Comparative effects of climate on ecosystem nitrogen and soil biogeochemistry in U.S. national parks

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FY 2001 SUMMARY

Introduction:

In 1998, the USGS Global Change program funded research for a network of Long-Term Reference Ecosystems initially established in national parks and funded by the National Park Service. The network includes Noland Divide, Great Smoky Mountains National Park, Tennessee; Pine Canyon, Big Bend National Park, Texas; West Twin Creek, Olympic National Park, Washington; Wallace Lake, Isle Royale National Park, Michigan; and the Asik watershed, Noatak National Preserve, Alaska. The watershed ecosystem model was used since this approach permits additional statistical power in detection of trends among variables, and the watershed is increasingly a land unit used in resource management and planning. The ecosystems represent a major fraction of lands administered by the National Park Service, and were chosen generally for the contrasts among sites. For example, two of the sites, Noland and West Twin, are characterized by high precipitation amounts, but Noland receives some of the highest atmospheric nitrogen (N) inputs in North America. In contrast, Pine Canyon and Asik are warm and cold desert sites respectively. The Asik watershed receives <1% the atmospheric N inputs Noland receives. The Asik site is at the northern extent (treeline) of the boreal biome in North America while Wallace is at the southern ecotone between boreal and northern hardwoods. The research goal for these sites is to gain a basic understanding of ecosystem structure and function, and the response to global change especially atmospheric inputs and climate.

One research emphasis is on the cycling of major nutrients, as N, and carbon (C) (energy). The C and N cycles are tightly linked in complex ways. Altering the availability and quality of one directly affects the other. For example, soil warming can increase the mineralization of both C and N subsequently releasing C as carbon dioxide (CO_2) to the atmosphere, altering N availability (as inorganic N) and therefore ecosystem production. The above-ground biomass has much higher C:N ratios than below-ground, and any change in below-ground availability of N, as nitrate (NO_3^-) or ammonium (NH_4^+), has a net effect of moving N above-ground, increasing the biomass, and likely altering biodiversity. In addition, soil warming and change in available N can increase the production and export of dissolved organic forms of carbon (DOC) and nitrogen (DON) to the aquatic ecosystem which will likely alter aquatic ecosystem production and biodiversity.

Another network research emphasis is on the global change effects on below-ground biological diversity and function. Greater than 90% of ecosystem biodiversity, most of which is microbial, is found in the forest floor and below-ground. Microbial functional groups regulate nutrient availability and quality and much of the energy, as C, to the above-ground biota. In turn, the below-ground microbial communities are impacted by global change, especially temperature, nutrient availability and its quality, and invasion by exotic microbiota.

Overview of Progress and Results:

In FY 2001, data collection focused on the N and C cycles, below-ground microbial functional diversity, and the likely biological relationships to soil temperature, moisture, and N availability. Our sites include locations covering the range of atmospheric N deposition (<0.3 to 30 kg ha^{-1} yr^{-1}) in North America, a factor to be considered when evaluating climate effects on ecosystem C and N cycles and ecosystem

biodiversity. The Nolan Divide ecosystem continues to retain atmospheric N inputs implying changes are occurring in both below- and above-ground biomass and biodiversity. The effects of soil temperature and moisture on soil respiration (CO_2 efflux) were examined at all sites. The study of linkages between global change, primarily climate and nutrient availability, and soil microbial functional diversity is most advanced at Pine Canyon, and suggests the soil bacterial and fungal communities respond differently to such environmental stimuli. At the cold desert Arctic Asik site, our research continued to focus on soil responses to changes in climate and hydrology to better explain the high ecosystem N export where atmospheric inputs are low. In 2001, at all sites we began studies evaluating change in soil microbial functional diversity and its likely response to global change. Past research results from most sites were presented in a series of papers at the Second International Nitrogen Conference in Potomac, Maryland. During the year, the global change sites and former Park Service small watershed study sites were merged into the Reference Ecosystems project, a component of the BRD Ecosystems Program.

Specific Accomplishments and Results:

At Nolan Divide, intensive study of the N cycle began to separate the relative contributions of atmospheric N inputs from N generated by processes within the ecosystem. Soil temperature control on inorganic N production and the hydrologic regulation of N, as NO_3^-, appear responsible for the variation in high autumn NO_3^- export in stream water. At Pine Canyon, the research emphasis was on the N cycle between forest and grassland sites. Bacterial functional diversity of the grassland soils continues to decline in response to the atmospheric inputs of N and sulfate (SO_4^{2-}). Research continued on the impacts of soil available N on microbial biomass and functional diversity, a study which has also been extended to other Reference Ecosystem sites. At West Twin, studies focused on the relationships between soil N mineralization and nitrification, soil respiration, and soil water dissolved organic C and N. This research serves as input toward completing a N budget for this mature, old-growth forest ecosystem. At the Asik site, research continued on 50 vegetation plots examining relationships between soil temperature and moisture, N availability (fertilized plots), soil water DOC and DON production, and DOC and DON export to stream water. Additional investigation focused on the specific physical and biological factors responsible for continued tree advancement into tundra. At Wallace Lake, background data were gathered for planned 2002 study linking terrestrial N and C mineralization processes to change in stream and lake DOC and DON concentrations. At Wallace, DOC concentrations are highest among the Reference Ecosystem sites, and 2002 study will begin to examine the relationship of change in lake DOC concentration, light attenuation, and biological production.

Progress towards integration with other Projects within Research Theme:

Research integration progressed along several lines. First, we examined data from all sites in preparation of research proposals for outside funding to extend the research on the relationships between global change and below-ground microbial functional diversity. We feel additional emphasis is needed in this area because of the importance of microbial communities. The vast majority of ecosystem biodiversity is below-ground. The below-ground community regulates almost all ecosystem nutrient availability, and it is sensitive to global change and exotic invasion.

Second, all sites are moving closer to good estimates of the N cycle in this diverse network of ecosystems. Nitrogen is the most significant limiting nutrient in these systems. The N cycle is fully linked with the C cycle, and N availability is affected by global change especially climate and atmospheric N inputs.

Third, additional work was done among sites on the relationships between climate, N availability, and soil DOC and DON production and likely export to the aquatic ecosystem. Dissolved organic C and N are important energy and nutrient sources to the aquatic ecosystem. Despite this, little research has investigated the linkages between global change and terrestrial dissolved organic production.

Fourth, more of our site research is being used or serving as a basis for the design of research and monitoring by other Federal programs. Examples include use of research results by the NPS in the design and implementation of the Inventory and Monitoring program at Olympic and Isle Royale National Parks; and data use by the National Marine Fisheries Service, the University of Washington, Colorado State University, and the U.S. Forest Service.

Plans for Coming Year:

Most of FY 2002 will be devoted to continuation of 2001 studies since a minimum of three full research years is required to complete our research objectives. At our April annual meeting of site Principal Investigators, we will discuss the status of site data sets to ensure future synthesis of results among sites. With the Nolan Divide database, we will simulate the short and long term dynamics in the C and N cycles, and the potential for N export from other watersheds within Great Smoky Mountains National Park. Natural isotope abundance studies, using C and N, will be expanded at Asik to better assess spatial and temporal variation in sources of dissolved organics to the aquatic ecosystem. We have organized a symposium for the Geological Society of America South Central Section meeting where research results from most sites will be presented.

Products:

a) Data Sets

Data sets for each study outlined above are maintained at three different geographical locations on PCs. The samples collected during FY 01 have not all been analyzed, but will be completed by February 2002. The data primarily relate to precipitation, stream, and soil water chemistry, climate, soil N and C pools and mineralization rates, and descriptive data regarding vegetation and soils. Specifics can be found in the attached detailed FY 2001 Progress Report.

b) Reports, Abstracts, and Presentations

Creed, I. F., H. Van Miegroet, and N. S. Nicholas. 2001. Climatic Controls on Soil N Fluxes in a Nitrogen Saturated Watershed. Poster presented at the Gordon Research Conference on Forested Catchments: Hydrological, Geochemical, and Biological Processes in Andover, NH, 22-27 July, 2001.

Dobranic, J. K. and J. C. Zak. 2001. Understanding the relationships between fungal functional diversity, taxonomic diversity, and decomposition rates. The Soil Ecology Society Biannual Conference, Callaway Gardens, GA. May 2001.

Hernandez, C. and J. C. Zak. 2001. Impacts of soil nitrogen on microbial dynamics in a Chihuahuan Desert landscape. The Soil Ecology Society Biannual Conference, Callaway Gardens, GA. May 2001.

Loscher, G., D. G. Tarboton, I. F. Creed, and K. L. Webster. 2001. Soil Moisture Variability in a Small Steep Forested Watershed. Poster presented at the American Geophysical Union Chapman Conference on State-of-the-Art Hillslope Hydrology in Sunriver, OR, 8-12 October.

McAfee, S. A., C. J. Volk, 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 Fall Meeting 2001. Poster B12C-0136.

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.

Sobek, E. and J.C. Zak. 2001. Elevational trends in soil fungal biodiversity in and arid landscape. Annual meeting of the Mycological Society of America, Salt Lake City, UT, August 2001.

Sobek, E., and J. C. Zak. 2001. Is functional diversity of soil fungal assemblages influenced by elevation in desert ecosystems? The Soil Ecology Society Biannual Conference, Callaway Gardens, GA, May 2001.

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. (abstract)

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., 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 Ecological Studies Center, Ft. Collins, 32 p.

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 (abstract).

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. 92) Ann. Rept. submitted to S. Coloff, Global Change Program Director, USGS-BRD, Reston, VA.

Toczydlowski, D., and R. Stottlemyer. 2001. Factors affecting the nitrogen budget in a boreal ecosystem, Isle Royale National Park. Isle Royale National Park Research Conference, Michigan Technological University, Houghton, Michigan, March 26-27, 2001. (abstract)

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.

Urbanczyk, K. 2001. Contemporary Water Supply in the northern Chihuahuan desert, presented at the 2001 Desert Fishes council meeting.

Van Miegroet, H., I. F. Creed, and N. S. Nicholas 2001. Spatial Variation in N Saturation in High-elevation Spruce-fir Forests of the Southern Appalachians. Paper presented at the 2nd International N conference N2001 held in Potomac, MD, 14-18 October, 2001.

Van Miegroet, H., N. S. Nicholas, and I. F. Creed. 2001. What creates spatial variability in N saturation at the level of a small catchment? Paper presented at the Spring Meeting of the American Geophysical Union, Boston, MA, 27 May-1 June 2001. *EOS Trans. AGU,* **82(20)**, Spring Meeting Suppl., H21B-02.

Webster, K. L., I. F. Creed, N. S. Nicholas, D. G. Tarboton, and H. Van Miegroet. 2000. Establishing links between N pools and export from a catchment. Poster presented at the American Geophysical Union Fall Meeting, December 15-19. San Francisco, CA. *EOS Trans. AGU*, **81(48)**, Fall Meet. Suppl., H21B-14, 2000.

Webster, K. L., I. F. Creed, and C. L. Tague. 2001. Modeling N Export from the Noland Divide Watershed: The importance of Climate on Nitrate-N Production and Transport. Poster presented at the Gordon Research Conference on Forested Catchments: Hydrological, Geochemical, and Biological Processes in Andover, NH, 22-27 July, 2001

Webster, K. L., I. F. Creed, C. L. Tague, H. Van Miegroet, and N. S. Nicholas. 2001. Nitrogen Retention in a Nitrogen-saturated System: Fact or Fiction? Poster presented at the 2nd International N Conference N2001 held in Potomac, MD, 14-18 October, 2001.

c) Other (Publications)

Dobranic, J. K. 2001. Temporal and spatial patterns of fungal diversity along an elevational gradient in an arid ecosystem. Ph.D. Dissertation, Texas Tech University, Lubbock, TX. 192 p.

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.

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

Stottlemyer, R. 2001. Ecosystem processes and nitrogen export in northern U.S. watersheds. Proc. 2nd International N conference N2001 held in Potomac, Maryland. The ScientificWorld (E-Journal).

Van Miegroet, H., I. F. Creed, N. S. Nicholas, D. G. Tarboton, K. L. Webster, J. Shubzda, B. Robinson, J. Smoot, D. W. Johnson, S. E. Lindberg, G. Lovett, S. Nodvin, and S. Moore. 2001. Is there synchronicity in N input and output fluxes at the Noland Divide Watershed, a small N-saturated forested catchment in the Great Smoky Mountains National Park? Proc. 2nd International N conference N2001 held in Potomac, Maryland. The ScientificWorld (E-Journal).

d) Latitude and Longitude of Study Site(s) or Geospatial Reference to the Study Area

	Latitude (N)	Longitude (W)
Nolan Divide	35° 43'	83° 20'
Pine Canyon	29° 15'	103° 15'
West Twin	47° 54'	123° 00'
Wallace Lake	47° 48'	88° 15'
Asik	67° 58'	162° 15'

Web Page Review:

An update of this has been forwarded to BRD MESC.

Updated SIS Description:

Updates to the SIS will be entered the week of February 10.

Detailed Report: A detailed annual report follows.

2. Introduction

In 1998, the USGS Global Change program funded additional research for a network of Long-Term Ecosystem Study sites (now USGS Reference Ecosystem sites) initially established and funded by the National Park Service and other subsequent sources such as the Electric Power Research Institute (EPRI). This network of research sites include Noland Divide, Great Smoky Mountains National Park, Tennessee; Pine Canyon, Big Bend National Park, Texas; West Twin Creek, Olympic National Park, Washington; Wallace Lake, Isle Royale National Park, Michigan; and the Asik watershed, Noatak National Preserve, Alaska. Most of these sites have other research underway, and the length of record for monitoring and research varies. The sites represent a major fraction of lands administered by the National Park Service, and were chosen generally for the contrasts among sites. For example, two of the sites, Noland and West Twin, are characterized by high precipitation amounts, but Noland receives some of the highest atmospheric nitrogen (N) inputs in North America. In contrast, Pine Canyon and Asik are warm and cold desert sites respectively. The Asik watershed receives <1% the atmospheric N inputs Noland receives. The Asik site is at the northern extent (treeline) of the boreal biome in North America while Wallace is at the southern ecotone between boreal and northern hardwoods.

The research goal for these sites is to gain a basic understanding of ecosystem structure and function, and the response to global change especially atmospheric inputs and climate. To detect incipient change in the terrestrial ecosystem, as may be induced by human activity, it is generally best to study processes. The processes studied in the present Global Change research are the cycling of energy and nutrients. However, to quantify response the ecosystem must be studied as an integrated unit which requires understanding both above-ground and below-ground processes, and their linkage to hydrology. One model used for such ecosystem-level research is the small watershed.

Carbon (C) is a major energy source in all ecosystems. Nitrogen is the principal limiting nutrient in terrestrial ecosystems, and seasonally limits aquatic ecosystem production. Many terrestrial ecosystems contain >90% of total ecosystem C and N in organic form below-ground. In forested ecosystems, about half of total productivity occurs below-ground. Greater than 99% of total ecosystem biodiversity is found in the forest floor and below-ground. The complex below-ground microbial communities perform a diverse set of functions which regulate the quality and quantity of nutrients and energy available to the ecosystem.

Our primary research objectives for this short 5-year global change study, which began in the field in 1999, are to 1) quantify multi-year trends in soil N status; 2) examine how change in soil N availability, temperature, and moisture alter N and C dynamics and export from the terrestrial to aquatic ecosystem; 3) determine if change in soil available N, temperature, and moisture alter the quality of DOC and DON produced; and 4) evaluate the response of forest floor and soil microbial biomass and functional diversity to climate and N availability.

3. Overview of Progress and Results

In FY 2001, data collection focused on the N and C cycles, below-ground microbial functional diversity, and the likely biological relationships to soil temperature, moisture, and N availability. Our sites include locations covering the range of atmospheric N deposition (<0.3 to 30 kg ha^{-1} yr^{-1}) in North America, a

factor to be considered when evaluating climate effects on ecosystem C and N cycles, and ecosystem biodiversity. The Nolan Divide ecosystem continues to retain atmospheric N inputs suggesting changes are occurring in both below- and above-ground biomass and biodiversity. The effects of soil temperature and moisture on soil respiration as carbon dioxide (CO_2) efflux were examined at all sites. The study of linkages between global change, primarily climate and nutrient availability, and soil microbial functional diversity is most advanced at Pine Canyon, and suggests the soil bacterial and fungal communities respond differently to environmental stimuli. At the cold desert site, the Asik watershed, our research continued to focus on soil responses to climate change and hydrologic changes in an attempt to explain the high ecosystem N export where atmospheric inputs are low. In 2001, at all sites we began studies evaluating change in soil microbial functional diversity and its likely response to global change. Past research results from most sites were presented in a series of papers at the Second International Nitrogen Conference in Potomac, Maryland. During the year, the global change sites and former Park Service small watershed study sites were merged into the Reference Ecosystems project, a component of the BRD Ecosystems Program.

4. Specific Accomplishments and Results (by site)

Noland Divide:

Baseline measurements at the Noland Divide Watershed (NDW), including deposition, throughfall, soil water, and stream water chemistry, and soil microclimate have continued as scheduled. Because the NDW does not span the full elevational range in which the spruce-fir forest exists in the GSMNP, our experimental design was expanded to examine soil nitrogen (N) and carbon (C) dynamics across 8 plots between 1525 m and 1980 m elevation [2 in the lower watershed NDW around 1700m; 2 in upper NDW around 1835 m; plus 4 additional forest inventory plots established by TVA as part of the National Acid Precipitation Assessment Program (NAPAP plots) (2 around 1525 m; 2 around 1980 m)]. All plots have similar aspect and stand structure (basal area: 48-64 m^2 ha^{-1}).

Measurements this year included the following: (a) Collection and analysis of precipitation, throughfall, soil and stream water samples (NPS-sponsored activity); (b) Collection of litterfall at twelve plots within NDW, stratified into 4 leaf area index classes and 3 elevation bands; (c) Continuous monitoring of soil temperature (5 cm soil depth) at 10 locations on watershed transect from a point below the weir (1680 m) to the top of the watershed (1920m).

Plot studies: (a) Determination of N mineralization using the resin core technique during summer (June-August) and fall (August-October); (b) Sample collection for microbial diversity in A-horizon (June); (c) Determination of soil respiration (July); (d) Measurements of soil temperature at 2-hour intervals (initiated in July); (e) Collection of litter material for litterbag study.

Our study also includes a modeling component in an effort to scale up N and C cycling processes. We have made progress in calibrating an N export model (RHESSys-N) to NDW, and gathering the data needed to run C and N dynamics models for NDW.

Water sampling and analysis. Sampling and chemical analysis of deposition, throughfall, and streamwater has proceeded on its routine biweekly schedule; discharge is gauged continuously; soil

solutions are collected using tension lysimeters at 3 soil depths and subsampled monthly (NPS-sponsored activity). Available N flux data through 1998 have been summarized in a presentation and paper prepared for the 2nd International N Conference - N2001, held in Potomac, Maryland. We examined the magnitude and timing of the N fluxes into, through, and out of NDW; and the role of climatic conditions in causing inter-annual variations in the N output signal. About half of the atmospheric N input (30 kg ha^{-1} yr^{-1}: two-thirds as NO_3^- - N; one-third as NH_4^+ - N) was exported annually in the stream water, primarily as NO_3^- - N (~15 kg ha^{-1} yr^{-1}). While most incoming NH_4^+ - N was retained in the canopy and the forest floor, the NO_3^- - N fluxes were very dynamic, in space as well as in time. There was a clear decoupling between NO_3^- - N input and output fluxes. Atmospheric N input was greatest in the growing season, while the largest NO_3^- - N losses typically occurred in the dormant season. Also, as water passed through the various catchment compartments, the NO_3^- - N flux declined below the canopy, increased in the upper soil due to internal N mineralization and nitrification, and declined again deeper in the mineral soil due to plant uptake and microbial processing. Temperature control on N production and hydrologic control on NO_3^- - N leaching during the growing season caused the observed inter-annual variation in fall peak NO_3^- - N concentrations and N discharge rates in the stream. Subsamples from June and July solutions were sent to Michigan Technological University for dissolved organic C (DOC) and N (DON) analysis. Results are still outstanding.

Litterfall. Total litterfall biomass return based on three full collection years (1999, 2000, and 2001) averaged 3125 kg ha^{-1} yr^{-1} (std. dev. = 565) for the NDW. There was considerable year to year variability in litterfall (3,400 kg ha^{-1} yr^{-1} in 1999; 3,500 kg ha^{-1} yr^{-1} in 2000; 2,450 kg ha^{-1} yr^{-1} in 2001), and litter return tended to decrease with elevation, reflecting the general distribution of live biomass.

Soil temperature. We have an uninterrupted soil temperature data record for 10 locations at the NDW between 1680 and 1910 m elevation starting June 1998 through July 2001, with temperatures recorded at 1-hour (1998, 1999) or 2-hour intervals (2000, 2001). There are indications of a soil temperature decline with increasing elevation at the NDW, but the statistical analysis of data is not yet completed. Soil temperature measurements were also initiated in the center of the 8 intensive plots in July. Data will be downloaded in Spring 2002.

Soil chemical properties. Soils were acid throughout the NDW, as shown by low pH and base saturation (BS); they were, however, spatially variable. All soil samples have a pH <4.5 (range 3.1-4.5). Forest floor pHs were generally lower in the upper NDW (pH <3.5). This was also reflected in a lower BS in the upper NDW. Most mineral soils had BS <10%, and BS generally decreased with soil depth, while elevational patterns were less pronounced and attenuated with soil depth. In the mineral soil, the pH was lowest in the A-horizon (range 3.1-3.9) and increased with soil depth. Lowest soil pHs were observed in the upper part of NDW, a trend which was especially pronounced in the upper 35 cm of the profile.

Microbial diversity. Four A-horizon samples (5-15 cm depth) were taken in June for determination of microbial diversity. These data are being analyzed and synthesized in conjunction with information from the other sites within the network.

N mineralization. Net mineralization and nitrification rates were determined for Summer (May-August) and Fall (August-October), at 4 locations in each of the 8 plots. A new set of incubation cores were

installed in October to overwinter and will be removed in May 2002. All resins and soil extracts are currently being analyzed for NH_4^+ - N and NO_3^- - N.

Soil respiration. In July, soil respiration measurements were initiated in the 8 plots, and during summer field and laboratory logistics of the soil respirations were determined. In some plots, assays were repeated due to bear damage. The carbon dioxide (CO_2) evolution rates ranged between 300 and 1800 mg CO_2 - C m^{-2} over a 24-hour period, and showed considerable variation both within and between plots (CV >30% at plot level). Measurements within NDW fell intermediate between the observed respiration rates. However, no clear trend with elevation emerged at this point.

N export modeling. An existing distributed catchment N export model (RHESSys - N) has been modified for the NDW. Application of the model required climate data (daily minimum and maximum air temperature, daily precipitation), atmospheric and throughfall N deposition data, discharge, and stream chemistry. A major undertaking this past year was to identify the sources of these data, negotiate access and acquisition of these data, and transform these data from analog to digital format. RHESSys - N enabled us to gain insight into the ecological and hydrological mechanisms involved in N cycling within the NDW. For the catchment-scale, RHESSys - N was used to extrapolate our summer field studies to (a) the water year so that the potential impacts and interactions of both hydrologic and ecological controls on N dynamics could be examined and (2) other water years so that the effects of natural variability in climate on N dynamics could be investigated. Current model results suggest the fate of the N that is not discharged from the catchment include retention in soil or plant pools (10 kg N ha^{-1} yr^{-1}) and denitrification (5 kg N ha^{-1} yr^{-1}). This research was presented at both the GORDON conference on Hydro-Biogeochemistry of Forests and the International N2001 conference.

Pine Canyon:

We continue to maintain the three primary meteorological stations located at Lost Mine, Sotol-Grassland, and Chilicotal Springs. We had a particularly difficult year in keeping these instruments working, particularly at the Sotol-Grassland and Lost Mine sites where black bears and rodents have caused considerable damage and downtime. We also have functional rain gages at Rice Tanks and Glenn Springs. Our groundwater sampling continues at Reynold's Well, Chilicotal Springs, Glenn Springs and Oak Springs, as well as at the NADP style samplers at Lost Mine and Chilicotal Springs.

We also continue to monitor soil temperatures at 15 cm, soil microbial activities, and soil nutrient and chemical dynamics data from sites located in the five vegetation zones comprising the Pine Canyon Watershed at Big Bend National Park. While meteorological and soil temperature data have been collected continuously since 1996, data on soil microbial activities and nutrient dynamics have been collected every January and August since 1996 to provide seasonal assessments of these parameters. Soil moisture equitensiometers were installed at the five sites in October 1999 and have provided continuous measurements of soil water potential since that time. Decomposition dynamics, carbon (C) chemistry, and fungal species and functional diversity associated with *Agave lechugilla* leaves placed within each of the vegetation zones along the watershed were assessed for the period June 1997 through June 2000.

This past April, we installed a series of stainless-steel open-top chambers around twelve *Opuntia,* Sotol, and Grama grass plants in the Sotol-Grassland site. These chambers will be used to investigate the interactive affects of water availability and timing of increased water availability on plant responses and soil microbial dynamics. The experiments are expected to begin in January 2002. We have used this past summer to take baseline measurements of plant photosynthetic response over the summer and fall.

We have begun to analyze the NADP (wet deposition) and CASTNET (dry deposition) data collected by the park for the period 1995 to 2001. These data will be used to evaluate seasonal trends in soil nutrient dynamics that have been determined for the five vegetation zones existing along the Pine Canyon Watershed gradient.

Preliminary research began in September toward understanding the microbial and soil nutrient dynamics that might influence the ability to reintroduce grasslands in vast areas of Big Bend National Park and the impacts of climate changes on grasslands within the National Park. Soil samples were taken from an area originally extensive grasslands prior to the development of the National Park. Historical records indicate the area was severely overgrazed in the 1930 to 1940s. Today the landscape is a mosaic of grass, shrub islands large patches of cyanobacterial crusts with no vegetation, and an abiotic crust with no vegetation and no cyanobacteria.

Groundwater Chemistry. The water chemistry data demonstrate expected increases in total dissolved solids (TDS) with decreasing elevation, ranging from 77.7 +/- 3.8 mg L^{-1} in the dilute water found at Reynold's well (n = 21) to 203.4 +/- 7.3 mg L^{-1} at Chilicotal Spring (n = 12) and 583.6 +/- 55.2 mg L^{-1} at Glenn Spring (n = 24). Total dissolved solids (TDS) at Oak Spring are intermediate (282.6 +/- 10.5 mg L^{-1}; n = 10). This variation is primarily due to aquifer residence time, evaporation/precipitation effects, and possibly variations in aquifer geology; all are natural, inorganic, and non-anthropogenic processes. As demonstrated by the increase in TDS, the abundance of most analytes increases with decreasing

elevation. Exceptions to this are the abundances of nitrate (NO_3^-) and sulfate (SO_4^{2-}). Nitrate and SO_4^{2-} levels are highest at Oak Spring (6.4 and 48 mg L^{-1}). Reynold's Well has the second highest NO_3^- concentration (1.7 mg L^{-1}), but a relatively low SO_4^{2-} amount (11.9 mg L^{-1}). We believe the elevated NO_3^- levels at Reynold's Well can be explained by interaction of local precipitation with the abundant leaf litter accumulation in upper Pine Canyon, which is the recharge area for this well. The elevated NO_3^- and SO_4^{2-} levels found at Oak Spring require an anthropogenic source. We speculate the sewage treatment ponds in the Chisos basin might be this source. An important note is that all NO_3^- and SO_4^{2-} values, including those from Oak Spring, are well under the EPA national primary or secondary maximum contaminant levels.

Microbial Dynamics. The multi-year drought, occurring since 1998, appears to have abated during much of 2001. Microbial biomass and bacterial and fungal functional diversity continue to be the highest in the closed canopy Oak Forest in the upper portion of the watershed, followed by the high elevation Pinyon-Juniper-Oak community at the top of the watershed. These two forests were highly disturbed in past years by an oak leaf caterpillar decimating the oaks in August. However, the insect was not evident this past summer. The lowest microbial biomass and bacterial functional diversity measurements continue to be observed in the low elevation Creosotebush and Lowland-Desert Scrub sites along the watershed. In response to the drought conditions, microbial activity is almost below our detection limits for the low elevation sites for either January or August samples. Bacterial functional diversity of the grassland soils continues to decline in response to the continuing in puts of atmospheric N and SO_4^{2-}.

Functional diversity of fungi associated with soil organic matter has been collected twice yearly (January and August) since 1999 from all locations along the watershed. Unlike bacterial functional diversity, fungal functional diversity has remained relatively stable within sites and across years. The highest fungal functional diversity is associated with the forested sites and in the Sotol-Grasslands. The two low desert locations have substantially lower fungal functional diversity. We have begun to evaluate various multivariate approaches for displaying and analyzing the functional diversity data. Preliminary evaluation of Step-wise Discriminant Function Analysis of the 1999 fungal functional diversity data for the Pine Canyon Watershed has determined that, while the Oak-Forest and Oak-Pine Forest sites are similar in fungal taxonomic diversity, there are substantial differences in fungal functional diversity between these two forest types. Interestingly, the high elevation Oak-Pine Forest is most similar to the Sotol-grassland with respect to fungal functional diversity.

Soil pH. Soil pH values continue to remain relatively constant within all vegetation zones except the high elevation forest and mid-elevation Sotol-Grasslands. Since January 1998, soil pH within the high elevation forest increases in January to near pH 7 and declines in August to near 6.5. The decline in soil pH continues at the Sotol-grassland site. This location contains the most acidic soils (mean of 5.9 in August 2000) of any site along the watershed. There are slight but significant declines in pH also occurring at the two forested locations that also began sometime between January and August 1998. NADP data report the pH of rainfall in the Big Bend has become significantly more acidic over the last two years than previously recorded.

Soil Nitrogen. Soil ammonium (NH_4^+) values are highest in the closed canopy Oak Forest and lowest in the low elevation shrub-dominated sites. The high elevation forest and Sotol-grasslands have similar NH_4^+ levels intermediate between the Oak Forest and shrub-dominated zones along the watershed. For

NO_3^- concentrations, the desert scrub site always has the highest NO_3^- amounts. There are no significant differences among the other vegetation zones. Each zone does experience pulses of NO_3^- into the system in August as compared with January. The NADP data collected by the National Park confirm these NO_3^- pulses in the soil are also detected in rainfall during this time.

Grassland Reclamation Project. Ten soil samples were collected to a depth of 15 cm from five vegetation zones within each of the designated reclamation areas: 1) solid Tobosa-Grass (*Hilaria mutica*), 2) fragmented Tobosa Grass, 3) Desert crust with cyanobacteria, 4) desert crust with no cyanobacteria, and 5) Fluff-grass (*Dasyochloa pulchella*). Soil N levels, soil organic matter, microbial functional diversity and soil pH were measured from each soil sample. Work is continuing to determine soil organic matter content, and levels of extractable NH_4^+. Microbial functional diversity data are currently being analyzed. The sites differed significantly in soil moisture levels, with soil moisture levels highest in the Fluff-grass area and least in the abiotic desert crust region. Soil pH was around 8.2 for all locations. Importantly extractable soil NO_3^- - N values differed substantially between locations. The highest values were recorded in the abiotic crust areas and the lowest in the cyanobacterial crust locations. The highest average level of NO_3^- - N was found for the fragmented Tabaso-Grass area (54.4 mg N kg^{-1}) and the least for the cyanobacterial crust locations (6.8 mg kg^{-1}). Surprisingly, the abiotic desert crust contained an average level of 39 mg kg^{-1}. These values are the highest recorded to date for soil samples obtained from Big Bend National Park.

West Twin Creek:

This study, entitled "Comparative Effects of Global Climate on Ecosystem Nitrogen and Soil Biogeochemistry in the U.S. National Parks" was initiated in July 1999 to determine the effects of increasing anthropogenic nitrogen (N) deposition on carbon (C) and N biogeochemical cycles. Olympic National Park provides an excellent location for gathering valuable baseline data from a pollution-free site for used in evaluating 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 (WTC) watershed in Olympic National Park, Washington. West Twin Creek is a first-order tributary of the Hoh River. This program includes basic monitoring of vegetation, precipitation, throughfall, stemflow, soil solution, stream chemistry, hydrology, litterfall rates, and litter decomposition rates. Tree health, growth, and mortality have 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 relatively pristine watersheds. In particular, increased nitrate (NO_3^-) deposition between 1993 and 1996, apparently related to transport of Asian pollution across the Pacific, has allowed us to examine early effects of anthropogenic change. In many eastern U.S. forests, monitoring did not begin until significant impacts had already occurred. The Comparative Effects study supplements the data we have already collected in the West Twin Creek watershed (Edmonds et al. 1998).

Calendar year 2001 was average in precipitation and temperature, although the first storms of the year occurred earlier than usual — in August instead of September or October, leading to slightly earlier than normal peaks in Hoh River discharge. Discharge in West Twin Creek more closely mimics precipitation because of the smaller catchment area and hydrologically active substrate. In addition, summer flows in the Hoh River are maintained by melt water from the Blue Glacier on Mt. Olympus. Summer temperatures were cooler than average, outside of the two standard deviation limits calculated for a nearby site. Winter temperatures were within average ranges.

Within the watershed are six 0.1 ha permanent research plots, chosen as representative of the six different vegetation communities located within the watershed. Two of these were chosen for indepth study of C and N cycling as part of the Comparative Effects study. Plot 1 is located in the lower portion of the watershed at an elevation of 342 m. Plot 4 in the upper watershed is located at 586 m.

Overview of Progress and Results:

1. Soil respiration has been measured quarterly since July 2000, and a seasonal trend is beginning to develop.
2. Open cores/resin bag systems have been used to measure net ammonification and nitrification in the upper 10 cm of the soil on a quarterly basis.
3. Soil is collected biannually (March and August) for Biolog and Fungilog analyses by John Zak at Texas Tech University.
4. Stream chemistry and discharge are measured monthly in West Twin Creek.
5. An ISCO water sampler was installed in October 2001 to measure N species in the water every 30 hours.
6. Stream channel bedrock was sampled for C and N content, and geologic N was determined to be a significant pool.
7. Lysimeters were removed from both plots, and soil water will be sampled by centrifuging.

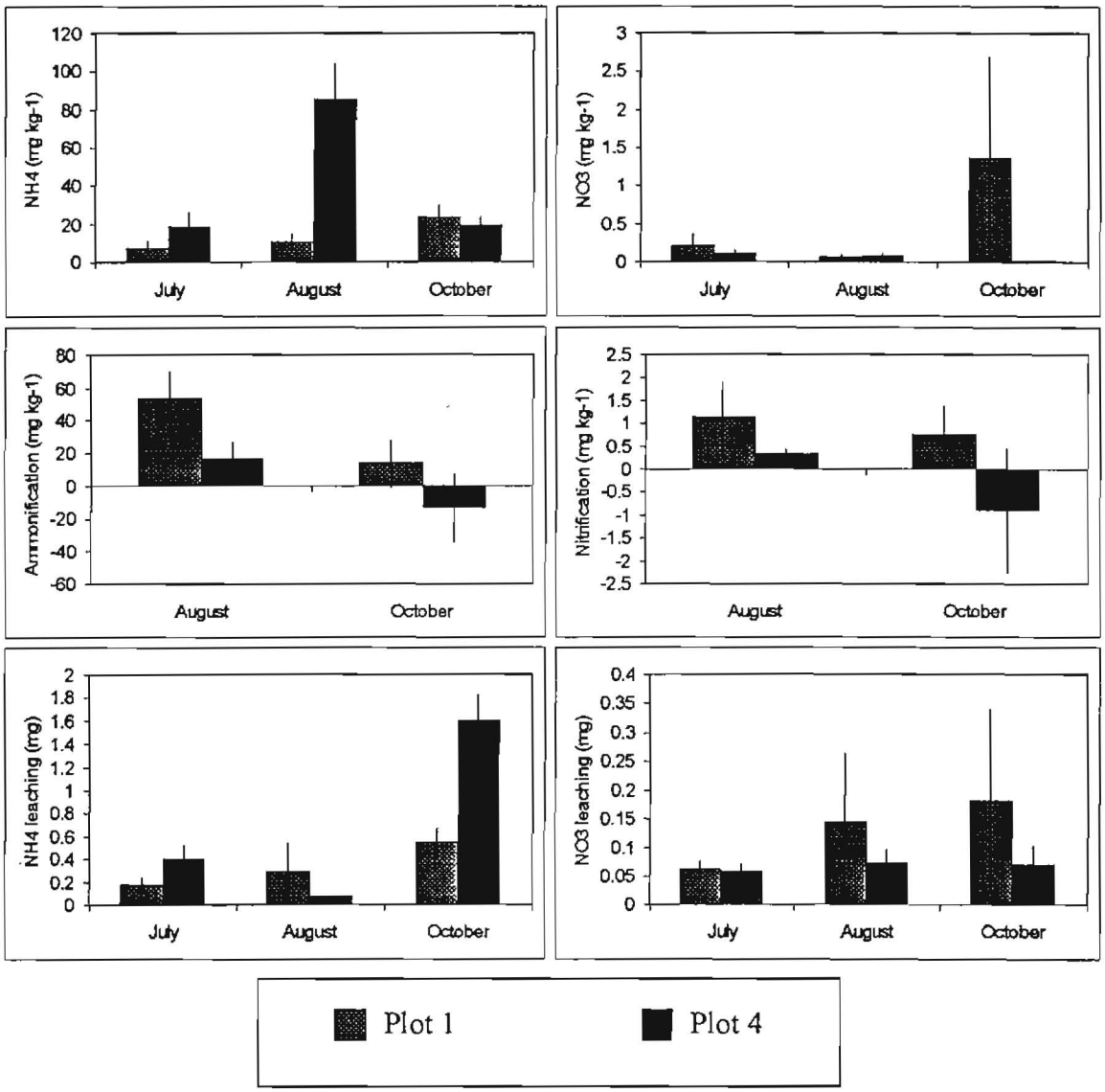

Figure 1. a. Ammonium and nitrate pools, **b.** production of NH_4^+ and NO_3^- during a 6-week incubation, and **c.** NH_4^+ and NO_3^- leaching. Values are the mean of 6-8 samples, and error bars show the standard error of the mean. Data are from 2000.

DIN Pools. Ammonium (NH_4^+) pools are larger than NO_3^- pools (10 — 20 mg kg^{-1} vs. <0.5 mg kg^{-1}), as expected, and the results are generally similar to those reported for similar forests in Oregon (Stark and Hart, 1997). There are two exceptions to this — the very high NH_4^+ measurement in Plot 4, August and NO_3^- in Plot 1, October (Figure 1a). 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 from near Plot 4 in buried coarse woody debris. Thus it is also possible that the August sampling period included woody debris or moss with a high N concentration. Although there are significant differences between months ($p=0.037$), this is mostly related to the high August measurement. In Plot 1, though, it appears that the NH_4^+ pool increases throughout the season, probably due to the high ammonification rates. Ammonium pools are generally larger in Plot 4, which has a larger accumulation or organic matter.

Transformations. More NH_4^+ and NO_3^- are produced in Plot 1 than Plot 4, and the seasonal patterns are the same for both species (Figure 1b). Ammonification rates are somewhat similar to those measured in laboratory incubations of soil from old growth forests (Hart et al., 1994), although the August measurement in Plot 1 is high. Nitrification rates are within average ranges (Stark and Hart, 1997). The fact that the patterns of N transformations are similar suggests that the same factors are limiting the activity of both ammonifying and nitrifying bacteria.

Leaching. Leaching is estimated by the amount of NH_4^+ or NO_3^- extracted from the resin bag. In both plots, NH_4^+ leaching increases from mid-summer through the early fall (Figure 1c), suggesting that is controlled by the flux of water through the soil. The same is true with NO_3^- in Plot 1. However, the NO_3^- flux is constant in Plot 4. This suggests that other factors, such as pool size or microbial uptake, act in combination with water flux to control NO_3^- loss from the upper soil.

Soil Moisture. 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, and this is likely due to the greater accumulation of organic matter at higher elevations.

There is also some concern that the method used to measure N-mineralization caused significant changes in the soil environment within the cores. In each plot, soil moisture in the cores is uncorrelated with soil moisture outside the cores, and a paired samples t-test found them to be significantly different. In Plot 1, soil within the core was always wetter than that outside the core, while in Plot 4 there was no clear bias. It is possible that the resin at the bottom of the core impedes water movement in the soil. Plot 1 has coarser soils than Plot 4, so equal amounts of flow disruption would cause a larger effect in Plot 1, which is consistent with the observed pattern.

pH. pH was measured in the lab with a slurry of 2:1 deionized water to soil, by mass. pH displays a seasonal cycle, with low pH values in the spring and high values in the fall that is statistically significant (Figure 2). The pH cycle does not mimic the soil moisture or precipitation cycles exactly, but is offset by one to two months. Soil moisture and pH were significantly correlated; however, 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 aluminum dissolution, all of which are at least partially dependent on soil water content. pH values in plots 1 and 4 are statistically different, and pH in Plot 1 is generally >0.1 units higher. Since the upper soil horizons are influenced primarily by 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.

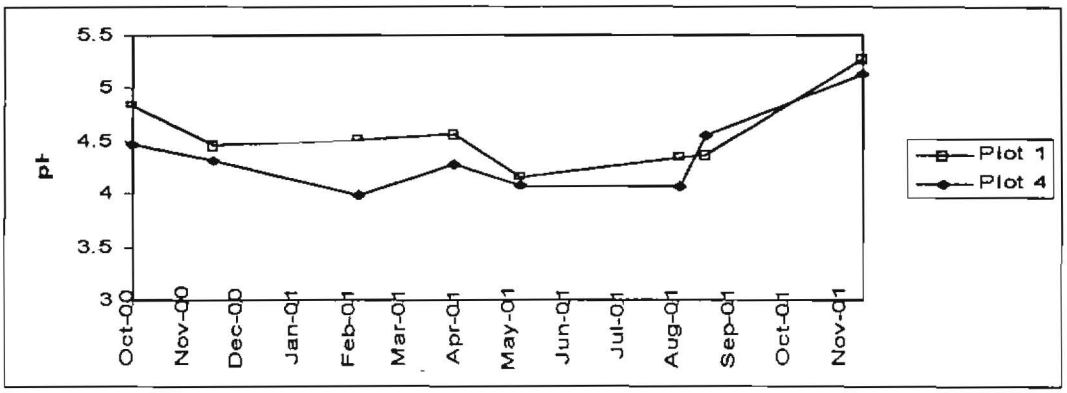

Figure 2. Soil pH. Values are the —log of averaged H^+ concentration for all soils collected in a plot on a given date.

Soil Respiration. Respiration was first measured in July 2000 and was repeated every six weeks until November 2000, when we changed to a quarterly sampling schedule. Thus far the highest values (~20 mg CO_2 m^{-2} da^{-1}) were measured in October 2000 (Figure 3), on a very warm day after the season's first rainfall. Average rates are in accord with those found by Marra and Edmonds (1994). In general, however, it appears that soil respiration peaks in the late spring with warming temperatures and diminishes throughout the summer, as soil moisture decreases. There are significant differences in respiration between plots 1 and 4. In the summer and fall, Plot 1 respiration is higher than that in Plot 4, although they are equivalent in the winter and spring. Plot 1, at lower elevation, is generally warmer than Plot 4, although it is also drier. It would be expected that soil respiration rates would be controlled by a 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 is similar to that at lower elevation. During the dry season, soil respiration is higher in the dry plot. 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.

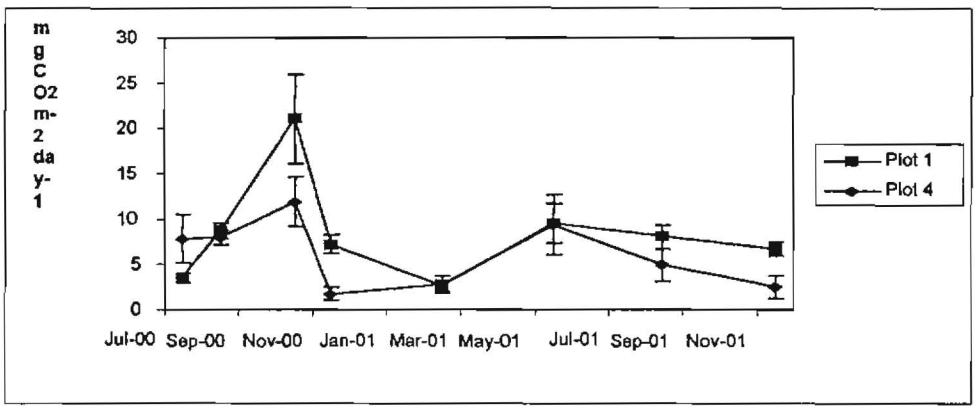

Figure 3. Soil respiration. Each value is the average of 10 samples (except Nov-00, n=5), and standard errors are shown by bars.

Soil Functional Ecology. Soils were collected for functional ecology analysis by Biolog and Fungilog biannually, in March and August. Currently, we have results only for the August 2000 sampling period. There were no statistically significant differences between the plots, although bacterial activity displays a border-line difference ($p=0.097$), with the higher value from Plot 4 soils. In general, bacterial activity is higher than fungal activity, but fungi are able to utilize a greater variety of substrates. The nearly significant correlation between bacterial and fungal activity suggests that environmental factors affect both populations similarly.

Geologic Nitrogen. Bedrock underlying the tributaries to the Hoh River was deposited in a near-shore marine environment, where high variability in water velocity, depth, and productivity transmute into large textural and chemical differences in subsequent rock formations. The differences in N and organic C between sandstones and siltstones are of particular importance. 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. Differences in the N content of siltstone and sandstone, and the proportions of each rock type in the basin are correlated with the stream water NO_3^- concentration.

Samples of unweathered sandstone and siltstone were collected from West Twin, and nearby Twin, Canyon and Lindner Creeks. Due to the heavy vegetation and thick soils, bedrock mapping is nearly impossible. However, bedrock is exposed in stream channels and can be mapped as a transect. Reaches of two creeks, Linder and Canyon, were mapped and percent sandstone and siltstone calculated for each. To determine the lithology of other basins, a two-end member mixing equation was derived, which allowed the calculation of sandstone and siltstone percentages from the average fall silicon (Si) concentration in stream water.

Siltstone has significantly more C and N than sandstone, as well as greater Si release rates (Table 1). Although Si release rates are not necessarily correlative with N release rates, higher Si release does imply greater overall weathering. Nitrogen could be concentrated in one or both of two phases; as NH_4^+ replacing potassium (K^+) in clays, potassium feldspar, and micas or bound into organic matter. It is more likely that the N in stream water is derived from mineral NH_4^+ than organic matter. Organic material in siltstone is likely to be highly recalcitrant as the low hydrogen-to-carbon ratio (H/C) implies a high degree of aromaticity. Such material is less likely to weather in surface conditions than other minerals in which NH_4^+ could be sequestered. Thus, the Si release rate may be a reasonable metric for N release.

Table 1. Average chemical composition and calculated Si release rates for non-calcified lithologies from Hoh River Tributaries.

	Siltstone	**Sandstone**
C (mg kg^{-1})	7280 (517)	995 (84)
N (mg kg^{-1})	1235 (15)	473 (22)
Si Release Rate (3 months)	0.006%	0.0007%
H/C	8.38 (0.50)	35.8 (3.2)

The stream NO_3^- concentrations in West Twin Creek peak in the late summer and early fall (Figure 4), a pattern replicated in a number of rivers along the west coast of the Olympic Peninsula (U.S. Geological

Survey, 1972, 1973, 1986). This seasonal cycle has also been noted in the Molekumne River in California, where geologic N sources have also been implicated (Holloway et al., 1998).

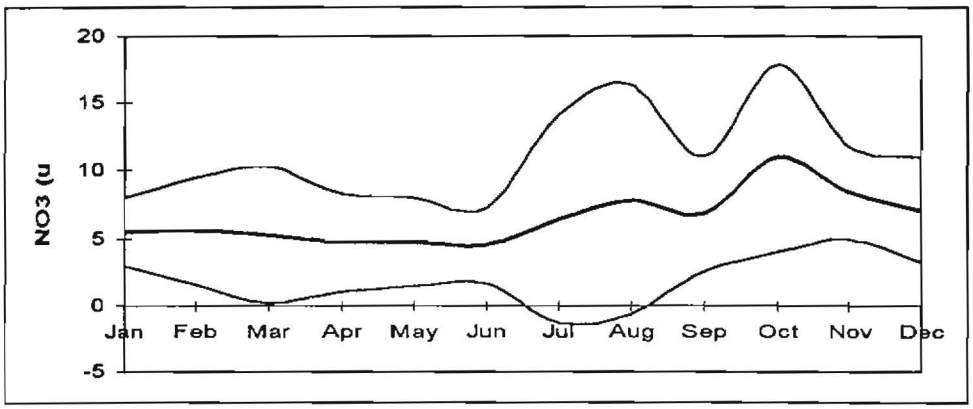

Figure 4. Average NO_3^- concentration in West Twin Creek, 1985-June 2001. Light gray lines delineate one standard deviation around the mean.

Asik Watershed:

A recent (Sept. 2000) report by the National Research Council (NRC), and commissioned by the National Science Foundation, documented the high priority global environmental research needs where U.S. research dollars should be committed. The top priority research was the biogeochemical cycling of carbon (C), nitrogen (N), sulfur (S), phosphorus (P), and other elements in soil, air, and water, and how change in their balance will affect ecosystem function and biodiversity. A series of recent studies published in the journal *Science* and elsewhere provide a much firmer association between human activity and climate change. With recent data, as from the Arctic, fed into improved models, the United Nations Intergovernmental Panel on Climate Change (IPCC) has revised upward its estimate of warming (1.5 - 6° C). With culpability comes the mandated obligation to quantify the effect of global change in national park ecosystems for a much-needed policy position. All ecosystems can not be meaningfully studied, but selected systems representative of major land holdings under National Park Service (NPS) management can be investigated in detail.

In the 1950's, an ecosystem model was developed where major parameters could be measured directly in the field. By linking hydrology with other system processes, the "small watershed" ecosystem model permitted quantification of biogeochemical cycles and other processes sensitive to change. In the 1980's, a network of such research sites, nine in all, was established mainly within the National Park System. The sites are representative of a large fraction of land under Federal protection. The long-term research goal is to obtain an understanding of ecosystem structure and function. The focus of present research is on the effects of global change, especially atmospheric inputs and climate, on ecosystem processes as the C and N cycles. To quantify response, the ecosystem is studied as an integrated unit which requires understanding both above-ground and below-ground processes, and their linkage to hydrology. Terrestrial ecosystems, and especially boreal, may have >90% of total C and N in organic form below-ground. Half of total productivity can occur below-ground, and >95% of total ecosystem biodiversity is usually in the forest floor and below-ground. The complex below-ground functions regulate the quality and quantity of nutrients and much of the energy available to the ecosystem. Ultimately, such functions will determine overall ecosystem biodiversity.

Much research has focused on the effects of human perturbations on above-ground ecosystem processes and biodiversity. However, below-ground processes regulate the nutrient and much of the energy supply to the above-ground biomass and to aquatic ecosystems. Up to 95% of terrestrial ecosystem C, N, and P resides as soil organic matter (SOM), and the dynamics of this largely unavailable pool are highly related to the diversity of the soil microbial community which, in turn, responds to climate and nutrient availability especially N (Garten et al., 2000). The C and N cycles are tightly linked. Change in climate and available soil N, as from organic mineralization or atmospheric inputs of ammonium (NH_4^+) and nitrate (NO_3^-), will affect the C cycle, whether C is retained above- or below-ground, or lost to the atmosphere as carbon dioxide (CO_2).

It is theoretically possible to trace C and N through the terrestrial ecosystem and into the aquatic system using a combination of procedures such as natural and enriched isotopes, chemical analyses, and spectroscopic procedures. Quantifying change in C and N flux, and quality in time and space would locate sensitive ecosystem components in the landscape. However, relatively little work has been done using these techniques at the ecosystem level or to link terrestrial processes and their effect on nutrient and energy export to the aquatic ecosystem. We have refined our watershed-ecosystem conceptual model to better link terrestrial and aquatic ecosystems using new technology such as C and N natural

isotope abundance analyses. Should the methodology prove feasible in quantifying ecosystem spatial and temporal relationships, a similar approach might be applied to other limiting nutrients. The basis for the model is as follows.

Change in available N, as from organic N mineralization in warming soils or atmospheric inputs, in grasses and shrubs can result in above-ground competitive displacement of plant species less able to take advantage of the additional N (Bowman and Steltzer 1998, Chapin et al. 1998). Subsequently, species displacement can result in positive feedbacks on N cycling further altering species' presence, and making more N available for the soil microbial community or leaching to surface water. In forested ecosystems, increased available N appears to be retained initially by the soil microbial community and to lesser degree by small (<1 mm diameter) roots (Aber et al. 1998, Zogg et al. 1998). However, there is little long-term study on the ecosystem effects of chronic low-level increases in available N. It is expected the result would be change in microbial functional diversity and gain in biomass. Such scenarios demonstrate the potential for human activity to alter below- and above-ground biodiversity and function and C storage by just modifying available N.

There is increasing evidence soil warming will increase available N and soil respiration (mineralization) of organic C (Oechel et al. 2000). Concurrent with this will be an increase in terrestrial production of dissolved organic C (DOC) and N (DON). The importance of such change will likely be most evident in northern ecosystems where soil C and N reservoirs are especially large, moisture is not generally limiting, and climate warming is most pronounced. Dissolved organics have a large fraction which is labile and of ecological importance. Terrestrial-derived DOC dominates the energy flux in freshwater aquatic ecosystems, and DON is an important aquatic nutrient seasonally. In addition, change in aquatic DOC concentration can affect lake or pond productivity by altering the depth of the photic zone which in turn can modify the base of the food web from primary production to bacteria-based production (Jannson et al. 2000). The latter is a much less efficient production base. Use of natural isotope abundances for ^{13}C and ^{15}N is a potential tool to detect where are the seasonal sources and fates of soil and stream water DOC and DON.

Climate, hydrologic flowpath, and atmospheric inputs can also alter the broad quality of dissolved organic matter (DOM) in soil, stream, and lake water. But here there is even less understanding. Complicating this question is the fact freshwater DOM quality reflects shifts in the relative contributions of dissolved organics from the aquatic and terrestrial system. Change in both the soil microbial community and aquatic bacteria diversity and biomass can be rapid with altered DOM quality especially if the chemical change is toward simpler, more soluble N-rich compounds (Qualls and Haines 1992). In general, increased fulvic acids (hydrophobic) in surface water indicate greater terrestrial (allochthonous) DOM contributions. Hydrophyllic acids (non-humic) have higher N content, and indicate an increase in autochthonous (in-stream, pond, or lake) DOM contributions. Chemical fractionation of soil and surface water DOM can be used to detect seasonal shifts in relative contributions of humic and non-humic materials, and the quality of DOC and DON (Aiken et al. 1992).

Research Objectives. Our boreal ecosystem research at the Asik and Wallace Lake (Isle Royale) sites has four objectives: 1) Quantify seasonal and spatial change in surface water DOM quality and quantity with concurrent change in terrestrial soil water, N mineralization rates, and soil respiration rates to link change in soil temperature and N availability with stream DOM chemistry; 2) Test use of soil organic matter (SOM) natural isotope abundance ratios, $^{15}N/^{14}N$ and $^{13}C/^{12}C$, to detect spatial and temporal

change in terrestrial source area for C and N in a watershed aquatic ecosystem (present Asik study); 3) Link stream water DOM quality to change in hydrologic flowpath; and 4) Quantify seasonal change in surface water DOM quality and flux to boreal lakes or ponds to determine the chemical and physical effects on lake light transmission and primary production.

Overview of FY 2001 Progress and Results

The Noatak funding did not come available until late in the FY. As a result we limited sampling directly related to this study objective, and focused on collecting further data ancillary to the research question. Some funding will be spent during this winter for sample analyses.

We also refined the sampling protocols necessary for handling dissolved organic material for mass spectroscopic analyses. With the new technology, it is now easier to obtain a sufficient sample size. Other aspects of the original proposal will remain.

Specific FY 01 Accomplishments and Results

Studies focused on the characterization of intra- and inter-annual variability in watershed and ecosystem processes to improve prediction of the response of a northern treeline system to global change. This has been the central theme of the Noatak research which is then subsequently refined somewhat based upon research results.

1). We continued the routine monitoring of weekly up- and down-stream (five stations) water and precipitation inorganic chemistry and DOC and DON, continuous stream stage height and discharge at upper and lower stream gauges (including Aqua Rod), precipitation at upper and lower collection points, and the data loggers for air and soil temperature and basic meteorology. The objective here is to quantify overall ecosystem response to changes in terrestrial and aquatic processes (see Stottlemyer 2001). We replaced a bulk collector and added a second bulk collector for winter precipitation in the lower watershed. A recording rain gauge was also added to better characterize seasonal variation in precipitation amounts. Stage height of the lower watershed is now being recorded by an Aqua Rod, which replaced a stream Level Logger. An upper stage height stake was placed in the stream to improve estimates of discharge from the alpine region of the watershed.

2). We continued study on the watershed vegetation plots to examine ecosystem processes and response to changes in inorganic nitrogen (N) availability (fertilization). We emphasized characterizing north and south slopes of alpine tundra and spruce forest. Routine measurements included the following: soil respiration, soil water for DOC and DON, net N mineralization (incubation bags), soil DOC and DON production, monitoring of soil and air temperature, litter production, and exchange resin KCl extracts.

The following studies were initiated with the vegetation plots: soils incubated for net N mineralization rates were also extracted with distilled water to measure DOC and DON production. This should give an accurate estimate of the actual mobility of DOC and DON in soils. Alpine vegetation plots were established on the north and south facing slopes above 400 m elevation. The plots are 5 x 5 m with 8 plots on each aspect. Control plots continued to be monitored, and the plots designated for N additions were fertilized at a rate of 20 kg N ha^{-1} yr^{-1}.

3). Watershed stream periphyton. The objective here is to determine up- and down-stream nutrient limitations to aquatic primary production in periphyton. Measurements included the following: chlorophyll *a*, biomass, taxonomy, rate of nutrient loss from artificial substrata, stream flow and depth at each station, periphyton presence and absence at each station.

Changes in the study design relative to FY 00 were the following. Artificial substrata were placed at five of the sampling stations for water chemistry and one additional station in the upper watershed. The nutrient diffusing pots were harvested more frequently (every two weeks) throughout the season with the exception of the first set, which was in the stream for three weeks. One additional set of pots at the mouth of the watershed was not harvested for periphyton production, but instead was studied for just the rates of nutrient leaching from the pots. For all pots, stream flow and depth were measured each sampling date. To assess any site preference for the artificial substrates, periphyton on rocks within the stream was collected at the start of the season and with each harvest of the artificial substrata. In addition, a 10 m stream transect through the channel of highest flow was characterized for the presence or absence of periphyton on the streambed surface.

4). Treeline biogeochemistry plots: Characterization of the spatial demography of a spruce - tundra toposequence and associated patterns of variability in N cycling. The objective of this study is to characterize variation in ecosystem processes associated with increasing forest density and decreasing tussock cover across a riverside toposequence. This research follows our earlier examination of the advance of white spruce into tussock tundra in response to the warming climate (see Suarez et al. 1999). Measurements taken during FY 01 were the following: KCl extracts of exchange resins in soils, soil C:N and SOM analysis, net N mineralization (buried bag), soil DOC and DON production, soil extractable ions, soil incubation temperature, change in depth of the soil active zone, soil temperature (hobos and one date by microsite), and understory species presence.

FY 01 additions to this project were the following. Resins were placed within four microsites in each vegetation type. The microsites were under spruce, tussock, *Carex*, and moss-dominated areas within each of the 25 plots. Soils from under spruce, tussock and *Carex* were collected to 10 cm depth and incubated for one month in a common environment to measure potential net N mineralization rates and DOC and DON production. These soils will also be analyzed for total C, total N and SOM. Water extracts of soils will be analyzed for total ions to determine the cation exchange capacity of the soils and ion availability.

5). Treeline spatial demography. The objective of this study is to characterize spatial variation in forest structure in relation to topography, depth of the soil active zone, and depth of organic soil. Measurements taken during FY 01 were the following: slope, depth of the soil active layer, depth of organic soil (to mineral soil or frozen soil), and tree cores for age.

The FY 01 additions to this study were as follows. For each of 91 plots, slope was measured for the majority, but was not completed. The depth of the soil active layer was measured monthly during the growing season. The depth of the organic soil was measured in late July on each plot, and more intensively for a subplot within the tundra and the forest. The largest tree within each plot was cored to determine time since tree establishment across the toposequence.

6). Patterns of treeline spruce seedling establishment, growth, and nutrition across a forest-tundra toposequence. The objective of this study is to examine growth and nutrient status of white spruce seedlings at treeline in relation to variation in forest density and microsite character. Measurements taken during FY 01 were as follows: seedling height (total and for 0-5 years of age), age (by bud scars and verification by tree cores), biomass of shoot (new production and total - needles and stems), root length and biomass, and N content (total and foliar).

Additions to this study during FY 01 were the following. The proportion of ground cover and seedling presence was measured for 10 one m^2 quadrats within each of 25 vegetation plots across the toposequence. Seedlings were collected and aged by counting bud scars along the main axis. Total shoot and root length was measured. Plant tissue will be split into current year's foliage and stem production, previous foliage and stem production, and root tissue. Each tissue type will be weighed and a subsample analyzed for N. Soils were collected to determine the soil seed bank and collection trays were left in the field to measure the seed rain.

7). Tree island soil accumulation. The objective of this study is to identify whether soil mass or biogeochemistry varies under tree islands in comparison with surrounding open tundra. Measurements taken were as follows: soil mass, soil C and N, SOM, soil pH, soil temperature, soil C fractions, plot (location, elevation, aspect, slope, distance to nearest tree), tree (height, DBH, crown diameter, age), and description of understory and surrounding vegetation.

Additions to the study in FY 01: Thirty tree islands were selected in either alpine, tussock, shrub or heath tundra. For each tree island, soils were collected immediately under the tree canopy, and in the tundra at 3 m and 6 m distance from the tree. Soil will be weighed and analyzed for total C, total N, SOM, pH and perhaps soil C fractions. The location of each tree and tree character were quantified (slope, aspect, elevation, tree age, and tree biomass).

8). Spruce and alder limits to spruce growth. The research objective is to determine the potential for N to limit spruce growth in tundra and upland forest within a treeline landscape by examining growth of white spruce in the presence and absence of alder at treeline. Measurements taken in FY 01 were the following: tree age and production, foliar total N and ^{15}N, soil net N mineralization (buried incubation bags), soil incubation temperature, buried exchange resin KCl extractions, seedling character (biomass, age, height, N, and ^{15}N), and soil C:N.

Additions to this study during FY 01. This project was designed as a quick side study to combine techniques the research assistants had utilized in other studies during the summer. Spruce trees were sampled for age, wood production, foliar N and ^{15}N, height, and DBH. Soil N availability was assessed by net N mineralization in soils incubated in a common environment and from exchange resin inorganic N content. Foliage from understory species and any spruce seedlings present were collected for N and ^{15}N analysis.

Total samples collected and analyzed during FY 01 are as follows. 1) water chemistry, including precipitation, stream, and soil water lysimeters, 302 samples; 2) soil KCl extracts for mineralization rates in vegetation plots and treeline plots, 483 samples; 3) soil water extracts for DOC and DON production rates, approximately 380; 4) resin KCl extracts for vegetation plots and treeline plots, approximately 900 (this number is high since there were 3 resin bags/plot and cation and anion resins

were extracted separately); 5) water samples from periphyton experiment, 100 samples for NO_3^- and phosphate (PO_4^{3-}) analysis to determine rates of nutrient leaching from clay pot substrates; 6) periphyton samples, 150 samples total for chlorophyll *a* and biomass analysis; 7) soils for C:N analysis from treeline and spruce/alder study, 140 samples; 8) soil water extracts for treeline soils to determine cation exchange capacity, 100 samples; 9) tree cores for treeline, tree island, and spruce/alder studies, 182 cores; 10) spruce seedlings for treeline seedling study, 500 samples for biomass and 200 samples for N; 11) soil seed bank for treeline seedling study, 25 soil samples; 12) soil accumulation for tree island study, 90 soils for C:N, soil mass, SOM, and pH analysis; 13) spruce and alder foliage, 80 samples for N and ^{15}N analysis with potentially 40 more for understory vegetation; 14) spruce and alder seedlings, 30 samples for biomass, N and ^{15}N analysis.

5. Progress towards Integration with other Projects within Research Theme (by site)

Noland Divide:

No new information from the site, but results are included in the Pine Canyon discussion.

Pine Canyon:

Microbial functional diversity measurements and soil microbial biomass were obtained for the Noland Divide watershed, Great Smoky Mountains National Park (N.P.), from samples collected in June 2001 and from soil collected from the West Twin Creek watershed, Olympic N.P., in March and August 2001. The assessments of these data have not been completed. In addition, we received soil samples from Noatak National Preserve in Alaska and Isle Royale N.P. for determining bacterial and fungal functional diversity, and microbial. The data for these sites is currently being processed and analyzed. These samples will provide an extensive analysis of the mechanisms regulating microbial diversity across a range of forested ecosystems. Preliminary assessment of fungal functional diversity for the forested regions of Pine Canyon, West Twin Creek, and Noland Divide indicate the highest fungal functional diversity is associated with the forested sites within Pine Canyon in Big Bend N.P. The lowest fungal functional diversity is associated with the West Twin Creek sites, with the Noland Divide location more similar to Pine Canyon than to the Olympic sites.

West Twin:

Data produced by research for the Global Change project provide a valuable complement to 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 us to calculate changes in watershed storage of a number of elements, which creates a context for C and N cycling processes. In particular, the Comparative Effects project has provided a broader frame of reference for stream ecologists studying the effect of red alder (*Alnus rubra*) on stream food webs and soil scientists studying the role of buried coarse woody debris in N retention.

Asik Watershed:

In FY01, we submitted research proposals to undertake study on research objectives 1 and 4. In addition, a research proposal on the sensitivity of below-ground microbial functional diversity has been submitted to DOE and includes all research sites in the network.

6. Plans for Coming Year (by site)

Noland Divide:

1. Continue measurement of net mineralization and nitrification in the 8 plots on a year-round basis (summer, fall, winter/spring).
2. Expand periodic soil CO_2 efflux measurements at the 8 plots.
3. Initiate litter decomposition experiment (spring).

In addition, the following activities will continue:
4. Soil temperature monitoring along the elevational transect in the NDW and in the additional 8 intensive monitoring plots.
5. Soil water and stream sampling - this activity will be coordinated with personnel from the NPS and the University of Tennessee to also include subsampling for DOC and DON analysis.

In the area of modeling and scaling-up the following activities are planned:
6. Simulate both short and long term dynamics in C and N cycles within the NDW based on the 100-yr climate record we have developed. We will examine environmental and ecosystem controls on the spatial and temporal distributions of C within the forest.
7. Assessment of catchment N export potential: Since NDW is the only experimental catchment within the GSMNP, we will investigate N export potential from other catchments in the GMSNP. Simulation scenarios that are representative of the range in ecological (i.e., changes in stand age and structure) and hydrological (i.e., changes in soil temperature and moisture) gradients in the spruce-fir forest of the GSMNP will be conducted on the NDW data to examine their control on N dynamics within and export from catchments
8. Analysis of the topographic variability of catchments within the spruce-fir forest of the GSMNP.
9. Scaling from first to higher order catchments: If access to required data is possible, we will scale-up the first order N catchment model to higher order catchments within the spruce-fir forest of the GSMNP. The ability of the models to predict N export from higher order catchment will be evaluated using existing synoptic data collected as part of the I&M Program.

Pine Canyon:

1. Continue to collect meteorological, soil temperatures at 15 cm, soil microbial activities, and soil nutrient and chemical dynamics data from sites located in the five vegetation zones comprising the Pine Canyon Watershed at Big Bend National Park.

2. Continue to collect N mineralization data from the two forest types and Sotol-grassland in Pine Canyon.

3. Analyze the impacts of soil N on microbial biomass, and microbial functional diversity at Big Bend, Great Smoky Mountains, Olympic, and Isle Royale National Parks, and Noatak National Preserve.

4. Continue the analysis of patterns of microbial biomass and functional diversity at Great Smoky Mountains and Olympic National Parks.

5. Continue collecting ground water chemistry data.

6. Begin the the climate change experiment in the Sotol-Grasslands.

West Twin:

Monitoring of soil N mineralization and nitrification, soil respiration and soil water dissolved organic C, dissolved organic and inorganic N will continue on a quarterly basis. Soil samples will be taken for Biolog© and Fungilog© analyses twice a year in August and March. In addition to these analyses, we plan to create a N budget for the watershed, including standing vegetation, forest floor, and mineral soil pools.

Asik Watershed:

The focus of 2002 research will be in four areas: 1) continue routine ecosystem monitoring; 2) update the vegetation plot studies detailed above; 3) conduct the research outlined in the NPS 1999 proposal quantifying the source of surface water DOC and DON, and 4) complete the change of all computer software to the IBM and Linux operating systems with Oracle database and SAS statistical applications.

7. Products (all completed unless noted)

a. Data sets

Data sets for each study outlined above are maintained at three different geographical locations on PCs. The samples collected during FY 01 have not all been analyzed, but will be completed by February 2002.

Soils data: (Complete)

Description: soil characterization for 50 plots within Nolan Divide.

Metadata: composite of 4 samples per plot, 50 plots, segregated by depth into O, A, 15-25cm, 25-35 cm, 35-45cm +45 cm. Analyses include pH, total C, total N (Leco analysis), total element concentration (digestion and ICP), CEC and exchangeable bases (completed in 2001)

Location: U.S.U., Dept. Forest Resources (H. Van Miegroet = custodian)

Litterfall data: (In progress)

Description: biomass and N return via overstory litterfall from 12 plots within NDW stratified into 3 elevation bands [low (1705-1768m), medium (1798-1828 m), high (1859-1920m)] and 4 leaf area index classes [3.44-6.57 m^2 m^{-2}; 6.58-9.71 m^2 m^{-2}; 9.72-12.85 m^2 m^{-2}; 12.86-16.00 m^2 m^{-2}]; separated into needles, deciduous foliage, twigs, and other.

Metadata: Litterfall collection from September 1998 through December 2001; biomass measurements (completed); nutrient analysis (1998-1999 completed; subsequent years in progress).

Location: U.S.U., Dept. Forest Resources (H. Van Miegroet = custodian)

Water chemistry data: (In progress)

Description: biweekly chemical analysis of deposition and throughfall solutions , and monthly chemical analysis is lysimeter samples collected at the IFS Tower site; discharge and biweekly chemical analysis of Noland Creek at approximately 1620 m elevation.

Metadata: pH, conductivity, alkalinity, major anions and cations for (a) atmospheric deposition and throughfall, biweekly since 1991; (b) soil solutions below the forest floor and at 10 cm and 40 cm soil depth, monthly since 1986; (c) NE and SW streamlet of Noland Creek, biweekly since July 1991;

Location: Great Smoky Mountains National Park (NPS=custodian); except soil solution chemistry U.S.U., Dept. Forest Resources (H. Van Miegroet = custodian)

Soil temperature data

Description: (a) Soil temperature data (5-10 cm soil depth) record for 10 locations at the NDW between 1680 and 1910m; recorded at 1-hour (1998, 1999) or 2-hour intervals (2000, 2001); (b) Soil temperature data (5-10 cm soil depth) in center of 8 plots between 1525-1980 m.

Metadata: (a) Record from June 1998 through July 2001; recorded at 1-hour (1998, 1999) or 2-hour intervals (2000, 2001); (b) record from July 2001- present (download not yet completed).

Location: U.S.U., Dept. Forest Resources (H. Van Miegroet = custodian)

b. Reports, abstracts, presentations

Creed, I. F., H. Van Miegroet, and N. S. Nicholas. 2001. Climatic Controls on Soil N Fluxes in a Nitrogen Saturated Watershed. Poster presented at the Gordon Research Conference on Forested Catchments: Hydrological, Geochemical, and Biological Processes in Andover, NH, 22-27 July, 2001.

Dobranic, J. K. and J. C. Zak. 2001. Understanding the relationships between fungal functional diversity, taxonomic diversity, and decomposition rates. The Soil Ecology Society Biannual Conference, Callaway Gardens, GA. May 2001.

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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.

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Urbanczyk, K. 2001. Contemporary Water Supply in the northern Chihuahuan desert, presented at the 2001 Desert Fishes council meeting.

Van Miegroet, H., I. F. Creed, and N. S. Nicholas. 2001. Spatial Variation in N Saturation in High-elevation Spruce-fir Forests of the Southern Appalachians. Paper presented at the 2nd International N conference N2001 held in Potomac, MD, 14-18 October, 2001.

Van Miegroet, H., N. S. Nicholas, and I. F. Creed. 2001. What creates spatial variability in N saturation at the level of a small catchment? Paper presented at the Spring Meeting of the American Geophysical Union, Boston, MA, 27 May-1 June 2001. *EOS Trans. AGU,* **82(20)**, Spring Meeting Suppl., H21B-02.

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c. Publications

Dobranic, J. K. 2001. Temporal and spatial patterns of fungal diversity along an elevational gradient in an arid ecosystem. Ph.D. Dissertation, Texas Tech University, Lubbock, TX. 192 p.

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.

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Stottlemyer, R. 2001. Ecosystem processes and nitrogen export in northern U.S. watersheds. Proceeding of the 2nd International N conference N2001 held in Potomac, Maryland and The ScientificWorld (E-Journal).

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d. Other products

Research proposals addressing specific components of this research were submitted to the NPS, DOE, and U.S. Geological Survey.

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