of C and N than West Twin. Alder Creek periphyton also had increased N levels in comparison to West Twin, although both had similar percent C composition. All three alder dominated streams, Alder, Canyon, and Lindner Creeks, had lower C:N ratios than West Twin and Snider Creeks in old-growth forest.

Grazers feeding on periphyton inhabiting study tiles can be used to monitor invertebrate life histories and seasonal grazing patterns. In 1999 the tile grazer abundances were greater in Lindner than West Twin Creek. In 2000, grazer abundances were lower in Lindner than West Twin Creek, presumably due to the riparian and community changes instigated by the December

1999 flood. Tile grazer abundances from additional red alder and coniferous sites have similar abundances, but these data are still being analyzed.

Seasonal benthic samples for 2001 have not yet been analyzed (community composition nor nutrient content). Initial observations suggest higher Plecoptera (stoneflies) populations in Lindner Creek than West Twin Creek. Conversely, large Ephemeroptera and chironomid populations (mayflies) have been found on West Twin, especially in 2000 after the December 1999 debris flow.

Two amphibian surveys were conducted along a 100 m stream reach in West Twin Creek in the summer of 2001 (June and September). A select number of Olympic torrents, tailed frogs, and Cope's giant salamanders were also collected from West Twin, Snider, Twin, Canyon, Alder, and Lindner Creeks. Initial lipid and nutrient analyses do not indicate any differences between alder dominated and coniferous streams, although further sample analyses are still under investigation.

Progress towards Integration with other Projects Within Research Theme:

Data produced by research for the Global Change project complements previous research in the West Twin Creek watershed by the Olympic Acid Rain project and also with other on-going projects of the National Marine Fisheries Service and the University of Washington. Monitoring of stream and precipitation chemistry through the Olympic Acid Rain Project allows for calculation of changes in watershed storage of select elements, creating a context for C and N cycling processes. In addition, work within the Global Change project provides background data for stream ecologists studying the effect of riparian vegetation on stream food web structure and soil scientists studying mechanisms of N retention in the watershed's soils.

Plans for FY 2002:

We have continued to collect monthly streamwater, and quarterly litterfall, benthic invertebrate, and periphyton samples from West Twin and Lindner Creeks in 2001. Surveying and individual tagging of amphibians along West Twin, Lindner, and Canyon Creeks is planned for the summer of 2002. Continued monitoring of biological populations and water chemistry at West Twin Creek over the next several years is especially important to record population and ecosystem-level responses and recovery from the flooding event of 1999.

We are collaborating with R. Bilby at Weyerhaeuser in preparation for a 15-20 stream fish survey of red alder and conifer streams in the spring of 2002. We also have plans to continue an additional study involving experimental channels at the Cedar River watershed in the summer of 2002. These experiments will test the effects of a gradient of red alder inputs on stream food webs (nutrient chemistry, periphyton, invertebrates, and fish). Based on our preliminary field observations, we hypothesize that additions of red alder will increase the production of invertebrates, which will increase fish growth rate and condition.

Also, three journal articles are in preparation or review, several presentations at Ecological Society of America, Geological Society of America, and American Fisheries Society meetings are planned, and a masters thesis will be completed this year.

Web Page:

The web page for the West Twin Creek study was last updated in spring of 2000. It can be found through the United States Geological Surveys Midcontinent Ecological Science Center web page, and specifically at http://www.mesc.usgs.gov/wshed-ecosys/olympic.html.]

Data Sets:

WEST TWIN CREEK AND VICINITY

Solution Chemistry

1. Precipitation amount and chemistry – 1984 – present (in clearcut on adjacent Department of Natural Resources (DNR) land)
2. Precipitation amount and chemistry – 1999 – present (in field on privately owned ranch near the park boundary).*
3. Precipitation amount and chemistry – Hoh Ranger Station 2001- present.
4. Precipitation amount and chemistry – transect from coast to 32 km – 1986-1990.
5. Storm events – amount and chemistry – 1987-1989.
6. Throughfall amounts and chemistry- 1986- present.
7. Soil solution chemistry – 1986-1988.
8. Stream chemistry at West Twin Creek weir, grab and proportional – 1984-present.
9. Stream chemistry at Lindner Creek, an adjacent watershed on DNR land – 1999 present.
10. Nutrient chemistry

*There is also National Atmospheric Deposition Program (NADP) data from the Hoh Ranger Station, 1980-present.

Vegetation

1. Vegetation on 6 permanent sampling plots (0.1 ha).
2. Tree growth and mortality – 1985-1990, 1990-1995, 1995-2000
3. Canopy gap dynamics – 1997-1999.

Biomass and Productivity

1. Above and belowground biomass and productivity, soil C.

Nutrient and Carbon Cycling

1. Litterfall in long-term vegetation plots – amount and chemistry – 1985-present.
2. Litterfall in stream channels (West Twin and Lindner) – amounts and chemistry 1999-present.
    a. Litterfall in stream channels (Alder, Canyon, Snider, Twin 2000-present
3. Litter decomposition – 1986-1991; LTER study 1990-1997, in canopy gaps- 19997-1999.
4. Nitrogen mineralization and nitrification – in canopy gaps 1997-1999; in plots 1 and 4 May 2000- present.
5. Forest floor and log respiration – June 1991-1994; forest floor respiration - May 2000 – present.
6. Soil description and chemistry.

Microclimate and Hydrology

1. Stream stage at West Twin Creek weir 1985-1999 (discharge).

2. Discharge at weir site January 2000- present.
3. Soil and air temperature, relative humidity, precipitation, wind speed and direction (East Twin Creek, Peterson Ranch) 1985-1995, 1995-1999.
4. Soil and air temperature, relative humidity, precipitation, wind speed and direction, and photosynthetically active radiation (PAR), West Twin Creek 1999?-present.
5. Discharge and stream temperature a Lindner Creek, 1999- present; other streams 2000-present.

Biodiversity

1. Fungi and invertebrates associated with logs and soil.
2. Functional microbial ecology of mineral soil from permanent sampling plots 1 and 4, biannually.

Stream Biota

1. Periphyton on tiles, 1999- present (WT), Fall 2000 – present (other streams)
2. Invertebrates on tiles and benthic samples, 1999- present (WT), Fall 2000-present (other streams)

HOH LAKE WATERSHED

1. Precipitation and snow chemistry – intermittent samples 1985-1987
2. Lake chemistry – intermittent samples 1985-1987
3. Aboveground biomass, including logs
4. Vegetation on 5 permanent sampling plots (0.1 ha)
5. Tree mortality and productivity, 1985-1990, 1990-2000
6. Litterfall, amounts and chemistry, 1985-1990
7. Weather station – soil and air temperature – intermittent data

ROCKY MOUNTAIN NATIONAL PARK: LOCH VALE WATERSHED

Investigators:

Jill Baron, Jorin Botte, Laura Landrum, Koren Nydick, Brenda Moraska LaFrancois, Heather Rueth, Kate Muldoon, and Sanjay Advani,
Natural Resources Ecology Laboratory, Colorado State University, Ft. Collins, CO

Project History:

Loch Vale Watershed was chosen as the site for a long-term biogeochemical study in 1981. Of 42 lakes surveyed throughout Rocky Mountain National Park, Andrews Tarn, Sky Pond, Glass Lake, and the Loch had the lowest summertime alkalinities, making these lakes more susceptible to acidification than those with higher acid neutralizing capacity (ANC). Another reason for choosing LVWS was for its variety of landscape form. As previously mentioned, there are alpine and subalpine lakes, wetlands, tundra, talus slopes, exposed bedrock, spruce/fir forest, and soils of differing degrees of depth and development. LVWS has a single surface water outlet at 3108 m, which facilitates direct measurement of yearly hydrologic outputs. LVWS is remote, yet accessible throughout the year.

Weekly sampling of LVWS surface waters began in 1982. A remote area weather station (RAWS) and a stream gage were installed in 1983. Weekly precipitation sampling began in 1983. All sampling sites have been nearly continuous in operation since their installation. Several agencies and universities have been measuring different data variables at Loch Vale over the time period including National Park Service; U.S. Geological Survey; U.S. Forest Service; U.S. Bureau of Reclamation; National Science Foundation; National Atmospheric Deposition Program; Water, Energy, and Biogeochemical Budgets (WEBB) Program; UNESCO's Man and the Biosphere Program; Colorado State University; and University of Colorado.

Our primary objective is to gain understanding of biogeochemical processes in order to be able to differentiate natural variability from human-caused disturbance. Through monitoring, experiments, and modeling, we study changes in ecosystems and climate that may be affected by increasing urban, agricultural, and industrial activity. Current research in Loch Vale has three themes: 1) long-term trends in climate and biogeochemical fluxes, 2) ecosystem/atmospheric responses to nitrogen (N) deposition, and 3) effects of global change on mountain ecosystems.

Study Site:

Loch Vale Watershed (660 ha) is a northeast facing glacial basin in Rocky Mountain National Park, located about 80 km NW of Denver, CO. Loch Vale Watershed's (LVWS) western border is the Continental Divide, at 4010 m. More than 80% of the basin surface consists of bedrock outcrop and active talus slopes. The bedrock of LVWS consists of various Precambrian granites, gneisses, and schists. The basin floor is divided into distinct alpine and subalpine elevational terraces. Sky Pond and Glass Lake are located below Taylor Glacier in the southern alpine basin, and Andrews Tarn rests at the base of Andrews Glacier in the northern alpine basin. Most of the vegetation in the alpine areas of LVWS consists of low herbaceous, dwarf-shrubs, and lichens. Several permanent snowfields and an active rock glacier are also present in the upper reaches of LVWS. The two alpine basins merge into a lower subalpine valley floor at the confluence of Andrews Creek and Icy Brook. The lower terrace has old-growth subalpine fir

(*Abies lasiocarpa*)/ Englemann spruce (*Picea engelmannii*) forest. Streams, wetlands, and ponds are also found in this subalpine portion of LVWS.

Progress during FY 2001:

1. We met our objectives for sample collection: precipitation for NADP, surface water chemistry and biology, hydrologic records and meteorology.

2. On October 1, 2001, field sampling efforts were transferred to Rocky Mountain National Park. Karl Cordova now oversees the field operation, and Steve King conducts routine field work. Baron and Botte assist when needed, and all sample processing is still conducted at NREL.

3. We removed another half ton of old equipment and supplies from Loch Vale, with help from the Rocky Mountain N.P. mules.

4. Metadata on Loch Vale meteorology, deposition, water quality was posted by the USGS (thanks to Terry Giles).

5. Forest fertilization plots were maintained, but not sampled.

6. We ran experimental mesocosms in The Loch during July and August with duplicate amendments of control, N, P, N+acid, and N+acid+P to look at changes in benthic and pelagic primary productivity, algal and invertebrate species composition, potential for acidification from N, and nitrogen cycling using a ^{15}N tracer.

7. We assisted Dr. Ruth Yanai from Syracuse University with a field experiment to explore root uptake dynamics with different N treatments.

8. We completed field work on hydrologic pathways and N cycling for Embryo Pond.

9. Heather Rueth completed and defended her doctoral research on forest biogeochemistry.

10. We worked with one Research Experience for Undergraduate student, and two high school teachers from Northridge H.S. in Greeley throughout the summer.

11. We applied the Regional HydroEcological Systems Simulation (RHESSys) to Loch Vale and have produced preliminary hydrological and biogeochemical simulations. This is important because the revised RHESSys in object-oriented language is far more complicated than the original, includes nutrient cycling, and has not been tested previously, and we are part of the initial troubleshooting.

12. Presentations were made to the Forest Service at the Rocky Mountain Station; U.S. Congress during Hearings of the House Science Committee on Atmospheric Deposition; a field trip of the Colorado-Big Thompson Project with approximately 50 local water managers; REU students field trip to Loch Vale; the All-Scientists International Geosphere-Biosphere Meeting in

Amsterdam; the Rocky Mountain Nature Association field trip; the American Society for Limnology and Oceanography; the Ecological Society of America at a special symposium organized by Rueth and Baron on western atmospheric deposition; the Denver Museum for Biodiversity Day; Utah State University; The Ecosystems Center at Woods Hole, MA; University of Minnesota; University of Louisville, KY; the Canon Envirothon - North American High School Environmental Science competition, Jackson, MS; the CSU Student Ecology Symposium; CSU Hydrology Days; Northridge High School; and the 2nd International Nitrogen Conference.

13. We and our USGS WEBB colleagues published eight manuscripts, one thesis and one dissertation. Five other manuscript are in press or preparation.

Progress toward integration:

Research and collaboration have extended beyond Loch Vale borders, and results are quite exciting. A symposium was held in August at the Ecological Society of America annual meeting, organized by Heather Rueth and Jill Baron, titled "Western nitrogen deposition: Is there cause for concern?" Papers were presented on the topic addressing aquatic and terrestrial responses to nitrogen deposition in diverse landscapes, including coastal sage scrublands of southern California, ponderosa pine ecosystems of the San Bernardino Mountains, fire-dominated coniferous ecosystems of the eastern Sierra Nevada, and a number of Colorado systems. A summary of western sensitivity to N deposition is in preparation. A synthesis of the propensity of western lakes for acidify or eutrophy was part of the symposium, and is being prepared for publication.

Other regional work has addressed coniferous forest responses to N deposition in northern Colorado, using both surveys and experimental fertilizations. An assessment of N emissions for the State of Colorado and the South Platte Basin was presented at ESA. Finally, a book manuscript was completed describing the effects of human disturbances on the Rocky Mountains. *Rocky Mountain Futures: an ecological perspective*, is an edited volume that will be published in 2002, the International Year of Mountains, by Island Press.

Plans for FY 2002:

1. Continue sampling physical, chemical and biological parameters.

2. Train park interpretation rangers in air quality, atmospheric deposition, and ecological effects, continue informing managers of findings and progress, and participate in the 2nd Rocky Mountain National Park all-scientist meeting.

3. Submit manuscripts on forest plot fertilization effects, Western Lake Survey nutrient status, Colorado N emissions, lake bioassay and N cycling results, and see Futures book through to publication.

4. Complete two doctoral dissertations on aquatic ecosystem responses to N, and one thesis on Embryo Pond flowpath and N source study.

5. Resample permanent forest plots in Loch Vale 15 years after installation.

6. Conduct taxonomic and biomass studies of understory plants of Loch Vale and Fraser control and fertilization plots.

7. Publish species lists of flora, aquatic organisms and algae on Loch Vale website.

8. Conduct analysis of long-term chemical data related to climate and hydrologic variability.

9. Conduct and interpret compound-specific C and N isotope analyses of Sky Pond sediments to understand whether observed isotopically-light N in sediments is due to changes in N emissions source, diagenesis, or changes in algal physiology from eutrophication. Analyses will be done at MIT.

10. Present RHESSys hydrologic and biogeochemical simulations for Loch Vale and Big Thompson Watersheds at the South-Central meeting of the Geological Society of America, American Geophysical Union meeting, Rocky Mountain Hydrologic Research Center annual meeting.

11. Extend RHESSys studies to the Big Thompson Watershed.

12. Prepare and submit two manuscripts on RHESSys simulations for Loch Vale and the Big Thompson watersheds.

13. Participate in the NERC-N workshop at Woods Hole in March entitled "A Cross Site Synthesis of Forest Ecosystem Response to Elevated Atmospheric N Deposition." NERC is the Northeast Regional Cooperative research effort of the Forest Service.

FRASER EXPERIMENTAL FOREST

Investigators:

Manual Martinez, Todd Mowrer, Louise O'Deen, Banning Starr, all U.S. Forest Service, Ft. Collins, CO; Robert Stottlemyer, USGS MESC, Ft. Collins, CO.

Project History:

The Fraser Experimental Forest (FEF) was established in 1937. The primary research objectives were to conduct long-term studies of 1) the effect of subalpine vegetation manipulation on the timing and magnitude of water yield, and 2) understand the ecology of selected commercial forest species. There are nine gauged watersheds including two sub-basins within the Deadhorse Creek watershed. Several watersheds have a continuous meteorological and hydrological database from 1940. Most watersheds have been continuously monitored since 1957, and two were started just recently (1986) when the number of gauged alpine catchments was increased. Research in biogeochemistry and nutrient cycling within major forest types began in 1965 (Stottlemyer and Ralston, 1970). Precipitation and surface water chemistry was intermittent between 1965 and 1982, and a continuous record exists since 1982.

Study Site:

The Fraser Experimental Forest, located 115 km west of Denver, west of the Continental Divide, contains 8650 ha, and ranges in elevation from 2665 to 3880 m. Nine FEF watersheds are gauged, and six meteorological stations are maintained within or conterminous the watersheds including Aerochem Metric wet precipitation collectors at 2730 and 3350 m elevation.

The FEF climate is cool and humid with long cold winters and short, cool summers (Alexander et al., 1985). Annual precipitation averages 0.74 m of which 65% falls as snow. Snowmelt accounts for >95% of the annual runoff (Troendle and King, 1985) most of which occurs during May 15 - July 1. Annual streamwater discharge averages 0.36 m. With the high snowfall, subalpine soils remain unfrozen throughout winter.

Bedrock consists of gneiss and schist. The watersheds were glaciated, and their streams flow over moraines at varying elevations. Soils are principally Inceptisols with surface CEC averaging about 20 $mmol_c$ 100 g^{-1}. Soil base saturation averages about 10 $mmol_c$ 100 g^{-1}, and pH ranges from 4.5 to 6.1 (Stottlemyer, forest floor and mineral soil chemistry of Deadhorse and Lexen Creek watersheds, 1986, unpub. data).

Canopy vegetation along stream bottoms, on north-facing slopes, and at upper elevations consists of old growth forest of Engelmann spruce (*Picea engelmannii* Parry) and subalpine fir (*Abies lasiocarpa* [Hook] Nutt.). Lodgepole pine (*Pinus contorta* Dougl.) generally dominates at lower and mid-elevations southern aspects. Alpine tundra occurs at about 3350 m (Alexander et al., 1985).

Progress during FY 2001:

We completed 19 years of continuous monitoring of precipitation and streamwater chemistry for the six primary watersheds. In addition, we have on average 15 years of streamwater chemistry for four alpine catchments, 15 years of comparison data for precipitation chemistry with elevation, 15 years of monthly snowpack chemistry along an elevation gradient, 6 years of intensive snowpack/snowmelt chemistry along an elevation and aspect gradient, a unique 15-year data set on change in soil solution chemistry with depth following paired plot clearcutting, and a decade of snowpack chemistry in a separate experiment with paired plots following clearcutting.

Last year we continued the basic monitoring of surface water chemistry in the nine gauged watersheds, the change in snowpack chemistry with elevation, and summarized our ten-year study of the effect of clear cutting on subsurface flow chemistry and budgets. Our research on experimentally disturbed sites led to requests to address likely impacts from clear cutting on surface water quality in National Forests of the Rocky Mountains. We have begun the two-year process of assembling and analyzing the long-term climate and hydrology database to integrate with our biogeochemistry for eventual publication in a monograph. The monograph topics will be similar to our recent book on Isle Royale, but will incorporate data from all nine watersheds, contain considerable more data on long-term change in snowpack and snowpack chemistry, and address the effects of subalpine canopy removal on hydrology and nutrient export from watershed ecosystems.

We continued the study, initiated fall 1999, to examine seasonal change of micro-climate, soil process rates, soil nutrient pools, and production and export of soil DOC and DON in response to aspect, elevation, and N availability in the Lexen Creek watershed. The study design and processes examined are similar to the study continuing in the Asik watershed, Noatak National Preserve, and research we will initiate this year at Wallace Lake on Isle Royale. We also placed emphasis last year on analyzing the large database on disturbance ecology at the FEF, and this coming year will have a series of publications on this topic. This topic will be one also included in the monograph.

Finally, we continue to disseminate research results through the principal investigators' conduct of workshops at the FEF for professional societies as American Society of Civil Engineers and Society of American Foresters, personnel from National Forest Systems, and Federal Congressional staffs. We also made significant upgrades in the cooperative USGS-USFS biogeochemistry laboratory in Ft. Collins, Colorado. Chief among these was improved equipment to help prepare soil, forest floor, and plant tissue samples for analysis, new laboratory computers, new laboratory software for converting analog to digital output with improved post-analysis computation options, and with support from the U.S. Forest Service a new PC-Titrate unit by Man-Tech for pH, conductance, and alkalinity determinations. The present laboratory, while short on space, is up to date and capable of analyses on large numbers of samples.

Progress towards Integration with other Projects Within Research Theme:

Two publications relating disturbance to long-term effects on ecosystem processes were either published or accepted for publication (not listed below). We also submitted a proposal regarding the effects of silvicultural practices on the long-term N budgets for major montane vegetation types within the FEF. The long-term effects of disturbance, primarily silvicultural practices, on hydrology and ecosystem processes will also be one chapter in the FEF monograph currently in preparation.

WALLACE LAKE, ISLE ROYALE

Investigators:

John Adler (Biology), Sarah Green (Chemistry), Kurt Pregitzer (Forestry), David Toczydlowski (Biology), all Michigan Technological University, Houghton, MI; Robert Stottlemyer, USGS, Ft. Collins, CO.

Project History:

A major advantage of conducting long-term, ecosystem-level research in a National Park is the legal protection provided against change in land use. Since the value of long-term study increases with time, the selected site can potentially represent a significant investment in terms of funding, time, and personnel. Removing the potential for arbitrary and incompatible land use or activity on or conterminous the site, which commonly happens on most public land outside wilderness and parks, is likely the most important site selection criterion.

Selection of the Wallace Lake watershed within Isle Royale followed an extensive 1980-81 survey of surface water quality in the park's streams and lakes. This survey was supported with funds from the National Park Service Water Resources Division. Our site selection criteria were 1) a watershed ecosystem with surface water quality characteristic of Isle Royale, and 2) a system vegetated exclusively by boreal forest. The latter objective limited our site selection to the northeastern two-thirds of the park since portions of the southwestern end of the park are vegetated by mature northern hardwoods. A final consideration was logistics. Sites within the interior of the park are especially difficult to reach in fall, winter, and early spring.

At the time of site selection, there was much interest in the response of sensitive lakes and streams to acid precipitation inputs. With completion of our 1980-81 surface water survey, it was apparent the lakes and streams of Isle Royale were, and are, not directly sensitive to acid precipitation. The lower specific conductance and pH waters on Isle Royale are dominated by high concentrations of dissolved organics. The absence of a clear water, directly sensitive system was not a limitation since our primary research goal was the long-term study of the structure and function of a southern boreal ecosystem, and how it responds with time to a variety of atmospheric inputs and climate change.

Study Site:

The 115 ha Wallace Lake watershed (48°03' N, 88°38' W) is located within the NE third of Isle Royale National Park, Michigan, in NW Lake Superior about 130 km N of Houghton in Michigan's Upper Peninsula. Within the watershed is located the 5 ha Wallace Lake and gauged first-order sub-catchment W1 (16 ha), the only sub-catchment with year-round stream discharge. This stream flows to the NNE into Wallace Lake, and Wallace Lake outflow to station W2 flows due north.

Watershed elevation varies from 195 m at the lower-most stream gauging station (W2) to 275 m on a ridge, the watershed's eastern border. The watershed has a northern aspect. Wallace is characterized by relatively flat topography broken by NE - SW oriented small (<5 m elevation change) bedrock ridges with most exposed by glaciation. Rock outcrops, generally vegetated by scattered white spruce, comprise approximately 40 ha within the watershed primarily in its western portion. One of these small ridges also dams Wallace Lake.

To provide a reference set of streamwater chemistry, the conterminous Sumner Lake watershed east of Wallace is also gauged. This watershed is slightly larger than Wallace, of identical elevation, but has a more NE aspect. Only streamwater chemistry is monitored here at two locations: the year-round surface stream feeding Sumner Lake (Station S1), and the Sumner Lake outflow (S3).

Prior to initiation of the Wallace study there were no continuous year-round climate data for Isle Royale. The National Oceanographic and Atmospheric Administration (NOAA) collects weather data at the Passage Island lighthouse 5.5 km to the NE of the main island and the Rock of Ages lighthouse 6 km to the SW. The Rock of Ages lighthouse is on a point of exposed bedrock and Passage Island is small. It is doubtful the climate data, except perhaps for wind direction, from these sources are representative of most of Isle Royale. The NOAA also operates a year-round weather station at the Houghton County airport 6 km from the Calumet watershed on Michigan's Keweenaw Peninsula.

At Wallace, the mean annual temperature since 1982 is $3^{O}C$ (standard deviation = $1.8^{O}C$). The mean annual minimum is 0.2^{O} and mean maximum $5.8^{O}C$. The mean annual temperature at Wallace is $2.4^{O}C$ lower than at the Houghton County Airport NOAA station for the same time period. Seasonally, temperatures range from $-9^{O}C$ in January to $15.8^{O}C$ in July. Mean annual precipitation at Wallace is 75 cm, and ranges from 57 to 104 cm. About 40% of annual precipitation occurs as snowfall. The Wallace precipitation is 7 cm less than at the airport NOAA station. Seasonally, mean monthly precipitation at Wallace ranges from 3.3 cm in February to 9 cm in November.

The bedrock sequence on Isle Royale consists of a series of lava flows (flood basalts) and sedimentary rock tilted to the SE. The sedimentary rocks are sandstones and conglomerates. The linear ridges, generally running NE to SW, are the edges of the individual stacked layers modified by erosion and glaciation. The rock sequence consists of two formations: the lowest and oldest is the Portage Lake Volcanics which includes the lava flows and minor imbedded sedimentary and pyroclastic rocks, and the upper more recent formation or Copper Harbor Conglomerate which contains only sedimentary rocks.

Isle Royale was overridden by ice in each of the four major glaciations. The last was the Wisconsin Glaciation about 12,000 years ago. Because of the resistant nature of Isle Royale's predominantly volcanic substrate, its ridges largely survived the glacial advances. Glacial striations are clearly visible over much of the exposed bedrock in the Wallace Lake watershed. The bedrock beneath Wallace is metamorphosed volcanics covered by scattered alkaline glacial till originally derived from limestone bedrock immediately south of James Bay.

Soils in the watershed are primarily Alfic Haplorthods, sandy to coarse loamy, mixed, frigid, between 3000 to 5000-years old, and were deposited during the post-glacial Lake Nipissing stage and resorted during the post-Lake Duluth state. Parent materials are sands and beachline deposits laid down during the post-glacial Lake Nipissing stage. Watershed soils are mapped (Shetron and Stottlemyer, 1991).

Over a dozen soil pits have been sampled and profiles described in the Wallace Lake watershed (Stottlemyer and Hanson 1989, Shetron and Stottlemyer 1991). Soil pits are located beneath each major vegetation type, and adjacent each permanent vegetation plot. Mineral soil horizons are moderately acidic. Deeper horizons are characterized by stratified clays and sands.

Soils in the watershed tend to be poorly drained because of the low topographic relief and shallow depth to bedrock.

Isle Royale is in the vegetation transition zone between the boreal forest on the north shore of Lake Superior and the eastern deciduous forest which predominates on the south shore. The watershed's overstory is dominated by trembling aspen (*Populus tremuloides* Michaux), white birch (*Betula papyrifera*), balsam fir (*Abies balsamea*), and white spruce [*Picea glauca* (Moench) A. Voss]. The birch-aspen vegetation type occupies about 61 ha in the watershed, spruce-fir 6 ha, alder 3 ha, cedar 1 ha, and wetlands >2 ha. A small portion of the watershed burned in a 1936 fire which covered the central one-third of Isle Royale. But there is no additional evidence of fire in the watershed for at least 125 years. There has been no direct human disturbance of the watershed.

Progress during FY 2000:

By the end of FY 01, we completed 19 years of precipitation and streamwater chemistry on the two ISRO watersheds, 21 years of intensive precipitation, snowpack, snowmelt, and streamwater chemistry at the Calumet watershed, and 15 years of intensive forest litter and soil solution monitoring during snowmelt at Calumet. We also completed a study of decomposition rates beneath major vegetation types in the Wallace Lake watershed, and a decade of monthly measurements of net soil nitrogen mineralization rates, inorganic nitrogen pools, and seasonal change in forest floor C:N ratios. This study will be evaluated to relate climate factors to soil processes, and determine if following such soil processes is a practical long-term terrestrial monitoring tool.

We have also developed the conceptual model to examine effects of global change using an approach easily elevated to the landscape level. This concept, to be implemented as funding permits at Wallace Lake, the Asik watershed, and the FEF, is heavily based upon the long-term observations at the sites and consists of three, slightly over-lapping components.

The first component focuses on quantifying the hydrologic flowpath from the terrestrial to aquatic ecosystem and, by use of natural isotope abundance study, determine the source of DOC and DON entering the stream and change in its upstream-downstream amount with biotic use. Most ecological studies on processes do not consider the significant, if not dominant, role of hydrology in accounting for variation in what is viewed as only biological changes. Because of the rapid environmental change now occurring in most boreal regions, several years of study are thought sufficient to quantify the process. Methods for determining hydrologic flowpaths are well established. One method to quantify change in N and C sources is through use of natural isotope abundances especially ^{15}N, ^{18}O, and ^{13}C (Peterson and Fry 1987). But the application of such procedures requires additional testing especially their use at the watershed or landscape level. The objective of this study component is to test use of natural isotope abundance ratios, such as ^{15}N/^{14}N and ^{13}C/^{12}C, to detect spatial and temporal changes in source area for C and N in watershed aquatic ecosystems.

Soil chemical and physical qualities are principal factors regulating stream nutrient export from watershed ecosystems especially during snowmelt. Surface soil character controls the proportion of snowmelt occurring as overland and subsurface flow (Stottlemyer and Toczydlowski 1991). The length and depth of the hydrologic flowpath for meltwater and rain also alter soil water chemistry (Rice and Bricker 1995). A better understanding of basic hydrology is necessary in ongoing ecosystem global change research and improve hydrochemical models (Obradovic and Sklash 1987). This is especially true for boreal ecosystems where potential nutrient reservoirs are 1) precipitation on saturated soils, 2) seasonal snowmelt, 3) the near-stream saturated zone, 4) wetlands, 5) subsurface flow from uplands, and 6) seasonal permafrost melt saturating lowland soils. For example, stream water NO_3^- can seasonally originate from any of these reservoirs, and most or all of them during spring runoff. Shifts in the relative contributions from these reservoirs complicate quantifying spatial and seasonal change in watershed biogeochemical budgets and their sensitivity to global change (Stottlemyer et al., 1998).

Dissolved organic carbon can be the largest C input to streams (Hall 1995). It is largely absorbed by benthic bacteria which in turn are utilized by primary consumers. We hypothesize the source area for stream water DOC varies spatially and temporally. With spring snowmelt, the increase in watershed-level DOC concentration and flux during the rising hydrograph limb suggests the rise in subsurface soil water level removes a large reservoir of DOC formed during winter in near-surface soils. Differences in annual watershed DOC export are due primarily to over-winter soil temperatures and spatial shifts in source area. In summer, a relatively greater proportion of DOC flux comes from in-stream processes. Spatially, headwater DOC comes primarily from terrestrial processes with in-stream processes of greater relative importance downstream. We hypothesize differences in foliar $^{13}C/^{12}C$, or $\delta^{13}C$, from C_3 and C_4 dominated vegetation will be reflected in soil organic matter and the more labile DOC derived from this organic matter, and the $\delta^{13}C$ will provide a mechanism to detect spatial and temporal change in DOC sources in stream water.

We will use three approaches to define the flowpath and relative importance of inorganic and organic nutrients and C from terrestrial processes to the aquatic ecosystem: 1) trace precipitation, snowmelt, and soil water NO_3^- contributions during spring runoff using the ^{15}N and ^{18}O compositions of NO_3^- (Kendall et al., 1995), 2) examine trends in fractionation of the $^{15}N/^{14}N$ ratio ($\delta^{15}N$) through terrestrial N pools (N fixing plants, their understory vegetation, soil organic N pools) and upstream-downstream DON to quantify the magnitude of watershed N output from terrestrial N fixation; and 3) quantify the source of terrestrial C contributions using change between $^{13}C/^{12}C$ ratios ($\delta^{13}C$) in plant communities dominated by C_3 or C_4 photosynthetic pathways, the soil organic C beneath them, and upstream-downstream DOC in stream water draining from such plant communities. The $\delta^{13}C$ signature differences in soil organic matter (SOM) from C_3 and C_4 plants can be used, in part, to assess past and present spatial differences in terrestrial DOC and particulate organic carbon (POC) contributions to surface water.

Soil organic matter contains a record of shifts in $^{13}C/^{12}C$ isotopic composition associated with trends in the past indicating the presence of C_3 or C_4 vegetation. Atmospheric CO_2 has about 1.1% ^{13}C and the remainder is ^{12}C. During photosynthesis, plants discriminate against the heavier isotope, and C_3 plants much more so than C_4 plants. This discrimination results in a different range of $\delta^{13}C$ values within the organic matter of C_3 or C_4 plants. This difference permits use of SOM isotopic changes to detect past temporal and spatial shifts in above-ground plant composition. If present C_3 or C_4 plant communities are sufficiently diverse, some indication of this may also be seen in surface water DOC and POC. In better drained soils, which often is not the case in boreal soils, heavy isotope enrichment for C also increases with SOM depth.

The second component of this research examines relative change in isotope abundance with depth of soil SOM both to determine its rate of deposition (age) and relative contributions to stream water DOC and DON with soil drying as during summer or with increased depth of thaw.

In theory, change in SOM isotopic composition spatially and with depth should be reflected in soil water and stream water DOC, DON, POC, and particulate organic nitrogen (PON) isotopic compositions. This relationship may be most evident in boreal or similar ecosystems where SOM organic C and N amounts are large, the SOM deposition rates are slow, and the depth of the soil activity zone seasonally increases with warming during the growing season. Under such circumstances, natural isotopic abundances might be used to detect spatial and temporal change in sources of terrestrial C and N to the aquatic ecosystem. Such data would give a dynamic picture of ecosystem sensitivity to global change.

We hypothesize that 1) increases in SOM $\delta^{15}N$ and $\delta^{13}C$ values with soil depth may be reflected by change in isotopic compositions of surface water DON, DOC, POC, and PON during the growing season as the soil active layer depth increases; 2) by examining differences in $\delta^{15}N$ and $\delta^{13}C$ in stream water dissolved and particulate C and N along a gradient of permanent upstream-downstream monitoring stations, we should be able to obtain an integrated picture of change in active layer depth with elevation and vegetation (alpine tundra versus taiga).

The ^{13}C rationale and method is outlined in component one above. There are also consistent changes in SOM nitrogen isotopic composition with depth. Generally, the abundance of the heavy N isotope (^{15}N) relative to ^{14}N increases with SOM depth or decreasing soil organic N concentrations. By comparing change in SOM carbon and nitrogen isotopic composition with soil depth, the seasonal change in depth of the soil active zone, soil water DOC and DON isotopic composition, and the spatial and temporal change in surface water dissolved and particulate N and C isotope composition, we may detect from aquatic monitoring the integrated changes in the depth and flux of nutrients and energy from the soil active layer for the sub-catchment or catchment.

The third component deals primarily with the probable physico-chemical effects of change in dissolved organics on surface water especially ponds and lakes. Terrestrial production and export of DOC and DON to the aquatic ecosystem is a function of soil temperature, moisture, seasonal hydrologic flowpath, and basin morphology (Dillon and Molot, 1997; Battin, 1999; Brooks et al., 1999; Baker et al., 2000). In the aquatic ecosystem, DOC and DON provide significant amounts of energy and nutrients (Sun et al., 1997) especially in the boreal biome (Peterson et al., 1986; Easthouse et al., 1992). High DOC concentrations also regulate the quality and efficiency of foodweb energy flow in lakes (Jansson et al., 2000) and ultra-violet (UV) light penetration (Sommaruga et al., 1999). An extensive 1980-82 survey of lakes in Isle Royale National Park (Stottlemyer et al., 1998) showed all to be humic (colored) in varying degrees. The DOC in these lakes appears primarily derived from allochthonous (terrestrial) sources. Colored lakes have an open-water (pelagic) foodweb based largely on bacterioplankton energy mobilization from DOC (Jansson et al., 2000). In contrast, in clear water lakes the pelagic foodweb is based mainly upon phytoplankton photosynthesis. The efficiency of energy use is lower in humic lakes where production is based on bacterioplankton because of the additional links in the food chain than in clear lakes. Research in Europe and North America shows lake foodweb shifts between heterotrophic production (bacteria) and primary production (phytoplankton) can take place with modest changes (10 mg l^{-1}) in DOC concentration. Climate change could affect the DOC loading to lakes and therefore their biodiversity, biotic structure, and productivity (Schindler, 1998). On Isle Royale, warming soils will likely increase terrestrial DOC production and export to the aquatic ecosystem (Stottlemyer et al., 1998). However, a factor not considered in many flux estimates is the annual change in hydrologic flowpath especially where snowmelt dominates lake inputs from the terrestrial ecosystem. For example, during the May peak snowmelt period at Wallace Lake, stream water DOC concentration and especially flux (input) increase (Stottlemyer et al., 1998). The seasonal range in lake DOC concentration in some Isle Royale lakes can be sufficient to affect lake productivity and foodwebs. This seasonal cyclic change in lake DOC concentration is a function of hydrologic flowpath to the lake, over-winter soil mineralization rates, soil temperatures, aquatic biotic utilization, and aquatic DOC destruction by radiation absorption. Seasonal variation must be factored into any assessment of change in lake dissolved organic budgets due to climate or other components of global change, and this can only be initially done where long-term chemical and hydrologic datasets on seasonal terrestrial export of organics and lake chemistry exist.

Another dimension to this question is the relationship between light extinction, including UV, and lake DOC concentrations. In Wallace Lake the light extinction coefficient, a composite of lake light absorption by water, particles, and dissolved organics, is correlated to DOC concentrations ($p < 0.05$, $r^2 = 0.71$). An increase in lake water DOC concentration of 1 mg l^{-1} increases the extinction coefficient 0.09. Change in DOC concentration will affect the depth at which primary production can occur and thus the production of the lake. Presently, at Wallace Lake light is sufficient for primary production only to a depth of 1.3 m in mid-to late summer, but the epilimnion is slightly deeper. Our 1980-82 survey showed such depths relatively common in Isle Royale Lakes.

A final related question is how might global change alter the quality of DOC and the quality and quantity of DON available to the lake (Easthouse et al., 1992; Kallbitz et al., 2000)? The DOC and DON production and quality will likely be altered by the availability of soil inorganic N, shown responds to warming temperatures (Stottlemyer and Toczydlowski, 1999b). Wallace Lake presently experiences a pronounced seasonal shift in the relative importance of inorganic N, as NO_3^-, and DON as an essential nutrient.

The research objectives of this component are generally to 1) quantify seasonal change in the net primary production: bacterioplankton production ratio; 2) quantify the primary production: bacterioplankton respiration ratio; 3) relate these two ratios to lake DOC concentration to locate the DOC concentration where shifts in production pathways may occur; and 4) relate this finding to probable causal scenarios incorporating the effect of global change on terrestrial export of DOC and DON to the lake. It is most feasible to conduct such study in the context of long-term, ecosystem level study since success requires understanding of the relationships among soil warming, moisture, and nutrient availability on DOC and DON production and flowpath to the aquatic ecosystem.

Progress towards Integration with other Projects Within Research Theme:

During the last five years, most of the process studies conducted at Wallace Lake have also been duplicated at the Fraser Experimental Forest and the Asik Watershed sites. Past and present refereed publications summarize the results. Our process research emphasizes the relationships between forest floor and soil temperature and inorganic N availability on the production of organic C and N. Present research plans and proposals address the magnitude of soil and forest floor mineralization and the export of organics to the aquatic ecosystem. At least three investigators, one examining fish, another researching paleoecology, and an EPA/NCASI study on the effect of sample frequency and long-term trends, have used our data from the Wallace Lake watershed to complement their research.

ASIK WATERSHED

Investigators:

Dan Binkley and Heidi Steltzer, Colorado State University, Ft. Collins, CO; Dave Valentine, Glenn Juday, University of Alaska-Fairbanks, Fairbanks, AK; Chuck Rhoades, University of Kentucky, Lexington, KY; R. Stottlemyer, USGS MESC, Ft. Collins, CO.

Project History:

The National Park Service (NPS) manages 7 million ha in Northwest Alaska, or about 25% of the Nation's total land in National Parks. The Northwest Alaska area stretches inland from the Chukchi Sea almost 600 km mainly along the Brooks Range, and encompasses a major portion of Alaska's taiga-tundra treeline ecotone. A large amount of this NPS land is in the Noatak National Preserve which, along with the western portion of Gates of the Arctic National Park, contains the entire 500 km long Noatak River basin (Kepner and Stottlemyer, 1990). Ecological studies in the region are few and largely confined to wildlife. Except for the National Science Foundation studies at Toolik Lake and vicinity in east-central Alaska, few studies of ecosystem processes exist.

In 1989, we began studies in the Noatak National Preserve to assess surface water quality, treeline dynamics, and ecosystem processes which may regulate terrestrial nutrient and energy cycles, and terrestrial and aquatic ecosystem linkages. The primary research and monitoring objectives were to 1) characterize the spatial variation in stream, lake, and tundra pond water chemistry; 2) use this spatial data to select sites for intensive ecosystem studies; 3) implement long-term monitoring and research on terrestrial abiotic and biotic processes thought most sensitive to global change; 4) examine relationships between soil processes and expansion of forests into tundra and floodplain succession; and 5) examine linkages between terrestrial and aquatic ecosystems.

Study Site:

The Noatak National Preserve is just north of the Arctic Circle. Its southern boundary is the Baird Mountains and its north boundary is the Delong Mountains near the western end of the Brooks Range, Alaska. The Brooks Range represents the western end of the Rocky Mountain Physiographic Division of Alaska.

The bedrock is dominated by Quarternary deposits at low elevations in the western portion of the Preserve and Mesozoic rock along its northern border with the remainder of the Preserve underlined with Paleozoic and Precambrian bedrock. Most of the region is characterized by continuous permafrost, but large areas of discontinuous permafrost are present especially along forested southern aspects.

Temperatures in the region have warmed. Since 1950, the mean annual temperatures at National Oceanographic Atmospheric Administration (NOAA) stations in Bettles and Kotzebue, Alaska, have increased ($p < 0.001$, $r^2 = 0.28$, $b = 0.05°C\ yr^{-1}$; Herrmann et al., 2000). Most of the increase occurred in April ($p < 0.01$, $r^2 = 0.16$, $b = 0.16°C\ yr^{-1}$). The trend toward greater warming at higher latitudes is consistent with other findings (Illeris and Jonasson, 1999). Regional NOAA precipitation amounts present no trend.

The climate shows considerable annual variation. Winters are extreme with most of the annual precipitation (mean of 35 cm) occurring during the summer months. The snowpack rarely exceeds one meter in depth in protected areas. Wind re-distributes the snow in exposed areas, and the depth and duration of the snowpack are major factors regulating vegetation (Lavoie and Payette, 1994).

Bailey (1998) classifies the area as a western extension of the Subarctic Regime Mountains. Tundra dominates the north portions of the Preserve, taiga-tundra treeline in the central and western portion, and taiga along the south boundary with the Kobuk National Park. Forested areas are characterized by podzols mainly Spodosols with Histosols in wetter sites.

Our intensive research has focused on two sites: the Asik watershed and vicinity, and the lower Kugururok River terraces. The 800 ha Asik watershed (lat 67° 58', long 162° 15') is located in the south central section of the Preserve 95 km NE of Kotzebue. The watershed is at treeline, and its first-order stream drains from the north and west into the Agashashok River which in turn feeds into the Noatak River. Since 1996, the mean daily air temperature in the watershed has ranged from -47°C to 20°C. Annual precipitation averages 30 cm, with about 10 cm falling during the growing season (June to mid August). The peak snowpack depth averages about 1 m in the more sheltered lower and mid-elevations of the watershed. Soils are dominated by volcanic ash and loess. Discontinuous permafrost prevails in most of the watershed. The soil surface (5 cm) is frozen from late September to May except for upper reaches with southern aspects. The bedrock is sedimentary and metamorphic rock. About 5-7% of the watershed area is talus.

Upper elevation portions of the lower one-third and most of the middle half of the watershed are dominated by white spruce (*Picea glauca* [Moench] Voss). Spruce basal area varies from 23 $m^2 ha^{-1}$ in bottom land to 4 $m^2 ha^{-1}$ on south aspects (Suarez et al., 1999). Forest understory consists primarily of *Hylocomium splendens* (Hedw.) B.S.G, *Equisetum arvense* L., and *Boykinia richardsonii* (Hook.) Gray, with shrubs of *Salix* and *Vaccinium uliginosum* L. The understory of the taiga-tundra transition zone and tundra is dominated by tussocks of *Eriophorum vaginatum* L., *Vaccinium uliginosum*, *Potentilla fruticosa* L., and *Betula nana* L. The upper 20% of the watershed area is dominated by shrubs as *Betula nana*, scattered *Alnus crispa* (Ait.) Pursh on more northern aspects, and mesic non-tussock tundra. The stream alluvial area is dominated by *Salix* spp.

Our second intensive study site consists of a series of river terraces just north of the confluence of the Kugururok and Noatak Rivers (lat 68° 04', long 160° 50') in the west-central section of the Preserve. The Kugururok River drainage is about 375 km^2. The study terraces are at the northern limit of treeline in the transition zone between the Arctic Foothills Ecoregion and Brooks Range Ecoregion (Gallant et al., 1995). White spruce forests prevail on better drained sites often mixed with balsam poplar (*Populus balsamifera* L.). On poorly drained sites tussock tundra dominates. The river floodplain is composed of cobbles and gravel, and periodic floods deposit sand and silt caps of varying depths on the terraces. Vegetated terraces range from 2 to 8 m above river low-stage, and terraces >2 m above low-stage are being studied to examine ecosystem development. For further details on this site, see Binkley et al., (1997).

Progress during FY 2001:

Most of the routine watershed studies were a continuation of research started in 2000. A crew of four, led by Dr. Heidi Steltzer, was in the field during the entire season. The routine monitoring included climate, precipitation chemistry, stream water chemistry and hydrology at multiple stations, and depth of the soil active zone (thaw depth). The fifty 15 x 15 m plots established in major vegetation types in 1999 were fully instrumented, sampled, and monitored for soil respiration, net N mineralization, inorganic and organic N pools, C pools, litter fall, radiation, soil and air temperature, and soil moisture.

Grids of ten plots each were located on north and south aspects in spruce, in a scattered *Alnus* stand with north aspect, in *Betula* with opposing south aspect, and in a spruce-tundra transition zone with south aspect. In each grid, plots were located 100 m apart along two elevation tiers and instrumented as follows. About one-third of the plots were permanently instrumented with air (1 m height) and forest floor (5 cm in O2) thermisters (Onset), litter traps, and three ceramic cup tension lysimeters at 30 cm depth across the plot's lower boundary. An additional third of the plots were instrumented only with thermisters which were moved to an additional subset of plots each month of the growing season for comparisons with the record from the permanent instrumented plots. The O2 samples for analysis and incubations were collected with plastic tubes 5 cm in diameter and 7 cm long. Moisture (gravimetric), inorganic N pools (2M KCl), C:N ratios (Leco Model 1000 CHN Analyzer), net N mineralization rates, and O2/soil respiration (PP Systems, EGM-2) were monitored on all plots every three or four weeks at three to five points along the plot boundaries tangential the contour.

The O2 net NO_3^-, NH_4^+, and the total inorganic N mineralization rates beneath each species type was estimated using the buried polyethylene bag technique. With this method, net mineralization is the sum of the mineralized NH_4^+ plus NO_3^- from organic N, minus immobilization of NH_4^+ and NO_3^-. Net nitrification is the sum of NO_3^- from both organic N and NH_4^+ minus immobilization of NO_3^-. After removing intact the surface organic layer, the upper 5-7 cm of O2 horizon was sampled with a 5-cm diameter soil corer. Paired cores were pulled from each sampling point. One core from each pair, representing a nonincubated sample, was placed in a Whirl Pac bag, brought to the field laboratory and extracted with 2M KCl. The other core was placed in a 0.025-mm thick polyethylene bag and returned to the same hole for incubation. The surface organic matter was then replaced. After about 25+ days, the field incubated sample was removed and returned to the field laboratory for extraction.

After collection, forest floor samples were processed at the field station. Each core was weighed. A large subsample was then sieved. A 10 g subsample was extracted with 50 ml of 2M KCl, and NO_3^- (cadmium reduction) and NH_4^+ (indophenol) determined on the Lachat autoanalyzer at the U.S. Forest Service Rocky Mountain Research Station, Ft. Collins, CO. Another subsample was frozen for C:N analysis at the Colorado lab. The O2 moisture was determined by oven drying (105° C for 24+ h) a subsample in Kotzebue. Bulk density was calculated from total oven dry weight/volume.

We also set up the second year of a watershed study of nutrients limiting stream periphyton growth. We used a standard design with unglazed ceramic cups filed with agar enriched with N, phosphorus (P), or N and P, replicated at multiple stations upstream and downstream each site further paired by one set of replicates in shade and one in open light. We measured periphyton ash weight, chlorophyll a, and are examining biological diversity. All data but biodiversity have been fully analyzed, but not published.

This year we also continued ecosystem-level data synthesis from our earlier Asik watershed studies. The 2001 analyses summarized relationships between topographic aspect, soil temperature and moisture, inorganic and organic N pools, C pools, CO_2 efflux, growing season net N mineralization rates, and stream water chemistry. Forest floor (O2) C:N ratios, C pools, temperature, and moisture was greater on south than on north aspects. Increased permafrost melt rates accounted for the higher moisture. The O2 carbon and N content was correlated with moisture, inorganic N pools, CO_2 efflux, and inversely with temperature. Inorganic N pools were correlated with temperature and CO_2 efflux. Net N mineralization rates were positive in early summer, and correlated with O2 moisture, temperature, and C and N pools. However, net nitrification rates were inversely related moisture and total C and N. The CO_2 efflux increased with temperature and moisture, and was greater on south aspects. Annual watershed runoff averaged 45% of precipitation. Stream ion concentrations declined and DOC and DON increased with discharge. Stream inorganic nitrogen (DIN) averaged 30% 0f DON concentration. The DIN output exceeded input by 70% and DON outputs were >2 times DIN. Stream water inorganic C and DOC export was a small fraction of forest floor and soil C efflux.

Progress towards Integration with other Projects Within Research Theme:

Soil samples were collected to study differences in microbial functional diversity among a network of reference ecosystems. The sites include the original watershed study sites plus several additional sites in National Parks.

Much of this year's effort, both in the field and in data synthesis, was devoted to providing the context to better explain how global change effects on the terrestrial ecosystem might lead to alteration of the energy and nutrient budgets of the aquatic ecosystem. The data syntheses provided some of the insight to the experimental concept developed for the paired boreal site at Isle Royale.

FY01 PUBLICATIONS, REPORTS, and ABSTRACTS/PRESENTATIONS

The following list includes only those references in which our site investigator is author or co-author, and in some instances where data from the site was a significant part of another reference or presentation. In general, data from the sites are often used in other studies and references, but where our site personnel are not substantively involved such references are not listed here.

Peer-reviewed Papers:

Baron, J.S. 2001. Lessons learned from long-term ecosystem research and monitoring in alpine and subalpine basins of the Colorado Rocky Mountains, USA.. Ekológia (Bratislava) 20, Supplement 2:25-30.

Johnson, C.A., M.A. Mast, C.L. Kester. 2001. Use of $^{17}O/^{16}O$ to trace atmospherically-deposited sulfate in surface waters: a case study in alpine watersheds in the Rocky Mountains. Geophys. Resear. Let. 28:4483-4486.

Mast, M.A., J.T. Turk, G.P. Ingersoll, D.W. Clow, and C.L. Kester. 2001. Use of stable sulfur isotopes to identify sources of sulfate in Rocky Mountain snowpacks. Atmos. Environ. 35:3303-3313.

Rhoades, C.C., H. Oskarsson, D. Binkley, and R. Stottlemyer. 2001. Alder (Alnus crispa) effects on soils in ecosystems of the Agashashok River valley, northwest Alaska. Ecoscience 8(1):89-95.

Rueth, H.M. and J.S. Baron. 2001. Englemann spruce nitrogen dynamics across a nitrogen deposition gradient in Colorado, USA. Ekológia (Bratislava) 20, Supplement 2:43-49.

Stottlemyer, R. 2001. Biogeochemistry of a treeline watershed, northwest Alaska. Jour. Environ. Qual. 30(6):1990-1998.

Stottlemyer, R. 2001. Ecosystem processes and nitrogen export in northern U.S. watersheds. In: Optimizing Nitrogen Management in Food and Energy Production and Environmental Protection: Proc. N2001, the Second International Nitrogen Conference on Science and Policy. The Scientific World J (electronic journal).

Stottlemyer, R. 2001. Processes regulating watershed chemical export during snowmelt, Fraser Experimental Forest, Colorado. J. Hydrol. 245(1-4):177-195.

Stottlemyer, R., and C.A. Troendle. 2001. Effect of canopy removal on snowpack quantity and quality, Fraser Experimental Forest, Colorado. J. Hydrol. 245(1-4):165-176.

Sueker J.K., D.W. Clow, J.N. Ryan, and R.D. Jarrett. 2001. Effect of basin physical characteristics on solute fluxes in nine alpine/subalpine basins, Colorado, USA. Hydrol. Proc. 15:2749-2769.

Turk, J.T., H.E. Taylor, G.P. Ingersoll, K.A. Tonnessen, D.W. Clow, M.A. Mast, D.H. Campbell, and J.M. Melack. 2001. Major-ion chemistry of the Rocky Mountain snowpack, USA. Atmos. Environ. 25:3957-3966.

Wickland K.P., R.G. Striegl, M.A. Mast, and D.W. Clow. 2001. Carbon gas exchange at a southern Rocky Mountain wetland, 1996-1998. Glob. Biogeochem. Cyc. 15:321-335.

Wolfe, A.P., J.S. Baron, and R.J. Cornett. 2001. Unprecedented changes in alpine ecosystems related to anthropogenic nitrogen deposition. J. Paleolimnology 25:1-7.

Government and Unpublished Reports:

Adler, J., D. Toczydlowski, and R. Stottlemyer. 2001. Effect of global change on boreal ecosystem biogeochemistry and carbon budgets. Res. Rept. #89 Submitted to Dr. David Hamilton, Acting Section Leader, USGS-MESC, Ft. Collins, Colorado, 11 pp.

Clements, S. 2001. Spatial and temporal variations of bulk snow properties and stream water chemistry in an alpine/subalpine watershed, Rocky Mountain National Park. M.S. Thesis, Dept. of Earth Resources, Colorado State University, Ft. Collins, CO. 314 pp.

Rhoades, C.C., D. Binkley, and R. Stottlemyer. 2001. Soil N and C dynamics across white spruce-tussock tundra ecotones in northwestern Alaska. Res. Rept. #87 submitted to National Park Service, Kotzebue, Alaska.

Rhoades, C.C., H. Oskarsson, D. Binkley, and R. Stottlemyer. 2001. Alder (Alnus crispa) effects on soils vary with ecosystem type along the Agashashok River, northwest Alaska. Res. Rept. #86 submitted to National Park Service, Kotzebue, Alaska.

Rueth, H.M. 2001. Englemann spruce forest responses to nitrogen deposition in northern Colorado. Ph.D. Dissertation, Graduate Degree Program in Ecology, Colorado State University, Ft. Collins, CO. 105 pp.

Stottlemyer, R. 2001. Ecosystem processes and watershed nitrogen export in U.S. National Parks. Res. Rept. #90 Submitted to Dr. David Hamilton, Acting Section Leader, USGS-MESC, Ft. Collins, Colorado, 18 pp., 3 figures, 4 tables.

Stottlemyer, R. 2001. Precipitation and stream solute flux, 1965-2000, Lexen Creek, Fraser Experimental Forest, Colorado. Res. Rept. #91 Submitted to Dr. David Hamilton, Acting Section Leader, USGS-MESC, Ft. Collins, Colorado, 40 pp., 7 figures, 4 tables.

Stottlemyer, R., J. Baron, R. Edmonds, L. Scherbarth, and H. Steltzer. 2001. Long-term ecosystem studies in Isle Royale, Olympic, and Rocky Mountain National Parks; Noatak National Preserve, and Fraser Experimental Forest. Res. Rept. No. 88 submitted to D. Hamilton, Section Leader, U.S. Geological Survey, Mid-Continent Ecocological Studies Center, Ft. Collins, 32 p.

Stottlemyer, R., R. Edmonds, L. Scherbarth, K. Urbanczyk, H. van Miegroet, and J. Zak. 2001. Comparative effects of cliamte on ecosystem nitrogen and soil biogeochemistry in U.S. national parks. (Res. Rept. No. 85) Ann. Rept. submitted to S. Coloff, Global Change Program Director, USGS-BRD, Reston, VA, 12 p.

Virgillio, S. 2001. Nitrogen cycling dynamics in Lexen Creek watershed, Fraser Experimental Forest, Fraser, Colorado, USA. M.S. Thesis, Dept. Forest Resources, Utah State University, Logan, Utah, 56 p.

Abstracts and Presentations:

Kiffney, P.M. and R.L. Edmonds, 2001. Debris flows and stream benthic communities: A natural experiment at West Twin Creek, Olympic National Park, Washington. Center for Streamside Studies and Center for Urban Water Resources Management Annual Review. Seattle, WA. February 1, 2001. (abs)

Kiffney, P.M., C.J. Volk, and R.L. Edmonds. "Role of riparian red alder (*Alnus rubra*) on nutrient dynamics of coastal streams on the Olympic peninsula, Washington." International Conference on Restoring Nutrients to Salmonid Ecosystems. Eugene, OR. April 24-26, 2001. (abs)

McAfee, S.A. and R.L. Edmonds 2001. The effect of localized lithologic variation on stream water chemistry and nutrient cycling in the Hoh Rain Forest, Washington. American Geophysical Union Annual Meeting. San Fransico, CA. December 10-14, 2001. (abs)

Stottlemyer, R. 2001. Ecological factors affecting solute export, 1965-2000, Lexen Creek, Fraser Experimental Forest. Concurrent Session Abstracts, U.S. Forest Service All-Scientists meeting, April 23-24, 2001, Salt Lake City, Utah (abs)

Stottlemyer, R. 2001. Ecosystem processes and watershed nitrogen export in U.S. national parks. Abstracts of the Second International Nitrogen Conference, October 14-18, 2001, Potomac, Maryland, p. 115. (abs)

Stottlemyer, R. 2001. Merging climate monitoring with soil, root, and foodweb dynamics to understand mechanisms regulating C and N transformations, Olympic National Park. National Park Service Workshop on Biogeochemical Processes: Parameters for Long-term Monitoring in Pacific Northwest National Parks, Seattle, Washington, January 15-18, 2001. (abs)

Stottlemyer, R. 2001. Use of small watershed ecosystem to study and monitor system function. National Park Service Workshop on Biogeochemical Processes: Parameters for Long-term Monitoring in Pacific Northwest National Parks, Seattle, Washington, January 15-18, 2001. (abs)

Stottlemyer, R. 2001. Watershed chemical export during snowmelt, Fraser Experimental Forest, Colorado. Ecol. Soc. Amer. Abstracts, p. 350 (abs)

Stottlemyer, R., D. Binkley, and C. Rhoades. 2001. Relationships Between Climate Change, Flowpath, and Chemical Flux in a Treeline Watershed, Noatak National Preserve, Alaska. American Association Advancement of Science 52nd Arctic Science Conference, September 12-15, 2001, Anchorage, Alaska, p. 21 (abs)

Toczydlowski, D., and R. Stottlemyer. 2001. Seasonal terrestrial dissolved organic production and lake chemistry, Isle Royale National Park, Michigan. Ecol. Soc. Amer. Abstracts, p. 351-352 (abs)

Volk, C.J., 2001. Influence of riparian alder on aquatic communities in headwater streams: Olympic Peninsula, Washington. Center for Streamside Studies and Center for Urban Water Resources Management Annual Review. Seattle, WA. February 1, 2001. (abs)

Volk, C.J., P.M. Kiffney, and R.L.Edmonds. 2001. “The effects of riparian red alder on aquatic communities in headwater streams”. North American Benthological Society Annual Meeting. La Crosse, WI. NABS Bulletin, Vol. 18(1). (abs)

LITERATURE CITED

Aber, J., W. McDowell, K. Nadelhoffer, A. Magill, F. Bernston, M. Kamakea, S. McNulty, W. Currie, L. Rustrad, and I. Fernandez. 1998. Nitrogen saturation in temperate forest ecosystems: Hypotheses revisted. BioScience 48(11): 921-934.

Alexander, R.R., C.A. Troendle, M.R. Kaufmann, W.D. Shepperd, G.L. Crouch, and R.K. Watkins. 1985. The Fraser Experimental Forest, Colorado: Research program and published research 1937-1985. USDA Forest Service Gen. Tech. Rept. RM-118, 46 p.

Bailey, R. G. 1998. Ecoregions. Springer-Verlag, New York, 176 p.

Baker, M.A., H.M. Valett, and C.N. Dahm. 2000. Organic carbon supply and metabolism in a shallow groundwater ecosystem. Ecology 81(11):3133-3148.

Battin, T.J. 1999. Hydrologic flow paths control dissolved organic carbon fluxes and metabolism in an alpine stream hyporheic zone. Water Resour. Res. 35(10):3159-3169.

Benda, L. 1990. The influence of debris flows on channels and valley floors in the Oregon Coast Range, USA. Earth Surface Processes and Landforms 15(5):457-466.

Benda, L. and T. Dunne. 1997. Stochastic forcing of sediment supply to channel networks from landsliding and debris flow. Water Resour. Res. 33(12): 2849-2863.

Binkley, D., R. Bell, and P. Sollins. 1992. Comparison of methods for estimating soil nitrogen transformations in adjacent conifer and alder-conifer stands. Can. J. For. Res. 22:858-863.

Binkley, D., P. Sollins, et al., 1992. Biogeochemistry of adjacent conifer and alder-conifer stands. Ecology 73: 2022-2033.

Binkley, D., F. Suarez, R. Stottlemyer, and B. Caldwell. 1997. Ecosystem development on terraces along the Kugururok River, northwest Alaska. Ecoscience 4(3):311-318.

Bormann, B.T., K. Cromack, and W.O. Russell. 1994. Influences of red alder on soils and long-term ecosystem productivity. In: The Biology and Management of Red Alder. D.E. Hibbs, D.S. DeBell and R.F. Tarrant (eds.). Corvallis, OR. Oregon State University Press. Pp. 47-56.

Brooks, P.D., D.M. McKnight, and K.E. Bencala. 1999. The relationship between soil heterotrophic activity, soil dissolved organic carbon (DOC) leachate, and catchment-scale DOC export in headwater catchments. Water Resour. Res. 35(6):1895-1902.

Compton, J.E., D.W. Cole, P.S. Homann 1997. Leaf element concentrations and soil properties in first- and second-rotation stands of red alder *(Alnus rubra)*. Can. J. For. Res. 27(5): 662-666.

Dillon, P.J., and L.A. Molot. 1997. Effect of landscape form on export of dissolved organic carbon, iron, and phosphorus from forested stream catchments. Water Resour. Res. 33(11):2591-2600.

Easthouse, K.B., J. Mulder, N. Christophersen, and H.M. Seip. 1992. Dissolved organic carbon fractions in soil and stream water during variable hydrological conditions at Birkenes, Southern Norway. Water Resour. Res. 28(6):1585-1596.

Edmonds, R.L. and R.D. Blew 1997 Trends in precipitation and stream chemistry in a pristine old-growth forest watershed, Olympic National Park, Washington. J. Amer. Water Resour. Assoc. 33(4): 781-793.

Edmonds, R. L., R. D. Blew, J. L. Marra, J. Blew, A. K. Barg, G. Murray, and T. B. Thomas. 1998. Vegetation Patterns, Hydrology, and Water Chemistry in Small Watersheds in the Hoh River Valley, Olympic National Park. Scientific Monograph NPSD/NRUSGS/NRSM-98/02. United States Department of the Interior, National Park Service, 131 pages.

Feller, M.C. 1987. The influence of acid precipitation on stream chemistry in a small forested basin in southwestern British Columbia. In: Forest Hydrology and Watershed Management. R.H. Swanson, P.Y. Bernier, and P.D. Woodward (Eds.). IAHS Publ. No. 167, IAHS Press, Wallingford, Oxfordshire, England, pp. 33-47.

Fisher, S.G., L.J. Gray, N.B. Grimm, and D.E. Busch. 1982. Temporal succession in a desert stream ecossytem following flash flooding. Ecol. Monog. 52:93-110.

Gallant, A.L., E.F. Binnian, J.M. Omernik, and M.B. Shasby. 1995. Ecoregions of Alaska. U.S. Geol. Surv. Prof. Pap. No. 1567, U.S. Govt. Printing Office, Washington, D.C.

Galloway, J.N., W.H. Schlesinger, H.II Levy, A. Michaels, J.L. Schnoor. 1995. Nitrogen fixation: anthropogenic enhancement-environmental response. Glob. Biogeoch. Cyc. 9(2): 235-252.

Goldman, C.R. 1961. The contribution of alder trees (*Alnus tenuifolia*) to the primary productivity of Castle Lake, California. Ecology 42(2): 282-288.

Gregory, J.M., J.F.B. Mitchell, and A.L. Brady 1997. Summer drought in northern midlatitudes in a time-dependent CO_2 climate experiment. J. Climate 10(4): 662-686.

Hall, Jr., R.O. 1995. Use of a stable carbon isotope addition to trace bacterial carbon through a stream food web. J. N. Am. Benthol. Soc. 14(2):269-277.

Hecky, R.E. and R.H. Hesslein. 1995. Contribution of benthic algae to lake food webs as revealed by stable isotope analysis. J. N. Am. Benthol. Soc. 14(4): 631-653.

Hedin, L.O., J.C.von Fischer, N.E. Ostrom, B.P. Kennedy, M.G. Brown, G.P. Robertson. 1998. Thermodynamic constraints on nitrogen transformations and other biogeochemical processes at soil-stream interfaces. Ecology 79(2): 684-703.

Herrmann, R., R. Stottlemyer, J.C. Zak, R.L. Edmonds, and H. Van Miegroet. 2000. Biogeochemical effects of global change on U. S. National Parks. J. Amer. Water Resour. Assoc. 36(2):337-346.

Holloway, J.M., R. A. Dahlgren, W.H. Casey 2001. Nitrogen release from rock and soil under simulated field conditions. Chem. Geol. 174: 403-414.

Illeris, L., and S. Jonasson. 1999. Soil and plant CO_2 emission in response to variations in soil moisture and temperature and to amendment with nitrogen, phosphorus, and carbon in Northern Scandinavia. Arct. Antarct. Alp. Res. 31(3):264-271.

Jaffe, D., T. Anderson, D. Covert, R. Kotchenruther, B. Trost, J. Danielson, W. Simpson, T. Berntsen, S. Karlsdottir, D. Blake, J. Harris, G. Carmichael, and I. Uno 1999. Transport of Asian air pollution to North America. Geophys. Res. Lett. 26(6): 711-714.

Jansson, M, A. Bergstrom, P. Blomqvist, and S. Drakare. 2000. Allocthonous organic carbon and phytoplankton/bacterioplankton production relationships in lakes. Ecology 81(11):3250-3255.

Kahlert, M. 1998. C:N:P ratios of freshwater benthic algae. Archaeologie Hydrobiologie Special Issues: Advanced Limnology 51: 105-114.

Kallbitz, K., S. Solinger, J. H. Park, B. Michalzik, and E. Matzner. 2000. Controls on the dynamics of dissolved organic matter in soils: A review. Soil Sci. 165(4):277-304.

Kendall, C., D.H. Campbell, D.A. Burns, J.B. Shanley, S.R. Silva, and C.C.Y. Chang. 1995. Tracing sources of nitrate in snowmelt runoff using the oxygen and nitrogen isotopic compositions of nitrate. In: Biogeochemistry of Seasonally-Covered Catchments. K.A. Tonnessen and M.W. Williams (eds). IAHS Publ. No. 228. p. 339-347.

Kepner, R., and R. Stottlemyer. 1990. Spatial trends in lake, pond and streamwater quality, Noatak National Park and Preserve, Alaska. Ecol. Bull. 71(2):210-211. (Abstract)

Lamberti, G.A., S.V. Gregory, L.R. Ashkenas, R.C. Wildman, K.M.S. Moore. 1991. Stream ecosystem recovery following a catastrophic debris flow. Can. J. Fish. Aqua. Sci. 48(2):196-208.

Lamberti, G.A., S.W. Gregory, L.R. Ashkenas, A.D. Steinman, C.D. McIntire 1989. Productive capacity of periphyton as a determinant of plant herbivore interactions in streams. Ecology 70(6): 1840-1856.

Lavoie, C., and S. Payette. 1994. Recent fluctuations of the lichen-spruce forest limit in subarctic Quebec. J. Ecol. 82:725-734.

Lynch, J.A., J.W. Grimm, and V.C. Bowersox. 1995. Trends in precipitation chemistry in the United States: a national perspective, 1980-1982. Atmos. Environ. 29(11): 1231-1246.

Mackay, R.J. 1992. Colonization by lotic macroinvertebrates-A review of processes and patterns. Can. J. Fish. Aqua. Sci. 49(3):617-628.

Montgomery, D.R., K.M. Schmidt, H.M. Greenberg, W.E. Dietrich. 2000. Forest clearing and regional landsliding. Geology 28(4): 311-314.

Obradovic, M.M., and M.G. Sklash. 1987. An isotopic and geochemical study of seasonal snowmelt runoff in the Apex River watershed. In: Seasonal Snowcovers: Physics, Chemistry, Hydrology. H.G. Jones and W.J. Orville-Thomas, (eds.). D. Reidel Publishing Co., Boston, MA. pp. 643-659.

Perakis, S.S. and L.O. Hedin. 2001. Fluxes and fates of nitrogen in soil of an unpolluted old-growth temperate forest, southern Chile. Ecology 82(8): 2245-2260.

Peterson, B.J., J.E. Hobbie, and T.L. Corliss. 1986. Carbon flow in a tundra stream ecosystem. Can. J. Fish. Aquat. Sci. 43:1259-1270.

Rice, K.C., and O.P. Bricker. 1995. Seasonal cycles of dissolved constituents in streamwater in two forested catchments in the mid-Atlantic region of the eastern USA. J. Hydrol. 170:137-158.

Schindler, D. W. 1986. The significance of in-lake production of alkalinity. Water Air Soil Polln. 30:931-944.

Shetron, S. G., and R. Stottlemyer. 1991. Soil resource inventory of Isle Royale National Park. Draft final report on mapping of the soils of Isle Royale submitted to Dr. Ron Hiebert, Chief Scientist, Midwest Region, National Park Service, Omaha, NE. 255 p.

Sidle, R.C. and D.N. Swanston. 1982. Analysis of a small debris-slide in coastal Alaska. Can. Geotechn. J. 19(2):167-174.

Sommaruga, R., R. Psenner, E. Schafferer, K. A. Koinig, and S. Sommaruga-Wograth. 1999. Dissolved organic carbon concentration and phytoplankton biomass in high-mountain lakes of the Austrian Alps: potential effect of climatic warming on UV underwater attenuation. Arct. Antarct. Alp. Res. 31(3):247-253.

Stottlemyer, R., R. Edmonds, L. Scherbarth, K. Urbanczyk, H. van Miegroet, and J. Zak. 2001. Comparative effects of climate on ecosystem nitrogen and soil biogeochemistry in U.S. national parks. (Res. Rept. No. 85) Ann. Rept. submitted to S. Coloff, Global Change Program Director, USGS-BRD, Reston, VA, 12 p.

Stottlemyer, R., and D. Hanson, Jr. 1989. Atmospheric deposition and ionic concentrations in Forest Soils of Isle Royale National Park, Michigan. Soil Sci. Soc. Am. J. 53(1):270-274.

Stottlemyer, R., and C.W. Ralston. 1970. Nutrient balance relationships for watersheds of the Fraser Experimental Forest. In: Tree Growth and Forest Soils. C.T. Youngberg and C.B. Davey (eds). Oregon Univ. Press, Corvallis, OR. p. 359-381.

Stottlemyer, R., and D. Toczydlowski. 1991. Stream chemistry and hydrologic pathways during snowmelt in a small watershed adjacent Lake Superior. Biogeochemistry 13:177-197.

Stottlemyer, R., and D. Toczydlowski. 1999. Seasonal change in precipitation, snowpack, snowmelt, soil water, and streamwater chemistry, northern Michigan. Hydrol. Process. 13:2215-2231.

Stottlemyer, R., D. Toczydlowski, and R. Herrmann. 1998. Biogeochemistry of a mature boreal ecosystem: Isle Royale National Park, Michigan. National Park Service Scient. Monogr. NPS/NRUSGS/NRSM-98/01, U.S. Dept. Interior, Washington, D.C., 116p.

Suarez, F., D. Binkley, M. W. Kaye, and R. Stottlemyer. 1999. Expansion of forest stands into tundra in the Noatak National Preserve, Northwest Alaska. Ecoscience 6(3):465-470.

Sun, L., E.M. Perdue, J.L. Meyer, and J. Weis. 1997. Use of elemental composition to predict bioavailability of dissolved organic matter in a Georgia River. Limnol. Oceanogr. 42(4):714-721.

Surface Water Data for the United States, Unites States Geologic Survey, Department of the Interior. http://water.usgs.gov/nwis/monthly/?site_no=12041200&agency_cd=usgs

Tabor, R.W. and W.M Cady. 1978. Geologic Map of the Olympic Peninsula, Washington. Department of the Interior, Unites States Geologic Survey, Map I-994.

Talbot, R.W., J.E. Dibb, K.I. Klemm, J.D. Bradshaw, S.T. Sandholm, D.R. Blake, G.W. Sachse, J. Collins, B.G. Heikes, G.L. Gregory, B.E. Anderson, H.B. Singh, D.C. Thornton, and J.T. Merrill. 1996. Chemical characteristics and continental outflow from Asia to the troposphere over the western Pacific Ocean during September - October 1991: results from PEM-West A. J. Geophys. Res.-Atmos. 101(D1): 1713-1725.

Tarrant, R.F. and E.F. Miller 1983. Accumulation of organic matter and soil nitrogen beneath a plantation of red alder and Douglas-fir. Soil Sci. Soc. Amer. Proc. 27:231-234.

Troendle, C.A., and R.M. King. 1985. The effect of timber harvest on the Fool Creek Watershed, 30 years later. Water Resour. Res. 21:1915-1922.

Turner, M.G., V.H. Dale, E.H. Everham III. 1997. Fires, hurricanes, and volcanoes: comparing large disturbances. BioScience 47(11):758-768.

Vander Zanden M.J. and Rasmussen J.B. 2001. Variation in delta N-15 and delta C-13 trophic fractionation: Implications for aquatic food web studies. Limnol. Oceanog. 46(8): 2061-2066.