

Final Report for Period: 12/2005 - 11/2006

Submitted on: 02/28/2007

Principal Investigator: Seastedt, Timothy R.

Award ID: 9810218

Organization: U of Colorado Boulder

Title:

LTERR: The Niwot Ridge LTER Research Program 1998-2004: Controls on the Structure, Function & Interactions of Alpine & Subalpine Ecosystems of the Colorado Front Range

Project Participants

Senior Personnel

Name: Seastedt, Timothy

Worked for more than 160 Hours: Yes

Contribution to Project:

Principal Investigator, 1992-2004. He provided continuity in leadership as well as mentoring as M. Williams transitions to the current lead PI position. His research interests focus on terrestrial ecosystem studies, including factors influencing primary productivity, soil carbon dynamics, decomposition and mineralization processes, and how these processes affect short- and long-term ecosystem-atmosphere interactions. Ongoing research collaborations involve cross-site comparisons of mechanisms controlling nutrient availability, carbon storage, and biotic productivity, invasive species, and ecosystem processes-biodiversity relationships.

Name: Townsend, Alan

Worked for more than 160 Hours: Yes

Contribution to Project:

Dr. Alan Townsend is a Co-I on the NWT LTER project. His research is largely within the fields of terrestrial ecosystem ecology and biogeochemistry, with a focus on tropical and alpine ecosystems which include: controls over nutrient limitation and carbon storage in moist tropical and alpine tundra ecosystems; the effects of human activity on regional to global scale carbon and nitrogen cycling, and the effects of changing biogeochemical cycles on human health.

Name: Wessman, Carol

Worked for more than 160 Hours: Yes

Contribution to Project:

Dr. Carol Wessman served as CO-PI during the 1998-2004 interval. Her expertise is on using remote sensing techniques to understand ecosystem processes. During this interval she developed expertise in the regional analysis of carbon storage by montane ecosystems.

Name: Williams, Mark

Worked for more than 160 Hours: Yes

Contribution to Project:

Dr. Mark Williams was co-PI during 1998-2004 and is the current PI of the NWT LTER project. His research areas are in snow hydrology, surface-groundwater interactions, terrestrial-aquatic interactions, and biogeochemistry. During the 98-04 interval his major accomplishment was to take a leadership role in developing the concept of nitrogen saturation in high elevation ecosystems.

Name: Bowman, William

Worked for more than 160 Hours: Yes

Contribution to Project:

Dr. William Bowman is Director of the Mountain Research Station. His research has focused on the interaction between plants and their resources, broadly defined from plant adaptations to low resource availability to how plants influence soils and subsequently ecosystem function. Over the past decade his work has concentrated on the interaction between alpine plants and nutrients, examining the response of plants to low nutrient supply, as well as the influence that plants have on their nutrient environment. He, along with Dr. Suding, is the major contributor to the plant community dynamics program at NWT.

Name: Caine, Nel

Worked for more than 160 Hours: Yes

Contribution to Project:

Nel Caine is a former lead PI on the NWT LTER project. His involvement provides continuity in leadership as well as a historical

perspective for the NWT LTER program. He is a hydrologist, glaciologist, and geomorphologist who is now looking at responses of these systems to changes in climate over the last several decades. While now retired as a CU faculty member, he remains active in his summaries of surface morphological phenomena at Nitwot Ridge.

Name: Diggle, Pamela

Worked for more than 160 Hours: Yes

Contribution to Project:

Dr. Diggle sponsored important work on the effects of the alpine environment on plant developmental morphology. Her student, Tara Forbis, has authored or coauthored work related to Dr. Diggle's most recent collaborations. Dr. Diggle terminated her alpine studies in 2002.

Name: Elias, Scott

Worked for more than 160 Hours: Yes

Contribution to Project:

After several decades of work that focused on the paleoecology and development of the Alpine, Dr. Elias moved to England in 2001. His NWT legacy is evident in our bibliography.

Name: Monson, Russell

Worked for more than 160 Hours: Yes

Contribution to Project:

Russ Monson is in charge of the (now independent) Ameriflux tower system in the NWT subalpine. He and his students have been supported by LTER infrastructure, including logistical support for the vegetation-atmosphere studies. A number of comparative studies (alpine-subalpine and tree line - subalpine) are ongoing and represent partnerships between the LTER and additional NSF or DOE tower-related projects.

Name: Sanford, Robert

Worked for more than 160 Hours: Yes

Contribution to Project:

Dr. Sanford is a professor in Biology at the University of Denver and has been involved in plant-soil interaction studies in the tundra and at tree line. He is also director of the Mt Evans Research Program and has used that facility to provide 'replication' for several high-altitude studies.

Name: Schmidt, Steven

Worked for more than 160 Hours: Yes

Contribution to Project:

Steve Schmidt is a professor of EEB and has mentored a large number of studies on soil microbiology and microbial diversity of high elevation ecosystems. In addition, he has become the PI of a Microbial Observatory effort developed from Niwot Ridge LTER efforts.

Name: Sievering, Herman

Worked for more than 160 Hours: Yes

Contribution to Project:

Dr. Sievering is a Professor in Atmospheric Chemistry at CU-Denver and INSTAAR Affiliate. He has studied the nitrogen chemistry of the alpine atmosphere and he continues to maintain a program investigating the influence of canopy N uptake on chlorophyll fluorescence and gas exchange.

Name: Walker, Donald

Worked for more than 160 Hours: Yes

Contribution to Project:

Dr. Walker worked on plant community dynamics of the alpine tundra through 1999, at which time he moved to the University of Alaska.

Name: McKnight, Diane

Worked for more than 160 Hours: Yes

Contribution to Project:

Dr. McKnight's research focuses on biogeochemistry, organic carbon dynamics, limnology, aquatic ecology, reactive transport of metals and organic material in mountain streams and rivers. She is the NWT LTER lead on K-12 outreach activities. Her outreach

activities included publishing 'My Water Comes from the Mountains', a textbook for 4th and 5th graders developed from her K-12 program.

Name: Losleben, Mark

Worked for more than 160 Hours: Yes

Contribution to Project:

Mark Losleben was climatologist at the NWT LTER through 2006, a position he has held continuously since 1982. His position was changed from 50% LTER and 50% MRS to 100% LTER, with the 50% that was previously supported by the MRS now supported by INSTAAR. That position has continued beyond Mark's move to Arizona at the end of 2006.

Name: Bourgeron, Patrick

Worked for more than 160 Hours: Yes

Contribution to Project:

Dr. Bourgeron is a research scientist at INSTAAR and has been involved with the program since 1998. He co-chairs the US portion of ILTER activities. His research focuses on ecotone/Treeline studies.

Name: Suding, Katie

Worked for more than 160 Hours: Yes

Contribution to Project:

During the 1998-2004 interval, Dr. Suding was a postdoctoral researcher in charge of plant community analyses. She now is a faculty member at UC-Irvine and remains an active component of NWT plant community dynamics research.

Post-doc

Name: Suding, Katie

Worked for more than 160 Hours: Yes

Contribution to Project:

Graduate Student

Name: Carrasco, Jon

Worked for more than 160 Hours: Yes

Contribution to Project:

Name: Costello, Elizabeth

Worked for more than 160 Hours: Yes

Contribution to Project:

Name: Damm, Mary

Worked for more than 160 Hours: Yes

Contribution to Project:

Name: Dykstra, Gamlyn

Worked for more than 160 Hours: Yes

Contribution to Project:

Name: Erickson, Tyler

Worked for more than 160 Hours: Yes

Contribution to Project:

Name: Forbis, Tara

Worked for more than 160 Hours: Yes

Contribution to Project:

Name: Gardner, Eileen
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Gartner, John
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Hamann, Hillary
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Hood, Eran
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Larson, Julia
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Ley, Ruth
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Liptzin, Dan
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Liu, Fenjing
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Manthorne, David
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Meloche, Chris
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Meyer, Allen
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Miller, Amy
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Mujica-Crapanzano, Laura

Worked for more than 160 Hours: Yes

Contribution to Project:

Name: Nemergut, Diana

Worked for more than 160 Hours: Yes

Contribution to Project:

Name: Schadt, Christopher

Worked for more than 160 Hours: Yes

Contribution to Project:

Name: Sherriff, Rosemary

Worked for more than 160 Hours: Yes

Contribution to Project:

Name: Torrizo, Andreas

Worked for more than 160 Hours: Yes

Contribution to Project:

Name: Tomaszewski, Tim

Worked for more than 160 Hours: Yes

Contribution to Project:

Name: Turner, Paul

Worked for more than 160 Hours: Yes

Contribution to Project:

Name: Raby, Kim

Worked for more than 160 Hours: Yes

Contribution to Project:

Name: Hanne, Ingrid

Worked for more than 160 Hours: Yes

Contribution to Project:

Name: Cordalis, Dan

Worked for more than 160 Hours: Yes

Contribution to Project:

Name: Nanus, Leora

Worked for more than 160 Hours: Yes

Contribution to Project:

Name: Anderson, Craig

Worked for more than 160 Hours: Yes

Contribution to Project:

Name: Meier, Courtney

Worked for more than 160 Hours: Yes

Contribution to Project:

Name: Miller, Matt

Worked for more than 160 Hours: Yes

Contribution to Project:

Name: Abood, Paul

Worked for more than 160 Hours: Yes

Contribution to Project:

Undergraduate Student

Technician, Programmer

Name: Ackerman, Todd

Worked for more than 160 Hours: Yes

Contribution to Project:

Data Manager/GIS Coordinator

Name: O'Reilly, Andrew

Worked for more than 160 Hours: Yes

Contribution to Project:

Field Technician

Name: Seibold, Christine

Worked for more than 160 Hours: Yes

Contribution to Project:

Name: Carbone, Mariah

Worked for more than 160 Hours: Yes

Contribution to Project:

Name: Chowansky, Kurt

Worked for more than 160 Hours: Yes

Contribution to Project:

Field Technician

Other Participant

Name: Litaor, M.

Worked for more than 160 Hours: Yes

Contribution to Project:

International scholar here on sabbatical. Supported by his home institution supplemented with LTER support

Research Experience for Undergraduates

Name: Renaud, Carrie

Worked for more than 160 Hours: Yes

Contribution to Project:

Years of schooling completed: Junior

Home Institution: Other than Research Site

Home Institution if Other: University of Denver
Home Institution Highest Degree Granted(in fields supported by NSF): Doctoral Degree
Fiscal year(s) REU Participant supported: 2001
REU Funding: REU supplement

Name: Scott, Alexis

Worked for more than 160 Hours: Yes

Contribution to Project:

Years of schooling completed: Junior
Home Institution: Same as Research Site
Home Institution if Other:
Home Institution Highest Degree Granted(in fields supported by NSF): Doctoral Degree
Fiscal year(s) REU Participant supported: 2000
REU Funding: REU supplement

Name: Polling, Elizabeth

Worked for more than 160 Hours: Yes

Contribution to Project:

Years of schooling completed: Junior
Home Institution: Other than Research Site
Home Institution if Other: Vanderbilt
Home Institution Highest Degree Granted(in fields supported by NSF): Doctoral Degree
Fiscal year(s) REU Participant supported: 2000
REU Funding: REU supplement

Name: Froeschner, Holly

Worked for more than 160 Hours: Yes

Contribution to Project:

Years of schooling completed: Junior
Home Institution: Same as Research Site
Home Institution if Other:
Home Institution Highest Degree Granted(in fields supported by NSF): Doctoral Degree
Fiscal year(s) REU Participant supported: 1998
REU Funding: REU supplement

Name: Baer, Rory

Worked for more than 160 Hours: Yes

Contribution to Project:

Years of schooling completed: Junior
Home Institution: Same as Research Site
Home Institution if Other:
Home Institution Highest Degree Granted(in fields supported by NSF): Doctoral Degree
Fiscal year(s) REU Participant supported: 1998
REU Funding: REU supplement

Name: Clark, Adrian

Worked for more than 160 Hours: Yes

Contribution to Project:

Years of schooling completed: Freshman
Home Institution: Same as Research Site
Home Institution if Other:
Home Institution Highest Degree Granted(in fields supported by NSF): Doctoral Degree
Fiscal year(s) REU Participant supported: 2001
REU Funding: REU supplement

Name: Janik, Caroline

Worked for more than 160 Hours: Yes

Contribution to Project:

Years of schooling completed: Junior
Home Institution: Other than Research Site
Home Institution if Other: Western Colorado
Home Institution Highest Degree Granted(in fields supported by NSF): Bachelor's Degree
Fiscal year(s) REU Participant supported: 1999
REU Funding: REU supplement

Name: Linsenbart, Amy

Worked for more than 160 Hours: Yes

Contribution to Project:

Years of schooling completed: Junior
Home Institution: Other than Research Site
Home Institution if Other: Western Missouri
Home Institution Highest Degree Granted(in fields supported by NSF): Master's Degree
Fiscal year(s) REU Participant supported: 1999
REU Funding: REU supplement

Name: Major, Sheridan

Worked for more than 160 Hours: Yes

Contribution to Project:

Years of schooling completed: Sophomore
Home Institution: Other than Research Site
Home Institution if Other: Clark University
Home Institution Highest Degree Granted(in fields supported by NSF): Bachelor's Degree
Fiscal year(s) REU Participant supported: 1999
REU Funding: REU supplement

Name: Yablonski, Adam

Worked for more than 160 Hours: Yes

Contribution to Project:

Years of schooling completed: Sophomore
Home Institution: Other than Research Site
Home Institution if Other: Washington and Lee
Home Institution Highest Degree Granted(in fields supported by NSF): Bachelor's Degree
Fiscal year(s) REU Participant supported: 2000
REU Funding: REU supplement

Name: Tucker, Colin

Worked for more than 160 Hours: Yes

Contribution to Project:**Years of schooling completed:** Junior**Home Institution:** Same as Research Site**Home Institution if Other:****Home Institution Highest Degree Granted(in fields supported by NSF):** Doctoral Degree**Fiscal year(s) REU Participant supported:** 2002**REU Funding:** REU supplement**Name:** Ordoyne, Calley**Worked for more than 160 Hours:** Yes**Contribution to Project:****Years of schooling completed:** Junior**Home Institution:** Other than Research Site**Home Institution if Other:** Mt. Holyoke**Home Institution Highest Degree Granted(in fields supported by NSF):** Associate's Degree**Fiscal year(s) REU Participant supported:** 2002**REU Funding:** REU supplement**Name:** Albright, Meredith**Worked for more than 160 Hours:** Yes**Contribution to Project:****Years of schooling completed:** Junior**Home Institution:** Other than Research Site**Home Institution if Other:** Colorado College**Home Institution Highest Degree Granted(in fields supported by NSF):** Doctoral Degree**Fiscal year(s) REU Participant supported:** 2002**REU Funding:** REU supplement**Name:** Thacher, Chessie**Worked for more than 160 Hours:** Yes**Contribution to Project:**

Chessie Thatcher, a junior at Colorado College, worked with Tim Seastedt on the effects of snowpack change on plant species richness and diversity. The student is expected to continue this project as a senior thesis.

Years of schooling completed: Junior**Home Institution:** Other than Research Site**Home Institution if Other:** Colorado College**Home Institution Highest Degree Granted(in fields supported by NSF):** Doctoral Degree**Fiscal year(s) REU Participant supported:** 2002**REU Funding:** REU supplement**Name:** Vergera, Sintana**Worked for more than 160 Hours:** Yes**Contribution to Project:****Years of schooling completed:** Junior**Home Institution:** Other than Research Site**Home Institution if Other:** Cornell**Home Institution Highest Degree Granted(in fields supported by NSF):** Doctoral Degree**Fiscal year(s) REU Participant supported:** 2002

REU Funding: REU supplement

Name: Portmess, Kim

Worked for more than 160 Hours: Yes

Contribution to Project:

Kim Portmess studied the effect of nutrients (N and P) and benthic grazers on the growth of benthic algae in Green Lake 4. She worked in collaboration with another REU student and two graduate students, and her results will be integrated with those from other experiments conducted during the summer.

Years of schooling completed: Junior

Home Institution: Other than Research Site

Home Institution if Other: Cornell

Home Institution Highest Degree Granted(in fields supported by NSF): Doctoral Degree

Fiscal year(s) REU Participant supported: 2002

REU Funding: REU supplement

Name: MacDougall, Sarah

Worked for more than 160 Hours: Yes

Contribution to Project:

Years of schooling completed: Junior

Home Institution: Other than Research Site

Home Institution if Other: University of New Hampshire

Home Institution Highest Degree Granted(in fields supported by NSF): Doctoral Degree

Fiscal year(s) REU Participant supported: 2003

REU Funding: REU supplement

Name: Heigle, Dawn

Worked for more than 160 Hours: Yes

Contribution to Project:

Years of schooling completed: Junior

Home Institution: Same as Research Site

Home Institution if Other:

Home Institution Highest Degree Granted(in fields supported by NSF): Doctoral Degree

Fiscal year(s) REU Participant supported: 2003

REU Funding: REU supplement

Organizational Partners

National Park Service

During the 1998-2004 interval, NWT LTER investigators collaborated with scientists and managers from a variety of NPS organizations, but primarily those working at Rocky Mountain National Park and Glacier National Park. NWT LTER personnel have assisted in the development of NPS monitoring and assessment programs, which, in turn, should provide validation data for NWT studies and experiments. Direct comparisons of species richness patterns of NWT were compared with those of RMNP (ROA project by Patricia Weigant). RMNP has and continues to conduct N deposition studies in conjunction with NWT investigators, and Mark Williams continues to take a leadership role in developing credible N deposition monitoring at high elevation sites for the NADP network, including many national parks.

University of Denver

Dr. Robert (Buck) Sanford is a senior investigator on the NWT LTER. His activities were partially compensated by NWT LTER support, but Dr. Sanford's analytical laboratory facilities at DU provided us with substantial data that otherwise would have cost much, much more or would simply not be available. His work on C:N:P relationships in plants and soils of the alpine and subalpine region are ongoing.

Other Collaborators or Contacts

Dr. Rick Boyce, Northern Kentucky University, worked with Dr. Herman Sievering on N uptake in the subalpine forest during 2002-2004. Preliminary results from their studies indicate that canopy uptake of N provides ~ 15% of N requirements for this forest.

Dr. Barry Rosenbaum, Univ. Puget Sound, conducted small mammal surveys at NWT in 2003 and 2004. In 2004 he was assisted by Dr. Norman Clippinger and two REU students supported by a non-LTER source. These are the first quantitative data obtained on small mammals in over a decade, and results are in the process of being evaluated with respect to a substantive historical database to evaluate what, if any changes in species composition or abundances have occurred during this interval.

Dr. Iggy Litaor of Tel-Hai University, Israel, rejoined the NWT LTER group as a sabbatical participant in 2004. Dr. Litaor was one of NWT LTER's most prolific scientists during the late 1980s, with expertise in soils, especially soil phosphorus, and geostatistics. He worked with Drs. Townsend, Bowman, Williams and Seastedt on landscape patterns of phosphorus availability to plants. These data are critically important as our biogeochemical focus moves from one that emphasizes carbon and nitrogen to one that emphasizes carbon, nitrogen and phosphorus amounts, ratios, and interactions.

Dr Patricia Weigant (RUI supplement to LTER 2000) provided a comparison of species richness at NWT versus a richer soil site at Rocky Mountain National Park. These data should prove particularly useful for regional analysis and developing N deposition studies with the National Park.

Activities and Findings

Research and Education Activities:

Major Research and Education Activities

The importance of alpine tundra to regional biogeochemical and atmospheric processes is far greater than that indicated by its small area. Niwot Ridge is the only multidisciplinary, long-term alpine tundra study site on the continent. As such, our site is an essential benchmark for regional, national, and global networks that measure biological changes and feedbacks and experimentally determine mechanisms for these relationships. The research conducted during this period was a continuation of a theme: to understand the influence of increased snowpack and atmospheric N deposition on ecosystem processes and landscape patterns, with increased emphasis on the biotic feedbacks and ecosystem responses to these changes. Our goals were to 1) provide a hierarchical perspective to the ecology of high elevational ecosystems, 2) explore the coupling between the alpine and the subalpine, and 3) document the biotic responses to anthropogenic influences occurring within each ecosystem and compare these responses between ecosystem types. A new dimension for the 1998-2004 LTER program, and one that is ongoing, involved the explicit analysis of the subalpine interface, an area identified as being most likely to be undergoing anthropogenically-driven changes.

Our education activities were seamlessly merged with our research program via postdoctoral, graduate, undergraduate and K-12 studies. We produced a total of 30 theses and dissertations during this interval. We mentored 12 undergraduate researchers as part of the LTER program, and another dozen or so supported by the field station's site REU program. Diane McKnight operated a K-12 outreach activity that resulted in the production of an elementary school textbook, an effort that received mention in a report sent by NSF to congress. By standard metrics, the combined research and education activities resulting from the NWT LTER effort and from projects that emerged from this LTER effort are, we believe, impressive.

Major 'spin-offs' of the LTER program include the Schmidt soil microbiology biodiversity effort, and the Monson vegetation-atmosphere interaction projects. Those projects, although now funded through other programs, have relied and continue to rely heavily on NWT LTER programs, data, and infrastructure for their success.

Findings:

A review of our recent publications demonstrates substantial advancement of knowledge in all areas of high elevation ecology and high elevation biogeochemistry. The total number of peer-reviewed publications, books and book chapters, and graduate dissertations exceeded 200 contributions for the 1998-2004 interval. All of our senior scientists have or are in the process of contributing findings published in national and international journals. Our synthesis activity, first summarized by the edited 2001 Springer-Verlag volume on the NWT LTER program, has continued with a 2004 BioScience article that provided a conceptual model and status report of alpine-subalpine interactions.

Training and Development:

The NWT LTER, located above a field station with a long history of training in field-oriented physical and biological sciences, has provided a

unique high-elevation, outdoor laboratory for K-12, undergraduates, graduates, and visiting researchers. Skill training includes age-appropriate or background-appropriate training in a variety of physical, climatological, and chemical (including isotopic) procedures, biological diversity and ecological analytical procedures.

Outreach Activities:

The 1998-2004 LTER program initiated the 'virtual field trip' to the tundra, which has counted 14,000+ visitors since its construction. The LTER program has also enhanced and maintained the real-time tundra camera, which has produced millions of images and comments from numerous users across the globe. Locally, the site has served as a focus for educational activities in mountain hydrology, climatology, and atmospheric chemistry, the latter focusing primarily N deposition impacts.

Because of its location just south of Rocky Mountain National Park, the information obtained at Niwot is being used to interpret changes occurring at the national park. Hence, when the Park has a perceived problem, reporters now look to NWT for data and interpretation of the problem.

As previously discussed, the NWT K-12 program, which includes a traditional summer visitation program for elementary students and for the training of elementary school teachers, has been both a local and national success and model for similar activities at other LTER sites.

Journal Publications

Gross, K.L., M.R. Willig, L. Gough, R. Inouye, and S.B. Cox., "Patterns of species density and productivity at different spatial scales in herbaceous plant communities.", *Oikos*, p. 417, vol. 98, (2000). Published

Baron, J.S. and N. Caine., "Temporal coherence of two alpine lake basins of the Colorado Front Range, U.S.A.", *Freshwater Biology*, p. 463, vol. 43, (2000). Published

Conley, A.H., E.A. Holland, T.R. Seastedt and W.J. Parton, "Simulation of carbon and nitrogen cycling in an alpine tundra", *Arctic, Antarctic, and Alpine Research*, p. 147, vol. 32, (2000). Published

Lipson, D.A., S.K. Schmidt and R.K. Monson, "Carbon availability and temperature control the post-snowmelt decline in alpine soil microbial biomass", *Soil Biology and Biochemistry*, p. 441, vol. 32, (2000). Published

Losleben, M.V., N. Pepin, S. Pedrick, "Relationships of precipitation chemistry, atmospheric circulation, and elevation at two sites on the Colorado Front Range", *Atmospheric Environment*, p. 1723, vol. 34, (2000). Published

Addington, R.N. and T.R. Seastedt, "Activity of soil microarthropods beneath snowpack in alpine tundra and subalpine forest", *Pedobiologia*, p. 47, vol. 43, (1999). Published

Bowman, W.D., A. Keller, and M. Nelson, "Altitudinal variation in leaf gas exchange, nitrogen and phosphorus concentrations and leaf mass per area in populations of *Frasera speciosa*", *Arctic, Antarctic, and Alpine Research*, p. 191, vol. 31, (1999). Published

Brooks, P.D., M.W. Williams, "Snowpack controls on nitrogen cycling and export in seasonally snow-covered catchments", *Hydrologic Processes*, p. 2177, vol. 13, (1999). Published

Chase, T.N., R.A. Pielke, T.G.F. Kittel, J.S. Baron, and T.J. Stohlgren, "Potential impacts on Colorado Rocky Mountain weather and climate due to land use changes on the adjacent Great Plains", *Journal of Geophysical Research*, p. 16673, vol. 104, (1999). Published

Greenland, D., "ENSO-related phenomena at long-term ecological research sites", *Physical Geography*, p. 491, vol. 20, (1999). Published

Hood, E., M. W. Williams, and D. Cline, "Sublimation from a seasonal snowpack at a continental, mid-latitude alpine site.", *Hydrologic Processes*, p. 1781, vol. 13, (1999). Published

- Lipson, D.A., T.K. Raab, S.K. Schmidt, and R.K. Monson, "Variation in competitive abilities of plants and microbes for specific aminods", *Biology and Fertility of Soils*, p. 257, vol. 29, (1999). Published
- Lipson, D.A., C.W. Schadt, S.K. Schmidt, and R.K. Monson, "Ectomycorrhizal transfer of amino acid-nitrogen to the alpine sedge *Kobresia myosuroides*", *New Phytologist*, p. 163, vol. 142, (1999). Published
- Lipson, D.A., S.K. Schmidt, and R.K. Monson, "Links between microbial population dynamics and nitrogen availability in an alpine ecosystem", *Ecology*, p. 1623, vol. 80, (1999). Published
- Parker, E.R., and R.L. Sanford, "The effects of mobile tree islands on soil phosphorus concentrations and distribution in an alpine tundra ecosystem", *Arctic, Antarctic, and Alpine Research*, p. 16, vol. 31, (1999). Published
- Raab, T.K., D.A. Lipson and R.K. Monson, "Soil amino acid utilization among species of the Cyperaceae: Plant and soil processes", *Ecology*, p. 2408, vol. 80, (1999). Published
- Reich, P.B., D.S. Ellsworth, M.B. Walters, J.M. Vose, C. Gresham, J.C. Volin, and W.D. Bowman, "Generality of leaf traits: a test across six biomes", *Ecology*, p. 1955, vol. 80, (1999). Published
- Soranno, P.A., K.E. Webster, J.L. Riera, T.K. Kratz, J.S. Baron, P.A. Bukaveckas, G.W. Kling, D.S. White, N. Caine, R.C. Lathrop, and P.R. Leavitt, "Spatial variation among lakes within landscapes: Ecological organization along lake chains", *Ecosystems*, p. 395, vol. 2, (1999). Published
- Toetz, D., "Multiple limiting nutrients in a subalpine stream, Colorado Front Range", *Journal of Freshwater Ecology*, p. 349, vol. 14, (1999). Published
- Welker, J. M., Brown, K. A., and Fahnestock, J. T., "CO₂ flux in arctic and alpine dry tundra: comparative field responses under ambient and experimentally warmed conditions", *Arctic, Antarctic and Alpine Research*, p. 308, vol. 31, (1999). Published
- West, A.E., P.D. Brooks, M.C. Fisk, L.K. Smith, E.A. Holland, C.H. Jaeger III, S. Babcock, R. Lai, and S.K. Schmidt, "Landscape patterns of CH₄ fluxes in an alpine tundra ecosystem", *Biogeochemistry*, p. 243, vol. 45, (1999). Published
- Wickland, K.P., R.G. Striegl, S.K. Schimdt and M.A. Mast, "Methane flux in subalpine wetland and unsaturated soils in the southern Rocky Mountains", *Global Biogeochemical Cycles*, p. 101, vol. 13, (1999). Published
- Williams, M.W., D. Cline, M. Hartman, T. Bardsley, "Data for snowmelt model development, calibration, and verification at an alpine site, Colorado Front Range", *Water Resources Research*, p. 3205, vol. 35, (1999). Published
- Williams, M.W., R. Sommerfeld, S. Massman, and M. Ridders, "Correlation lengths of meltwater flow through ripe snowpacks, Colorado Front Range, USA", *Hydrologic Processes*, p. 1807, vol. 13, (1999). Published
- Walker, M.D., D.A. Walker, J.M. Welker, A.M. Arft, T. Bardsley, P.D. Brooks, J.T. Fahnestock, M.H. Jones, M. Losleben, A.N. Parsons, T.R. Seastedt, and P.L. Turner, "Long-term experimental manipulation of winter snow regime and summer temperature in arctic and alpine tundra.", *Hydrological Processes*, p. 2315, vol. 13, (1999). Published
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Web/Internet Site**URL(s):**

<http://culter.colorado.edu/>

Description:

This is our core LTER website

Other Specific ProductsContributions**Contributions within Discipline:**

The 1998-2004 NWT LTER made significant contributions in a) high elevation climatology, b) high elevation hydrology and biogeochemistry, c) high elevation microbiology and microbial ecology, and d) high elevation community ecology. Our group also made significant contributions in the area of climate change and atmospheric change impacts on plant-soil interactions.

We continued our long-term climate monitoring at Niwot Ridge, which began in the 1950s with the installation of meteorological stations along an elevational gradient. The NWT LTER operates the longest-duration, high-elevation meteorological program in the United States. Temporal analysis of four decades (1951-1996) of instrumented climate records show (1) decreasing autumn temperatures ($-0.043^{\circ}\text{C}/\text{yr}$) but no significant annual cooling; (2) a decrease in incident summer solar radiation ($-1.04 \text{ W}/\text{m}^2/\text{yr}$) between 1965 and 1996; and (3) an annual precipitation increase of $11.0 \text{ mm}/\text{yr}$ (Greenland and Losleben, 2001). Additional research has found: (1) an extreme cold temperature event from 1981-86 (Kittel et al., 2002); (2) different lapse rate changes at different elevations between 2,200 and 3,749 m (Pepin, 2000); (3) elevationally dependent differences in precipitation chemistry (Losleben and Pepin, 2000); and (4) decoupled climate conditions between upper and lower troposphere (Kittel et al., 2002; Williams et al., 1996a). The increase in annual precipitation and decrease in summer shortwave radiation are consistent with most model scenarios using doubled atmospheric CO_2 of increased annual precipitation and increased water vapor, but the lack of an annual temperature increase on Niwot Ridge is inconsistent with model predictions of increasing air temperature.

We have continued our long-term experimental program on climate interactions with ecosystem processes. A snowfence 60 m long and 2.8 m high was erected in 1993 to study long-term effects of changing winter snow conditions on the integrated physical-biological processes of alpine tundra. The anoxic conditions produced by enhanced snow increased denitrification rates by an order of magnitude (Brooks and Williams, 1999). Initial findings suggested that decomposition rates increased because of enhanced snow (Williams et al., 1998), and this effort was subsequently expanded with litterbag studies (Bryant et al., 1998). Re-inventories of plant species richness and species composition have been obtained (e.g., Seastedt and Vaccaro, 2001, and the experiment is ongoing).

The NWT LTER program continues its participation in the National Atmospheric Deposition Program (NADP), which began in the early 1980s, maintaining the highest-elevation site in the US at 3,520 m on Niwot Ridge, and also the subalpine Sugarloaf site at 2,524 m. Annual deposition of inorganic N in wetfall at the Niwot Ridge site showed a significant increase of $0.3 \text{ kg}/\text{ha}/\text{yr}$ for the 1984-1996 interval (Williams and Tonnessen, 2000). A sophisticated analysis of atmospheric deposition of pollutants throughout the entire Rocky Mountain Region from Canada to Mexico shows that nitrate and sulfate deposition increase from north to south, with hot spots of deposition in the Colorado Front Range (Nanus et al., 2003). Burns (2003a) shows that the increase of inorganic N in wetfall in the Front Range is partly driven by increases in the metropolitan population east of the Front Range. We have only elevational transect of NADP sites in the US. We are also working directly with NADP to test precipitation collectors that might improve measurements in snow-dominated regions.

We have continued our long-term experimental additions of nitrogen and phosphorus in terrestrial environments. Experimental additions of N have caused changes in species composition and reductions in species richness (Seastedt and Vaccaro, 2001). Such shifts in species composition may lead to increased leaching of nitrate from soils to aquatic systems because the favored species often has greater rates of net nitrification (Bowman and Steltzer, 1998; Steltzer and Bowman, 1998). Additions of labeled N in the form of ammonium nitrate to snow showed that N uptake during snowmelt constituted over 12% of season-long uptake for a graminoid species, and averaged 7.4% for perennial forbs (Bilbrough et al., 2000). Nutrient addition studies generally support the hypothesis that long-term increases in atmospheric N deposition will likely shift terrestrial plant productivity in tundra ecosystems from N-limitation to P-limitation (Burns, 2003b). However, it remains unclear how changes in snow amount, duration, and timing interact with increases in N deposition to structure plant communities. Studies are ongoing, with Suding et al. 2005) providing a recent synthesis in Proceedings of the National Academy of Science.

Our finding that microbial communities are active under snow has changed the estimated global rates of biogeochemical processes beneath

seasonal snow packs. These results have prompted a re-evaluation of whether some seasonally snow-covered environments are sinks of atmospheric CO₂ (Fahnestock et al., 1999). In addition, under-snow microbial metabolism is an important biogeochemical N sink (Lipson et al., 1999). Unexpectedly, our results show that tundra soil microbial biomass reaches its annual peak under snow and not during the warmer summer months, and that fungi account for most of the biomass. Phylogenetic analysis of tundra soil fungi using microbiological and molecular techniques revealed a high diversity of fungi and three novel clades that constitute major new groups of fungi, divergent at the subphylum or class level, as published by Schadt et al., (2003) in Science.

Our 'discipline' here includes those physical and biological sciences required to understand the biogeochemistry of high elevation ecosystems. Understanding the short- and long-term responses of these systems to climatic and anthropogenic drivers requires a hierarchical perspective. First, we needed to carefully document the short- and long-term patterns of climatic and atmospheric drivers (Greenland, Losleben, Sievering). We knew that natural selection has produced a flora and fauna exhibiting a variety of traits that influence their respective responses to environmental change (Bowman, Diggle, Schmidt), and that these characteristics, in turn, can be used to reconstruct past environmental conditions (Elias). We know that, over a decadal to multiple century scale, the feedbacks between the biota and soils generated a landscape gradient in resources that also affect biotic responses (Bowman, Sanford, Seastedt, Townsend), and that these feedbacks are expressed in terms of canopy-atmosphere exchanges (Losleben, Monson, Sievering, Townsend, Wessman). The extent to which ecosystem structure influences both of these processes, as well as the biodiversity within this structure, requires a landscape perspective and analysis (Bourgeron, Walker). The integrated catchment responses, as well as aquatic-system processing of materials and energy, are the sum effects of abiotic and biotic processes occurring across the alpine and subalpine landscape (Caine, McKnight, Williams). We acknowledge the need to present this information in forms that can be used and understood by current and future scientists (Hartman, Bittenfield). Modeling is and will continue to be an essential exercise to evaluate the extent to which we think we understand the system, as well as an exercise to understand 'what's important' from a variety of spatial and temporal scales (Bourgeron, Holland, Seastedt, Townsend, Wessman, Williams). These interactive research and modeling efforts will then be combined with an extensive synoptic approach (e.g. the Western Lake Surveys, Regional vegetation inventories, etc.) to transfer our site-based knowledge to a larger regional and global context.

The 'swan song' for the 1998-2004 LTER involved our attempt to integrate all components into a description of high elevation ecosystems. The result, the Landscape Continuum Concept (Seastedt et al. 2004), now serves to direct a substantial portion of ongoing LTER research.

Contributions to Other Disciplines:

For the 1998-2004 interval:

Our tundra cam (<http://tundracam.colorado.edu>) remains one of the most popular web sites at CU.

Our field site has always suffered from the lack of year-around facilities. The first year-around lodge was completed at the Mountain Research Station in 2004. This building was the result of a consortium of NSF, Colorado, and private funding. This lodge is to be used by LTER scientists as needed, but its main function is to provide teaching, education, and outreach functions beyond those provided by our LTER effort.

Contributions to Human Resource Development:

As indicated elsewhere in our report, the NWT LTER program makes significant contributions to human resource development in science, engineering and technology. Our program contributes to the training of undergraduates directly (REU students and others) indirectly (through the use of NWT LTER data in classes and reference books) and through site visits by classes. We have and continue to train numerous graduate students, and provide valuable experience in interdisciplinary research and the value of long-term datasets. The Niwot Ridge Schoolyard LTER Program, provides formal and informal research experiences and science educational experiences to public groups, elementary students and K-12 teachers.

Contributions to Resources for Research and Education:

Niwot Ridge LTER site continued its leadership in providing data accessibility and data transfer. The web site has undergone several transformations since 1998.

We have initiated wireless data transmission from remote sites on Niwot Ridge and the Green Lakes Valley. These can now be imported into a relational database where a web interface allows users to query specific dates and variables more efficiently. These are now connected to a wireless transmission system to our central facility at the University in Boulder. Additional real-time weather data are now available on our web site.

Contributions Beyond Science and Engineering:

Niwot LTER researchers are active participants in environmental education issues for the Colorado Front Range. In particular, McKnight has a leadership role in environmental education, Williams and Bowman play leadership roles for nitrogen deposition issues, and Seastedt is a spokesperson for understanding ecosystem management and species change. All have been interviewed for local and regional (Denver) papers, and most have been on local or regional public radio programs. These activities have collectively contributed towards educating policy makers and stakeholders about the ecosystem services provided by high-elevation ecosystems. We feel our contributions regarding water quality and quantity issues as well as invasive species management practices have been well received.

Categories for which nothing is reported:

Any Product