Bob Baxter **Oral Presentation**

PHENOLOGICAL MODELLING - AN OPPORTUNITY FOR COLLABORATION WITH ITEX. Bob Baxter and Jon Bennie. University of Durham, UK.

The presentation will outline ongoing research within a UK Centre of Excellence in Earth Observation related to Arctic environments and the potential for future collaboration in a number of areas covered by this research, notably in phenological modelling and aspects of scaling-up of point and field-scale measurements of gas exchange across heterogeneous tundra landscapes.

M. Syndonia Bret-Harte **Oral Presentation**

SPECIES INTERACTIONS AND ECOSYSTEM RESPONSE TO PERTURBATION IN ARCTIC TUNDRA. M. Syndonia Bret-Harte. Institute of Arctic Biology, University of Alaska, Fairbanks, USA.

Species differ in traits that affect the cycling of carbon and nitrogen, but how much species affect ecosystem functioning and the relationship between diversity and ecosystem response to perturbation are still largely unknown. We removed single species and groups of species from tussock tundra, in the presence and absence of fertilization, starting in 1997. Our objective was to understand to what extent species can substitute for each other in ecosystem functioning and response to perturbation. We measured biomass and plant and soil nutrient content in a destructive harvest after 6 years of treatment. We also measured ecosystem light response curves after 7 years. We found that compensatory growth had occurred in response to most removal treatments, despite removals up to nearly the amount found under control conditions. Total community biomass was not greatly increased by fertilization, but some plant species benefited at the expense of others, and species richness declined. Vascular plant production increased under fertilization, and there was a large accumulation of litter, particularly under the combination of neighbor removal and fertilization, suggesting that C and N cycling was faster. Species composition and biomass affected ecosystem capacity for CO_2 uptake at high light intensity, but not the shape of the light response curves. These data suggest that 1) species interactions may be important under changing environmental conditions, and 2) C and N cycling rates will likely vary with community composition, especially over the longer-term.

Elisabeth J. Cooper **Oral Presentation**

GOOSE GRAZING AFFECTS ARCTIC PLANT PRODUCTIVITY IN A CHANGING CLIMATE. Elisabeth J. Cooper & Ingibjörg Jónsdóttir. The University Centre on Svalbard. Norwary.

Migratory geese breed in Svalbard in summer and return to Western Europe for the winter, feeding on wetlands and agricultural fields. Recent changes in climate, land use and the implementation of protective measures dramatically improved the birds' ability to survive the winter, increasing population sizes and thus the potential grazing impact on Svalbard. An EU funded project **FRAGILE**: Fragility of Arctic Goose habitat: Impacts of Land use, conservation and Elevated temperatures, has been investigating this impact on tundra ecosystems. We carried out a factorial experiment of grazing (control, normal and high grazing pressure using captive wild barnacle geese) and temperature manipulation (using OTCs) in a mesic and wet habitat in Adventdalen, Svalbard (78°N, 16°E) for three years. Here we present some of the main findings.

Open top chambers increased temperatures at surface level in both habitats and below ground in the mesic habitat; temperature increases were highest in the mesic habitat. OTCs increased the size of plants of *Alopecurus borealis* in the mesic habitat but reduced the size of *Dupontia fischeri* in the wet habitat. Geese are selective grazers- they prefer the wet habitats and start grazing *Equisetum* then *Dupontia* then switch to mosses. Trampling by the geese caused a reduction in the depth of moss in the wet habitat. We investigated the ability of tundra forage grasses to compensate for grazing, the role of temperature and nutrients, and the interactions between grasses and mosses. We also examined the effect of specific foraging on community composition.

Greg Henry **Oral Presentation**

ITEX RESEARCH IN THE CANADIAN HIGH ARCTIC: ALEXANDRA FIORD, ELLESMERE ISLAND. Greg H.R. Henry. University of British Columbia, Canada

Warming experiments were established at Alexandra Fiord in 1992 in five major tundra plant communities, where OTCs have remained in place for the past 14 years. Phenological and growth responses of individual species have been measured in the plots each year, although with decreasing intensity in the past few years. Species composition and abundance has been measured 5 and 10 years after the warming experiment was established, and are due to be repeated in the next years. Ecosystem level measurements have included nutrient and carbon fluxes. A complete survey of the effects of warming on availability of soil nitrogen was completed in 2005 using ion exchange membranes. In the past two years, an emphasis has been on following reproductive responses in major species across the gradient of plant communities. Germination and seedling survival were both significantly increased by the warming treatment. In addition, a study completed in 2005 confirmed that control plots in the wet sedge communities have shown significant increases in above and belowground biomass in response to general warming over the past 25 years. Highlights of the long-term research at Alexandra Fiord will be presented and discussed.

Annika Hofgaard **Oral Presentation**

Links between PPS ARCTIC-IPY and ITEX-IPY.

This is a short information update on progress with the development of the PPS-ARCTIC-IPY and ITEX-IPY and their connections.

Robert D. Hollister **Oral Presentation**

ABOVE AND BELOWGROUND PLANT BIOMASS RESPONSE TO EXPERIMENTAL WARMING. Robert D Hollister, Grand Valley State University, USA.

Plant biomass was examined following 3 to 4 years of experimental warming in a dry tundra near Barrow, Alaska (71°18'N, 156°40'W). There was a significant increase in aboveground biomass of graminoids in response to warming but no difference in total plant biomass. Allocation of biomass and mycorrhizal infection was examined in the dominant shrub and graminoid species, *Salix rotundifolia* and *Carex stans* respectively. *Carex stans* decreased root biomass resulting in a increase in the above to belowground ratio, while *S. rotundifolia* increased in both above and belowground biomass. Mycorrhizal infection rates showed no response to warming. These

results imply a competitive advantage with warming of sedges over shrubs in this high arctic site and suggest shifts in the above to belowground biomass ratios of tundra vegetation will occur in response to warming due to shifts in the abundance and allocation pattern of plant species.

Ingibjörg Jónsdóttir **Oral Presentation**

CIRCUMPOLAR BIODIVERSITY MONITORING PROGRAM AND ITEX. Ingibjörg Jónsdóttir, The University Centre in Svalbard, Norway.

The Circumpolar Biodiversity Monitoring Programme, CBMP, was launched 8 September 2005 in Cambridge. It is supported and led by Conservation of Arctic Flora and Fauna (CAFF: an Arctic Council Working Group) and linked to other key international programs, such as Arctic Monitoring and Assessment Programme (AMAP) and Convention on Biological Diversity (CBD). It builds on CBD Indicators and existing Arctic Monitoring Networks (e.g. ITEX, Rangifer, etc.). It applies a broad definition of biodiversity that includes people and is based on clearly defined threats to biodiversity in the Arctic. In this talk the ambitious aims of CBMP will be presented. Some ideas of how ITEX might fulfill the expectations linked with being a part of CBMP will be presented for further discussion.

Kari Klanderud **Oral Presentation**

EFFECTS OF SIMULATED CLIMATE CHANGE ON DOMINANCE HIERARCHIES, SPECIES COMPOSITION, DIVERSITY, AND INVASIBILITY OF AN ALPINE PLANT COMMUNITY. Kari Klanderud and Ørjan Totland. Norwegian University of Life Science, Norway.

Four years of experimental warming and nutrient addition altered dominance hierarchies, structure, composition, and diversity of an alpine plant community at Finse, south Norway. The previously dominant dwarf shrub *Dryas octopetala* was replaced by a few graminoid (*Festuca* spp., *Poa alpina*) and forb (*Cerastium alpinum*, *Potentilla crantzii*) species under nutrient addition and warming with nutrients. Community diversity declined due to decreased richness and abundance of low-stature forbs, bryophytes, lichens, and dwarf shrubs. The shift in dominance hierarchies changed community structure and dynamics through increased biomass, vegetation height, and competition for light. Community diversity dropped primarily because changes in the abiotic environment modified biotic interactions, highlighting that species interaction must be considered in climate change experiments and in models predicting climate change effects.

Dispersal is another factor that may control diversity. We examined the relative role of propagule availability and community-level interactions for the invasibility and diversity of the *Dryas* heath, and how climate warming may affect the colonization processes. Adding propagules from 27 regional species into heath vegetation increased community diversity significantly, suggesting that dispersal limit diversity. High resident species richness and cover of *Dryas* reduced invasibility. The establishment success of the "invaders" increased under warming, but propagule limitation and competitive exclusion from established species had stronger impact on community invasibility and diversity than the availability of safe sites and the experimental warming.

Julia A. Klein **Oral Presentation**

CLIMATE-ECOSYSTEM DYNAMICS ON THE NORTHEASTERN TIBETAN PLATEAU: INTEGRATING EXPERIMENTAL, GRADIENT AND ECOSYSTEM MODELING RESULTS. Julia A. Klein, John Harte, Xin-quan Zhao, and Dennis Ojima. Natural Resources Ecology Laboratory, Colorado State University, USA.

Four years of experimental warming of an alpine ecosystem on the northeastern Tibetan Plateau led to large and dramatic changes in vegetative properties. These include decreased productivity at the meadow sites, loss of species diversity at all sites, and shifts in the productivity of major plant growth form groups. Experimental warming also decreased the delivery of ecosystem services, such as the provisioning of medicinal plants and palatable forage production. Simulated grazing generally mediated the vegetation changes with warming. I will discuss these vegetative changes in more detail, the potential mechanisms driving these changes, and what factors led to relative resistance/vulnerability of plant species to the warming manipulation.

Climate-ecosystem relationships that were revealed by the warming experiment were not necessarily in agreement with climate-ecosystem relationships that were revealed by sampling across a 1,000 km climate transect and from modeling the system using the CENTURY ecosystem model. I will compare relationships among climate, vegetation, and soil carbon storage that emerge from the experimental manipulation, the transect study, and the modeling work. I will demonstrate how combining the sometimes disparate results from these study techniques can be a powerful way in which to develop a robust understanding of climate-ecosystem relationships and for predicting future short-term and longer-term ecosystem responses to climate change.

Steven F. Oberbauer **Oral Presentation**

RELATING NDVI TO ECOSYSTEM CO_2 EXCHANGE PATTERNS IN RESPONSE TO SEASON LENGTH AND CLIMATE MANIPULATIONS REVISITED: SPATIAL VERSUS TEMPORAL VARIATION, Steven F. Oberbauer, Inga C. Parker, and Thomas E. Philippi, Florida International University, USA.

Climate change in the Arctic will differentially affect physiological rates, leaf phenology, and species composition of tundra, resulting in changing patterns and magnitudes of ecosystem CO_2 flux. To assess how well such changes might be assessed using remote sensing, ecosystem CO_2 fluxes from within permanent chamber bases and normalized difference vegetation index (NDVI) images of base areas were compared throughout the 2002 growing season on experimental plots increasing growing season length and soil temperature. Carbon dioxide fluxes were measured using static chamber techniques and NDVI images were taken with an agricultural digital camera. The seasonal patterns of NDVI and gross primary productivity (GPP) showed an increase to a peak in early August, followed by an abrupt decline. The pattern of ecosystem respiration (R_e) mirrored that of GPP. Net ecosystem exchange (NEE) showed uptake of CO_2 early in the season leveling out to a slight loss of CO_2 at peak season for both control and extended season plots. NDVI was significantly correlated to GPP and ecosystem respiration ($R^2 = 0.50$ and 0.36 respectively) across plots, dates, and treatments combined. However, most of the covariation was across dates. After accounting for seasonal variation, NDVI never accounted for more than 25% of the remaining variation in flux measures. Analysis of covariance showed that a given NDVI value corresponded to different flux rates on different

dates and to different R_e among treatments after correcting for date. The slopes of the NDVI-GPP and NDVI-R_e relationships were much steeper across dates than across plots. Thus, extreme caution must be used when trying to estimate carbon flux rate responses to climate change across years or space using NDVI.

Paulo Olivas **Oral Presentation**

WATER AND TEMPERATURE EFFECTS ON THE CARBON BALANCE IN WET TUNDRA: A NEW ITEX WARMING EXPERIMENT AT BARROW ALASKA. Paulo Olivas and Steven F. Oberbauer. Florida International University, USA.

The complex hydrology and thermodynamics of arctic soil are highly influenced by climatic changes. Permafrost plays an important role in the hydrology of this fragile ecosystem. With climate warming, permafrost could thaw and make more carbon available for microbial decomposition. However, an increase in temperatures and decrease in permafrost will also affect soil water content. Soil water content plays an important role in plant growth by potentially limiting carbon uptake under water stress conditions and affecting nutrient and photosynthetic uptake under saturated soil conditions. Soil water content is also likely the dominant control on ecosystem respiration. How plant responses to these changes in soil hydrology are going to alter the carbon cycle is highly uncertain. The Barrow Biocomplexity project led by San Diego State University is carrying out a large-scale hydrological manipulation of a drained thaw lake at Barrow, Alaska, with the objective to determine the responses of wet tundra to three water table conditions: flooded, drained, and unchanged. As part of that project, we are adding a warming treatment to each of the three water table treatments using standard ITEX OTCs. With chamber-level, trace-gas flux measurements, we will evaluate the effects of warming, water table, the warming * water table interaction on the ecosystem carbon balance. In 2005, the project conducted a year of pre-manipulation measurements. Preliminary data from 2005 will be presented. The results of these experiments will help us not only understand, but also to predict how the ongoing climate changes could affect the carbon cycle in the wet tundra at Barrow.

Gus Shaver **Oral Presentation**

Title and authors to be determined

The general subject matter will be light and temperature effects on NEP at Toolik Lake, Abisko, and Svalbard

Jeff Welker **Oral Presentation**

VEGETATION RESPONSES TO LONG-TERM TEMPERATURE AND SNOW INCREASES AT TOOLIK LAKE, AK. Jeff Welker, Patrick Sullivan, Matt Rogers and David Huber, University of Alaska, Anchorage, USA

Changes in temperature and snow have been underway at Toolik Lake since 1994 as part of ITEX. We will present vegetation and trace gas exchange data depicting how these systems have responded to experimental manipulations. Our most recent studies suggest that snow depth increase is an important driver of vegetation cover and vegetation biomass as well as altering trace gas (CO_2 exchange) dynamics and mineral nutrition attributes of tundra plants. Our

findings suggest that winter precipitation increases may be equally or more important than temperature increases in driving changes in the arctic.

Andrea K. White **Oral Presentation**

THE POTENTIAL IMPACTS OF GLOBAL WARMING ON THE VEGETATION OF THE BOGONG HIGH PLAINS, VICTORIA, AUSTRALIA. Andrea K. White, Frith C. Jarrad, Sean G. Byars, Mark A. Burgman and Ari A. Hoffman. The University of Melbourne, Australia.

The Australian Alps are of national and international significance, as they represent a very rare and restricted land type totaling less than 5,000 km^2. The treeless vegetation zone is narrow compared with that of other alpine areas of the world, with limited high altitude refugia, making the Australian alps among the most vulnerable systems in Australia and globally. The Victorian Alps occur in the mountainous northeast of the state, the most extensive tract being the Bogong High Plains (BHP), covering an area of approximately 120 km^2. Itís been recognised that rising global temperatures are likely to have extensive impacts on Australiaís very valuable high mountain landscapes. These potential impacts are being investigated using a number of different approaches.

The effect of rising temperature on plant processes (phenology and growth) have been studied in the treeless alpine herbfields using the protocols of the International Tundra Experiment (ITEX). Population structure and genetic variability, which represent important factors in a species ability to adapt or migrate in response to environmental change, are being investigated by assessing variability and gene flow along altitudinal gradients for a number of herbaceous species.

The *Sphagnum* peatlands of the BHP are rare and vulnerable, and provide critical ecosystem services. It has been estimated that up to 50% of the BHP peatlands have been lost since European settlement. In addition to this many of the peatlands are in a degraded state. The potential impacts of climate change on the condition, function and distribution of peatlands on the BHP have been investigated.

Philip A. Wookey **Oral Presentation**

ITEX, THE CIRCUM-ARCTIC TERRESTRIAL BIODIVERSITY INITIATIVE, AND IPY. Philip A. Wookey. University of Stirling, UK

This is a short information update on progress with the development of the Circum-Arctic Terrestrial Biodiversity Initiative (CAT-B), an on-going project sponsored by IASC (the International Arctic Science Committee). The objective is to provide background information for a broader discussion of the linkages and opportunities afforded by several complementary initiatives (including ITEX and the Circum-Arctic Terrestrial Biodiversity Monitoring Program, CBMP, of CAFF), particularly in advance of International Polar Year (2007-2008). Further information on CAT-B is available at http://www.cat-b.stir.ac.uk/

Anna Maria Fosaa and Erla Olsen **Poster Presentation**

VEGETATION AND MYCORRHIZAL RESPONSES AFTER FOUR YEARS WITH A WARMING AND ENCLOSURE EXPERIMENT IN AN ALPINE, SUBARTIC OCEANIC ENVIRONMENT. Anna Maria Fosaa, and Erla Olsen. The Faroese Museum of Natural History.

In 2001, ten Open Top Chambers (OTC) were placed inside an enclosure in order to study a combined effect of warming and sheep grazing. The study site is on the mountain of Sornfelli (62°04'N, 6°57'W) at 600 m a.s.l. on Streymoy in the central part of the Faroe Islands. The temperatures are measured 1 cm below the soil surface and above the soil surface with Tiny Tag data loggers and the vegetation was sampled in 50 cm x 50 cm plots. Differences in vegetation cover, length of the graminoid leaves and changes in arbuscular mycorrhiza (AM) of the *Agrostis capillaris* were compared between plots inside OTCs and control plots with and without grazing. Significant differences ($p < 0.05$) were found between the three types of plots. The mean graminoid leaves were longest and the vegetation cover had the largest increase inside the OTCs. The shortest leaves were found in the grazed plots. Both the diversity of the AM fungi and the percent root length colonized (%RLC) with AM showed different patterns in 2002 compared with 2003. In 2002 the %RLC was relative high inside the OTC, but low in 2003. Measurements indicate no significant temperature differences between the plots inside and outside the OTCs at this windy site and the observed vegetational differences are most likely due to a combination of grazing and sheltering from wind inside the OTCs. Differences between the plots inside and outside the OTCs at this windy site and the observed vegetational differences are most likely due to a combination of grazing and sheltering from wind inside the OTCs.

Greg Henry **Poster Presentation**

EXPERIMENTAL WARMING IN A HIGH ARCTIC POLAR OASIS: LONG-TERM EFFECTS ON AERIAL AND SOIL SEED BANKS. Rebecca Klady and Greg Henry. University of British Columbia, Canada.

In the High Arctic, vascular cover is typically less than 5-10%, especially in polar deserts. Under predictions of climate warming, increased allocation to sexual reproduction will likely result in community-level changes in plant species composition and cover. We expect that these changes will be represented in the soil and aerial seed banks as improved germination. We investigated the effect of the long-term warming experiments at Alexandra Fiord (78° 53'N, 75° 55'W) (OTCs established in 1992) on seed germination of the major species in five tundra plant communities. Aerial seed bank samples were collected from plants in the experimental plots at the end of the 2004 growing season and in early 2004 and 2005, after an over-wintering period. Soil seed bank samples were collected in mid-season of 2004. Preliminary results show that the warming treatment significantly increased germinant abundance and seed germination. However, the responses were species-specific and varied depending on plant community. We also found that seedling survival was significantly increased by the warming treatments in most plant communities. In the polar desert site, seedlings only survived over-winter in the OTCs. The results seem to support the increased cover of shrubs found in the warmed plots, especially in mesic tundra communities.

Greg Henry **Poster Presentation**

SEDGE MEADOW COMMUNITY RESPONSES TO RECENT CLIMATE WARMING IN THE CANADIAN HIGH ARCTIC: RE-EXAMINING PLOTS AFTER 25 YEARS. Geoff B. Hill and Greg H. R. Henry. University of British Columbia, Canada.

There are a lack of long-term (>15 years) non-proxy studies of ecological responses to climate change in the Arctic. Ecological research on tundra plant communities at Alexandra Fiord, Ellesmere Island, began in 1980. Species composition and abundance and net primary production were measured for 2-4 years in each major plant community, and most sampling locations were permanently marked. In 2005, we collected samples from the same sedge meadow areas first sampled between 1980 and 1984 by G. Henry, using the same techniques. Above and belowground biomass data were analyzed with ANOVA, Non Metric Scaling and CCA to determine species and community responses to a warming trend at Alexandra Fiord that has been recorded for the past 25 years. Significant increases in both above and belowground biomass were found in nearly all the sedge meadow sites, with most of the increases due to greater growth in the major sedge species. These changes are interpreted as a response to the warming trend, as no significant annual variation in net production was found over the four years of the original study despite important differences in annual climate. These are the first results to show responses in high arctic tundra ecosystems to the warming climate.

Annika Hofgaard **Poster Presentation**

BIRCH SAPLING RESPONSE TO WARMING IN THE ALPINE ENVIRONMENT: PRELIMINARY RESULTS FROM A SEVEN-YEAR EXPERIMENT. J.O. LØkken[1], L. Dalen[1], A. Hofgaard[2], H. Hytteborn[1],[1] Department of Biology, Norwegian University of Science and Technology, Norway; [2]Norwegian Institute for Nature Research, Norway

Recent warming and projected climate change have led to concern about wide-ranging tree cover expansion into tundra regions. Tree saplings occur naturally beyond the treeline, and their response to warming is deterministic to tree cover expansion. In addition to climate the physiognomic stature of saplings is under grazing control. The importance of these main impact factors is essential for refinement of scenarios for climate change response. A warming experiment (standard ITEX OTCs) including fenced and grazed controls, was established 1999 at Dovre, Norway. Naturally established birch saplings were randomly appointed to 25 treatment replicates. Sapling height, length and width of the crown, number of short and long shoots, and the width and length of leaves were recorded for year 0, 1, 2, 3, 4, and 7. Warming has seemingly no effect on height and crown development. Grazed saplings show limited change in height growth and crown size over time, and are significantly smaller (t7: height p=0,004; crown p=0,009) compared to grazed and ungrazed saplings. Total shoot production show no significant difference among treatments, although number of short shoots is slightly lower for grazed saplings. Leaf area show a significant negative response to warming (p<0,001) compared to the grazed and ungrazed controls. These preliminary results show that grazing might have larger impact on birch growth in the alpine environment than temperature increase, which might even hamper sapling growth due to reduction in photosynthetic area. However, total leaf mass has yet to be tested for, which might alter results and drawn conclusions.

Ingibjörg Jónsdóttir **Poster Presentation**

PLANT-GOOSE INTERACTION IN THE HIGH ARCTIC IN EARLY SPRING, Christiane E. Hübner and Ingibjörg Jónsdóttir, The University Centre in Svalbard, Norway.

In spring, thousands of geese migrate from temperate wintering areas northwards to breed. After arrival in the Arctic, many goose species spend some time feeding in pre-breeding areas before they move to their breeding sites. Goose numbers in such areas are high during this short period in early spring and the grazing impact is immense. This study investigates the dynamic interaction between barnacle goose (*Branta leucopis*) and plants in a pre-breeding area in Svalbard, Norway. The area is characterised by early snowmelt compared to other regions in Svalbard and high nutrient input from a large seabird colony. The preferred feeding habitat for the geese during this period is wet moss tundra beneath a bird cliff and the main food source is the moss *Calliergon richardsonii* and this moss species is 80-90% of the goose diet. The dynamics of moss biomass, growth and depletion throughout the staging period of geese in relation to timing of snowmelt and temperature were assessed. Our results show that heavy goose grazing in early spring in this system significantly reduces moss biomass but does not affect moss growth. Furthermore, moss forage quality is greater below the seabird colony than elsewhere.

Paddy Sullivan **Poster Presentation**

TEMPERATURE AND MICROTOPOGRAPHY INTERACT TO CONTROL CO_2 EXCHANGE IN A HIGH ARCTIC FEN. Haley Ohms, Paddy Sullivan, Rod Chimner, Seth Arens, Sean Cahoon, and Jeff Welker, University of Alaska, Anchorage, USA.

Relatively few studies have examined constraints on carbon cycling in the High Arctic. Fewer still have examined carbon cycling in high arctic wetlands, which are hot spots for land-atmosphere carbon exchange in the high arctic landscape.

In June 2004, an open-top chamber (OTC) warming experiment was established in a high arctic fen near Thule, Greenland. Hummocks and pools (characterized by standing water) received chamber treatments. CO_2 exchange was measured using static chamber techniques on ten dates during the 2005 growing season.

Gross primary production (GPP) and ecosystem respiration (RE) were significantly higher in hummocks than pools, but net ecosystem exchange (NEE) was not significantly different when hummocks and pools were compared. Warming chambers stimulated hummock RE early in the growing season and hummock GPP late in the growing season, such that NEE was not affected by the chambers when the whole growing season was considered. In contrast, warming chambers did not affect CO_2 exchange in pools.

Measurements of CO_2 exchange are one facet of a larger study that includes detailed microclimate monitoring, measurements of leaf gas exchange, leaf and root growth (via minirhizotrons and ingrowth cores), biomass harvests and stable isotope investigations of plant source waters (delta ^{18}O and delta D) and plant biomass (delta ^{13}C, delta ^{18}O and delta D).