Accomplishments:
What are the major Goals of the project?

The objectives of the Arctic Long-Term Ecological Research (LTER) Project for 2017-2023 are to use the concepts of biogeochemical and community "openness" and "connectivity" to understand the responses of arctic terrestrial and freshwater ecosystems to climate change and disturbance. These objectives will be met through continued long-term monitoring of changes in undisturbed terrestrial, stream, and lake ecosystems in the vicinity of Toolik Lake, Alaska, observations of the recovery of these ecosystems from natural and imposed disturbances, maintenance of existing long-term experiments, and initiation of new experimental manipulations. Based on these data, carbon and nutrient budgets and indices of species composition will be compiled for each component of the arctic landscape to compare the biogeochemistry and community dynamics of each ecosystem in relation to their responses to climate change and disturbance and to the propagation of those responses across the landscape.

What was accomplished under these goals?
Major Activities:

Terrestrial

- During the summer 2018, LTER staff collected annual monitoring datasets for multiple LTER experimental plots including long-term warming, shading, and nutrient addition treatments in multiple plant communities: variables included thaw depth, vegetation relative abundance, NDVI, and soil N mineralization rates. We also established new greenhouses for new warming experiments in moist tussock tundra. Gus Shaver resampled historic sites for gap-filling in long-term data sets.
- Our ongoing collaborators worked with the LTER during the field season in various ways. A team lead by Ned Fetcher analyzed leaf toughness data collected from LTER fertilized and control plots. Adrian Rocha lead a team that continued monitoring carbon exchange on severely burned, moderately burned, and non-burned sites using eddy covariance and conducted a harvest of fertilized and control plots in the severe and non-burned sites. He and his students continue to run a decomposition experiment in LTER experimental plots at Toolik. Gough and her students sampled long-term nutrient addition plots that are maintained by the LTER to determine plant community composition change and mammal use. One of her students began a simulated herbivory experiment in the same plots. Rebecca Rowe's students sampled for small mammal density in three research sites near Toolik Field Station as well as the Anuktuvuk River burn sites. Eugenie Euskirchen maintained a FlouoSpec 2 Solar Induced Fluorescence (SIF) sensor at the tussock tundra eddy covariance tower in the Imnavait Watershed, the first continuous SIF measurements in arctic tundra (through a NASA ROSES grant, with lead PI, N. Parazoo at JPL). Euskirchen also conducted model simulations with the Terrestrial Ecosystem Model to evaluate how model parameter uncertainty and sensitivity to above- and belowground model parameters across key tundra types in northern Alaska (tussock tundra, shrub tundra, heath tundra, and wet sedge tundra) may influence uncertainty in model output.
- Michelle Mack has three projects in collaboration with ARC. For Deep Roots, Rebecca Hewitt, postdoc, sampled foliage from dominant plants in control and warmed plots of the LTER warming experiment to follow isotope concentrations

throughout the growing season from our ^{15}N addition in 2016. They harvested plants from the same treatments in 2018. We plucked above and belowground samples at TFS. For the Moss Dimensions project, Julia Stuart, PhD student, worked in areas adjacent to LTER long-term experiments. For the Snow-Shrub project, Haley Dunleavy, PhD student, examined enzymatic activity on ectomycorrhizal and ericaceous shrub root tips in LTER maintained fertilization plots.

- During summer 2018, Gough hosted Dr. Johan Olofsson and Ms. Elin Linden from University of Umea; they collected data from long-term herbivore exclosures maintained by ARC LTER in both moist acidic tundra and dry heath tundra as part of a circumpolar project examining effects of long-term mammalian exclosures on tundra ecosystems, Rastetter hosted Dr Stephen Porder of Brown University, who, along with E Rastetter, surveyed foliar chemistry for several species of plants along an surface age gradient with surfaces 14k to 5m years in age.
- LTER staff assisted other projects during summer 2018. Our RA collected and shipped soils to Rudd Rijkers, a Ph.D. student at Vrije Universiteit Amsterdam, who is conducting a circumpolar study investigating how tundra soil microbial communities respond to temperature. For the second year in a row, our RA assisted Ms. Rachel Cox and her high school students from the Riverdale Country School (Bronx, NY) with sampling plants from within LTER experimental plots.
- During the academic year we continue to process field samples, enter and prepare data for uploading to the LTER datasite, and work on associated tasks such as standardizing variables and metadata across multiple years. We also continue to develop manuscripts resulting from this work. One example is Gus Shaver beginning analysis of 40-year record of harvest data from several sites on the North Slope. Another is that Gough and her collaborators and their students are developing two manuscripts describing changes to plants and soils caused by long-term mammalian herbivore exclosures in two tundra communities.
- January 2019: Gough attended the Polar-ICE workshop devoted to how to better communicate results of polar research to the public and in our classrooms. She has been incorporating some of what she learned into her graduate Global Change Biology course for spring by creating an emphasis on polar research articles for class discussion. She is also planning for summer 2019 and having students and technicians make short videos while in the field that can then be shared via social media, university websites, and other platforms.

Land-Water

- The major research activities of **the Land-Water subgroup** include collection and analysis of inorganic and organic water chemistry in several long-term study lakes (E5, E6, Toolik lake) and in a series of lakes and streams in the Toolik Lake and Kuparuk drainage (25 sites total). These efforts are coordinated closely with the other ARC LTER subgroups of Lakes, Streams, and Terrestrial. We also measure the flow of water into Toolik Lake and in several streams in the "inlet series" of lakes and streams of the Toolik Lake basin using automated water-level gauges calibrated with hand measurements of discharge. In addition, we have measured bacterial production in Toolik Lake (weekly) and in the series of lakes draining into Toolik Lake (3 times per summer). Finally, we aid in the collection of and analysis of water samples in groundwater and stream water in the Imnavait Creek basin, and we conduct a thaw depth survey twice each summer in two catchments, Imnavait Creek, and

the Tussock Watershed just south of Toolik Lake.

- We coordinate our sampling closely with three other NSF projects: (1) the "Photo-Bio" project (Dr. Byron Crump, lead PI, R. Cory and G. Kling co-PIs) studying the microbial and photochemical degradation of organic matter in soils, lakes, and streams, (2) the NSF-AON project studying carbon and nutrient cycling at Imnavait Creek (Dr. Ed Rastetter and Donie Bret-Harte, lead PIs, G. Kling co-PI), and (3) the NSF hydrology project at the Kuparuk River and Imnavait Creek of Dr. Beth Neilson (lead-PI).

- In the summers of 2015-2018 we used LTER support to help investigate (1) the biogeochemical consequences of physical movement of groundwater down a hillslope, and the nature of riparian zone interactions with uplands and the stream, and (2) the active layer thaw dynamics measured on the ground and by satellite. The first investigation was done with a PhD student working with Dr. Bayani Cardenas at the University of Texas, and our activities included collection of water samples for analysis of chemistry. The second investigation was done with a PhD student working with Dr. Ann Chen at the University of Texas, who analyzed the remotely sensed, interferometric signal of synthetic aperture radar (InSAR) compared to our LTER ground measurements of soil thaw.

Streams

- The 2018 season marked our second year of post-fertilization monitoring in the Kuparuk River, following the conclusion of our 34-year fertilization experiment in 2016.
- We continued our long-term nutrient and biotic monitoring in the Kuparuk River and Oksrukuyik Creek, including:
    - Sestonic and benthic nutrient sampling (3 dates)
    - Monitoring growth of young-of-the-year Arctic Grayling (*Thymallus arcticus*) throughout the summer
    - Monthly sampling of benthic macroinvertebrates in the Kuparuk River (3 dates)
- We measured whole-stream metabolism in the reference and fertilized reaches of the Kuparuk River, which has been done annually since 2012. Despite the conclusion of nutrient addition to the fertilized reach, we still observed greater dissolved oxygen fluctuations in the fertilized reach due to higher levels of primary production.
- We measured whole-stream metabolism in the I-8 Inlet, I-8 Outlet, and Peat Inlet streams to supplement previous studies of these reaches.
- We completed our second full season of environmental DNA (eDNA) sampling, which included:
    - Repeated sampling of the Kuparuk River and its headwaters in Green Cabin Lake to detect the seasonal migration of Arctic Grayling
    - Mid-season and late-season sampling of the I-1 and I-2 lake outlets to inform study design for the lake closure experiment.
- We sampled benthic macroinvertebrates (3 dates), measured whole-stream metabolism and conducted riparian characterizations of the I-1 and I-2 outlets as baseline data for the lake closure experiment.
- We maintained RFID antennas to detect fish movement from late June through early September on the Kuparuk River (3 sites), Oksrukuyik Creek (4 sites), Toolik Inlet (1 site), and the I-1 and I-2 outlet streams (2 sites).
- We complemented our regular nutrient monitoring with several additional efforts, including:
    - Bi-weekly nutrient samples from the reference reaches of the Kuparuk, Oksrukuyik, and Trevor Creek, from late May through early October.
    - Bi-weekly benthic nutrient sampling in the reference reach of the Kuparuk from late June through late September.

- Assisted Abbott, Zarnetske and Aanderud's synoptic nutrient sampling and discharge measurement in the Kuparuk, Oksrukuyik and Trevor Creek watersheds, on two occasions.

Lakes

Information management

- Continued to consolidate and update long-term datasets. For example: lake's chlorophyll and primary production data are now in decadal files and fish data from lakes are in one file from 1986 to present. Datasets from several collaborating projects were added. All updated and added datasets are uploaded to Environmental Data Initiative (EDI) portal and where appropriate replicated to the Arctic Data Center.
- Implemented new fields in EDI dataset uploads to include project funding and data file checksums. (Funders are beginning to request dataset inventories by funding code. And the checksums enhance the efficiency of the uploads. Changes in only the metadata can be updated without the need to upload a new data file.)
- ARC information manager (IM) participated in the LTER All Scientist information manager meeting including a Drupal Environmental Information Management Systems (DEIMS) meeting where the ARC IM presented and demonstrated the Arctic LTER DEIMS site.
- Began the process of collating and analyzing the vegetation reflectance data. R scripts were developed to process and reanalyze the data. R scripts and notebook are being developed for future data collection to replace outdated software and to facilitate data entry and quality checking.

Specific Objectives:

Continue to maintain long-term experiments
Set up new experiments and measurements (see major activities above)
Continue synthesis to develop a long-term, integrated perspective on tundra landscapes.

Significant Results:

The Arctic LTER maintains long-term experimental manipulations in lakes, streams, and tundra plots. It is our policy to allow other researchers to make use of these experiments after review and approval. The data from these studies help advance LTER science, leverage off of existing LTER data, and are added to the LTER data base. In this section we report on findings from studies making use of LTER experiments and LTER supported personnel, facilities, and logistics.

Terrestrial

The terrestrial group is exploring the ways in which the tundra is relatively open or closed in multiple ways. We summarize below a few recent findings regarding how increased nutrients (an opening up of the biogeochemistry) affects plant and animal communities and the tundra ecosystem, how genetic makeup of the common sedge Eriophorum vaginatum has been affected by selection along a latitudinal gradient, and how fire might be opening up the small mammal community, among other activities.

- Gough contributed ARC data to meta-analysis examining patterns among plant community

responses to manipulations of global change drivers (LaPierre et al. in revision).

- Gough and her students found that long-term nutrient addition is affecting tundra herbivore activity in moist acidic tundra but only above a certain threshold of soil nutrient availability (Sheppy et al. poster).
- Schedlbauer et al. (2018) found increases or no differences in photosynthetic capacity of *E. vaginatum* ecotypes after two years at higher growth temperatures, along with little variation in specific leaf area and leaf N among ecotypes.
- Studies of flowering in *E. vaginatum* have shown that the fly *Pseudopachychaeta ruficeps* (Zetterstedt,1838) (Chloropidae) lay their eggs in the developing bud in late summer to develop the following spring. An unknown wasp that is also found in the flower heads appears to emerge during the early summer.
- GPP of transplanted ecotypes of *E. vaginatum* displayed home site advantage that was associated with differences in LAI. GPP of southern ecotypes exhibited a greater response to transplantation.
- Results of measurements and modeling of GPP demonstrate that ecotypic differentiation impacts the morphology and function of vegetation with implications for carbon cycling. The results also suggest that ecotypic control of GPP may limit the response of ecosystem productivity to climate change.
- During 2018, Rowe's students conducted a survey of the small mammals at the site of the 2007 Anaktuvuk River Fire. In August, a total of 480 trap nights yielded 22 small mammals, the majority of which were tundra voles. In the severe burn, we captured 18 individuals of 3 species; *Microtus oeconomus* (13), *Sorex* spp. (4), and *Dicrostonyx groenlandicus* (1). In the control habitat, we captured 4 individuals of 3 species; *Sorex* spp. (2), *Microtus oeconomus* (1), and *Myodes rutilus* (1). This trend of more small mammals in the severely burned site compared with an area that was not burned was also found in 2014 and 2017. In 2017 when vole numbers were low across the landscape, captures were dominated by shrews, whereas in 2014 the dominant species was *Microtus oeconomus* as found in 2018.
- Mack's group has found that several plant species in moist acidic tundra follow the thaw boundary in the soil by increasing rooting depth in plots experimentally warmed by the LTER. They have also quantified nitrogen fixation rates by mosses on the landscape near Toolik and determined that moss taxon is more important than moisture, active layer depth, and pH in determining these rates. Sampling for mycorrhizal activity in long-term fertilization experiments has revealed that ectomycorrhizal communities shift with added nutrients and that enzyme activities of mycorrhizae associated with ericaceous plant species are lowered with increased nutrient availability.
- Preliminary findings from the analysis of Terrestrial Ecosystem Model sensitivity by Euskirchen indicates the model is sensitive to parameters that influence gross primary productivity, including optimal and minimal rates of photosynthesis, the light extinction coefficient and specific leaf area.

Evaluating Long-Term Trends in Moist Tundra Production, Biomass, and Species Composition

Since the Dalton Highway opened in 1976, production, biomass, and species composition of moist tundra have been measured using identical harvest methods at multiple sites, often in multiple years, along this north-south transect across Alaska. Also since 1976, long term

fertilizer experiments have been maintained and responses monitored as climate itself has warmed over the past 40 years. Research in 2018 focused on three broad questions: First, how is climate warming affecting tundra ecosystems in the long term, and what controls the rate and pattern of response at the community and ecosystem levels? Second, how do changes in species composition interact with direct effects of climate change to control canopy structure, production and biomass, and overall ecosystem functions? Third, how do stoichiometric constraints on construction of plant biomass vary among species and among plant tissues and how are these constraints reflected in the overall stoichiometry of the whole vegetation's biomass?

Several conclusions may be drawn from this ongoing retrospective analysis:
1.) Although aboveground biomass and production at a single site may vary by 30-50% among years, there is no large or significant long-term trend in biomass or production at any site where we have a long-term record (>35 years at 4 sites). In contrast, dramatic increases in biomass and production consistently occur at sites disturbed by fire, fertilizer, or other direct manipulations.
2.) Changes in species composition also occur among years but the changes are inconsistent among sites, and deciduous shrub abundance is not increasing except at one site. Again, dramatic changes in composition occur on disturbed or manipulated sites
3.) Despite significant annual variation in species composition in control sites, and dramatic changes in composition in fertilized plots, canopy structure in moist tussock tundra appears to follow a single, constant relationship between canopy N content and leaf area, as well as a constant production:biomass relationship.
4.) At the Toolik "Historic" site, C:N:P ratios vary widely among plant tissue types in relation to the varying metabolic functions and structural requirements of those tissues (e.g., roots, stems, leaves). However, C:N:P ratios of whole plants of different species do not differ among species. C:N:P ratios of both individual tissues and whole plants/whole species are virtually constant over a range of 2-5 orders of magnitude in biomass and C/N/P mass.
5.) Biomass and C:N:P ratios of both individual tissues and whole plants are strongly affected by long term N+P fertilizer addition (N and P concentrations increase in all tissues and species), but the slopes of the relationships between biomass and C, N, or P mass are not changed by fertilizer. Thus, changes in N and P concentration have little impact on total biomass in this N- and/or P- limited vegetation. More important is the total amount of N or P acquired, not differences in how N and P are used by the various species.

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Landwater:

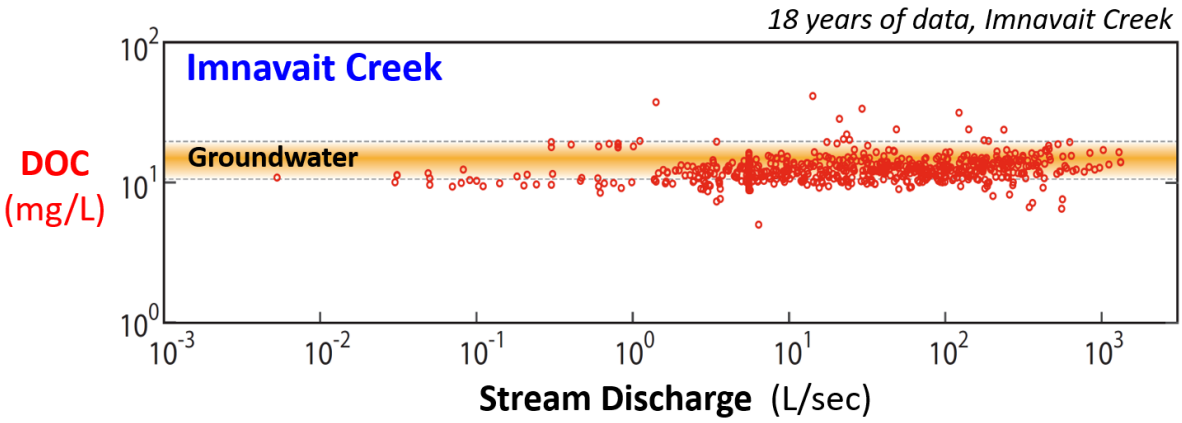
(1) <u>Exchanges of water and carbon from the land surface to deeper in the soil control dissolved carbon export from catchments.</u>

One of the central questions in our LTER grant is what controls the biogeochemical "openness" of different ecosystems. For example, what are the controls on how much carbon and nitrogen are exported from land into streams and rivers? Last year we completed an analysis of these controls (Neilson et al. 2018) and found that different processes are important at different watershed scales. This conclusion is highlighted by data showing a different relationship between the dissolved organic carbon (DOC) concentrations in groundwater and surface water at two watershed scales. At the scale of a small headwater stream (Imnavait Creek, Figure W), the

groundwater and stream water DOC concentrations are very similar, even across six orders of magnitude of discharge. This relative "chemostasis" regardless of discharge is surprising, because in very wet conditions (large rainstorms) one would expect overland flow of water reaching the stream that carries the low DOC character of rainfall. Instead, the consistently high DOC concentrations in the stream are likely caused by two processes. The first is the rapid leaching of the upper organic mat with rainwater. The second process is the consistent and rapid exchange of water from above the land surface with water deeper in the soils that has higher DOC concentrations. We used hydrologic models to show that microtopography on the land surface, caused by the mounds and hollows created by tundra vegetation, creates pressure differentials that drive water into the soil (similar to bedform-driven hyporheic flow in stream sediments) and thus cause the rapid exchange of overland flow with shallow groundwater. In other words, the water "porpoises" from just above to just below the land surface and back again as it moves downslope. Combined with the rapid leaching of organic carbon from soils, these findings provide a mechanistic explanation of long-term measurements showing high concentrations of carbon in soils and streams during high flow conditions for both spring snowmelt and summer storms (Neilson et al. 2018)

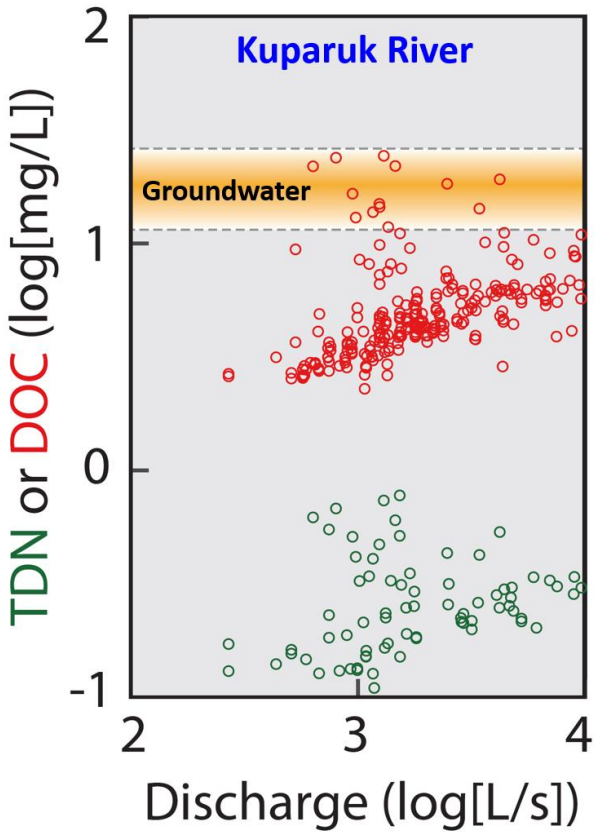
We next tested the importance of these mechanisms controlling DOC concentrations and basin export at a larger scale, that of the 4th-order Kuparuk River (adjacent to the 1st-order Imnavait Creek). At this larger At this larger scale we found a quite different pattern of DOC concentrations in soils and surface waters (Figure X). Here, the river water DOC values were consistently lower than the groundwater (soil water) values across a broad range of discharge. We believe that the same mechanisms of rapid leaching of

DOC concentrations in surface water of Imnavait Creek are similar to groundwater concentrations regardless of discharge



- The mechanism of this "chemostasis" is rapid leaching of organic material and vertical mixing of DOC in soils

Figure W. Dissolved organic carbon (DOC) concentrations in Imnavait Creek are similar to groundwater (soil water) concentrations in Imnavait basin over a wide range of discharge. This relative "chemostasis" with discharge is best explained by rapid leaching of organic soils and the surface-subsurface exchange of water moving downslope (Neilson et al. 2018).



DOC concentrations in the larger Kuparuk River are *lower* than groundwater concentrations

This difference is due to microbial and photochemical consumption of DOC in the river network:

$DOC_{river} = DOC_{groundwater}$
– (microbial respiration)
– (photomineralization)

Figure X. DOC concentrations in the Kuparuk River are lower than groundwater DOC concentrations in the basin. This difference is calculated to be caused by the consumption of DOC by microbes and the photo-mineralization of DOC to CO_2 in the river network.

organic mat soils and rapid surface-subsurface porpoising of water moving downslope are

occurring in the Kuparuk, but the scale of the river network allows for other processes to overprint the relationship we found in Imnavait.

After soil waters discharge into the smallest streams in the Kuparuk basin they must still travel through an extensive surface network to reach the 4th-order mainstem. In Imnavait there is only one small stream, and soil waters discharging into that stream rapidly reach our measuring point at the bottom of the catchment. During the longer travel times of water in the Kuparuk, two additional processes act on DOC: (1) microbial respiration of DOC to CO_2, and (2) photochemical oxidation of DOC to CO_2 (photomineralization). Our calculations indicate that microbial respiration plus photomineralization reduce the starting groundwater DOC concentrations to values similar to what we observe further downstream in the mainstem of the Kuparuk (see also Cory et al. 2014, 2015, Neilson et al. 2018).

Understanding how "open" these terrestrial systems are to the export of carbon and nitrogen from land to water, and what controls the degree of openness, is a first step in predicting how arctic watersheds will influence element export as thaw depth increases in a warmer climate.

(2) <u>Expansion and contraction of permafrost soils during summer thawing and winter freeze-up can be reliably detected from space.</u>

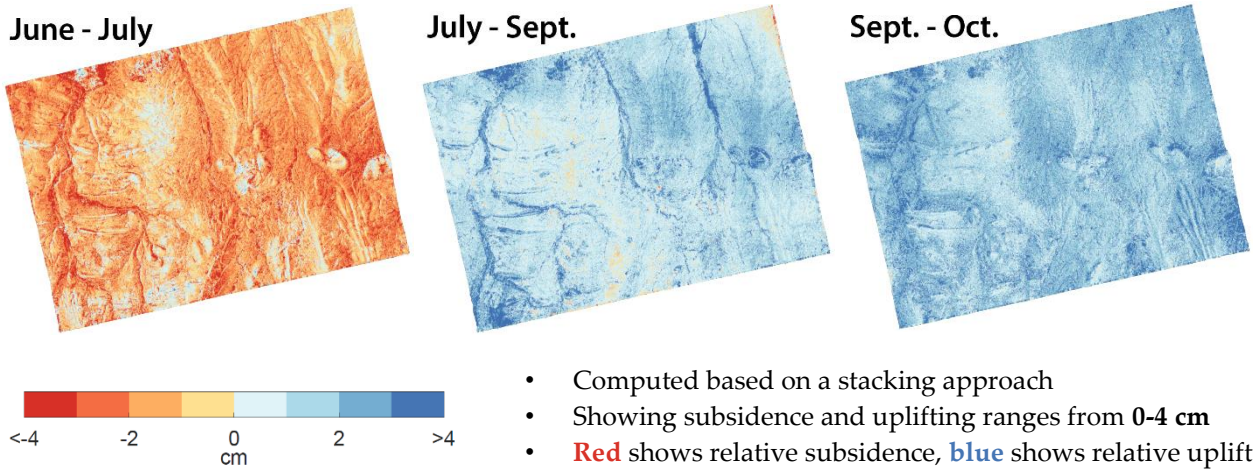


Figure Y. Ground surface rise and fall as measured by InSAR satellite data for the region near Toolik Lake (Toolik Lake itself, 1.5 km2, is the size of a small dot on these images). Red colors indicate the subsidence of the ground surface during summer as the soils thaw (ice melting and occupying less volume), and blue colors indicate uplift as soil waters freeze going into fall and winter (A. Chen and S. Wu, unpublished).

As climate warms our permafrost soils are thawing more deeply in summer, which has the potential to alter the amount of material transported from land to surface waters. However, our previous estimates of the amount of thaw have been limited to small grids assessed by hand measurements using thaw probes, and we have little to no information on changes in thaw depth at larger scales. In order to investigate the spatial variation in thaw depth at larger scales we began a new initiative with Drs. Ann Chen and Bayani Cardenas at the University of Texas to use synthetic aperture radar data from satellites (InSAR) to examine this problem. InSAR measures the "rise and fall" of the ground surface due to soil water

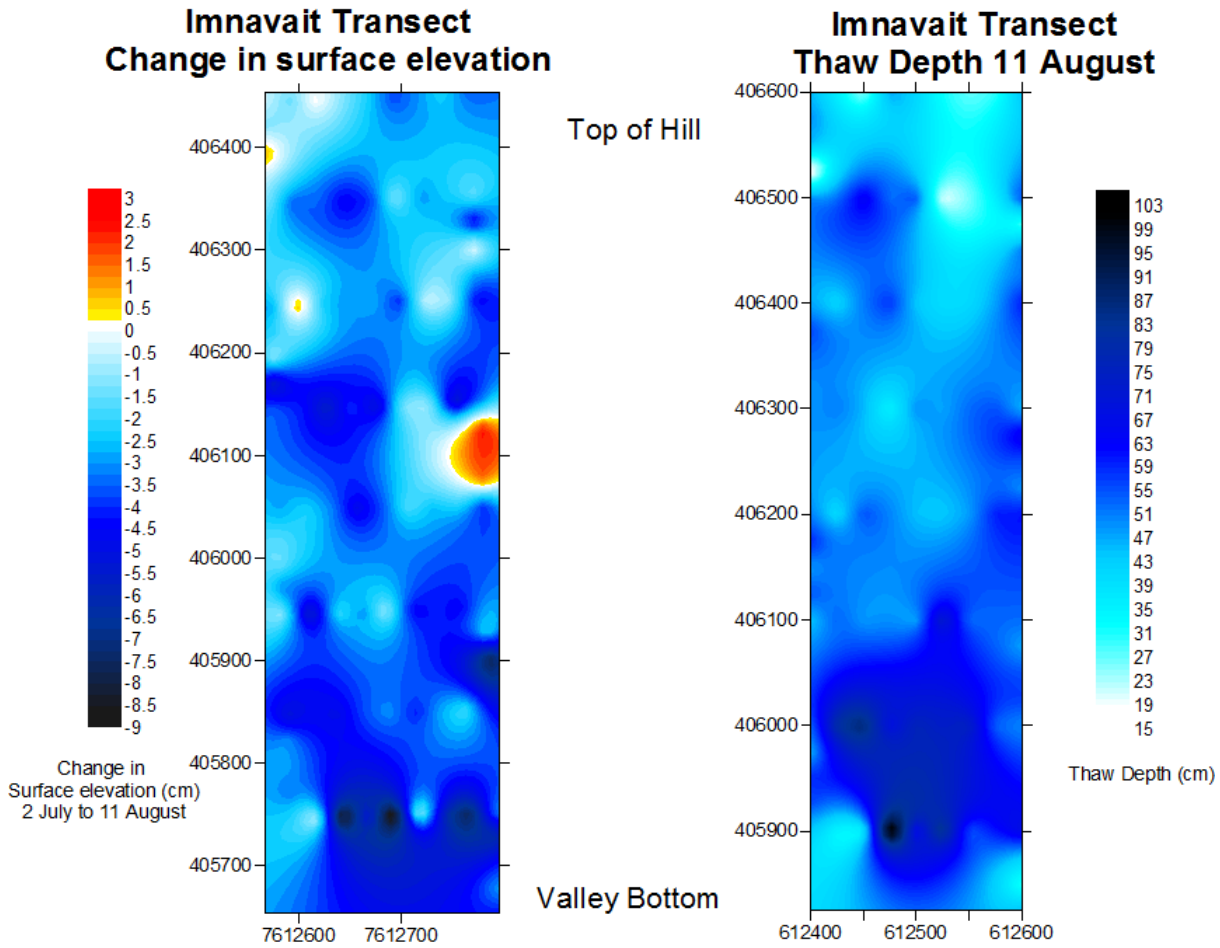


Figure Z. Left – Change in ground surface elevation between 2 July and 11 August 2018 measured by GPS in the Imnavait basin (coordinates in UTM). Right – Thaw depth measured at the end of the summer thaw season in August. Deeper areas of thaw are darker blue (near the bottom of the panels, representing the valley of the stream basin) contain more water and thus correspond to greater changes in surface elevation (darker blue) over the summer (left panel) (G. Kling and J. Dobkowski, unpublished).

freezing in the fall and thawing in the spring, because ice occupies more volume than liquid water.

A pilot study by Dr. Chen demonstrated that InSAR data acquired between 2006 and 2010 can characterize the seasonal active layer freeze-thaw cycle to detect changes over time, and qualitatively map the spatial distribution of groundwater storage. Figure Y provides a sense of the vertical subsidence during thaw in summer (red) and vertical uplift during freeze-up in fall (blue) as inferred from InSAR data from the Toolik region.

In 2018 we started a set of ground-truth calibration measurements in the Imnavait Creek basin using direct measures of thaw depth and ground surface elevation (relative to a GPS control point in the basin). Our preliminary analysis of this dataset in Figure Z shows a similar change in elevation (on average ~3 cm subsidence) to the satellite record during the summer thaw months (left panel in Figure Z). In addition, the maximum thaw depths at the end of summer in the basin occur near the valley bottom (darker blue in Figure Z), and these areas

hold more water and thus also show greater changes in land-surface elevation between spring and summer (left panel of Figure Z).

The next step in this project will be to correlate these changes in thaw depth and surface elevation with measurements of water content of the soil, which will be the final ground-truth validation step for using InSAR data to expand our coverage and understanding of the impacts of changing thaw depth on water flow and element cycling in the tundra near Toolik Lake.

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Cory, R. M., K.H. Harrold, B. T. Neilson, and G.W. Kling. 2015. Controls on dissolved organic matter (DOM) degradation in a headwater stream: the influence of photochemical and hydrological conditions in determining light-limitation or substrate-limitation of photo-degradation. Biogeosciences 12:6669-6685. *doi:10.5194/bg-12-6669-2015*

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Streams

The results from our first full season of eDNA sampling show promise for using this emerging technique to detect seasonal changes in fish abundance. Seasonal migration of Arctic Grayling has been well-studied in the Kuparuk River; therefore, it provides a unique opportunity to test the efficacy of eDNA sampling against known migration patterns. We repeatedly sampled the Kuparuk River as well as the outlet of its major headwater lake (GCL) – where Arctic Grayling overwinter – from late May through mid-September in 2017, capturing the majority of the expected migration period. Detections of Arctic Grayling eDNA were highest in the GCL in May, when fish were staged for outmigration, then dropped off until the fish started to return in early September (data not shown). Similarly, eDNA detections at the downstream site peaked in May and again in late August, presumably during migration from and to GCL (Figure 1). These data should be interpreted with caution, as many additional factors influence eDNA detection in lotic systems (e.g., discharge, temperature, UV radiation, fish behavior and metabolism); regardless, the initial results are promising. Moving forward, we intend to expand this investigation by pairing eDNA detection data with fish movement data from our RFID reader antennae on the Kuparuk.

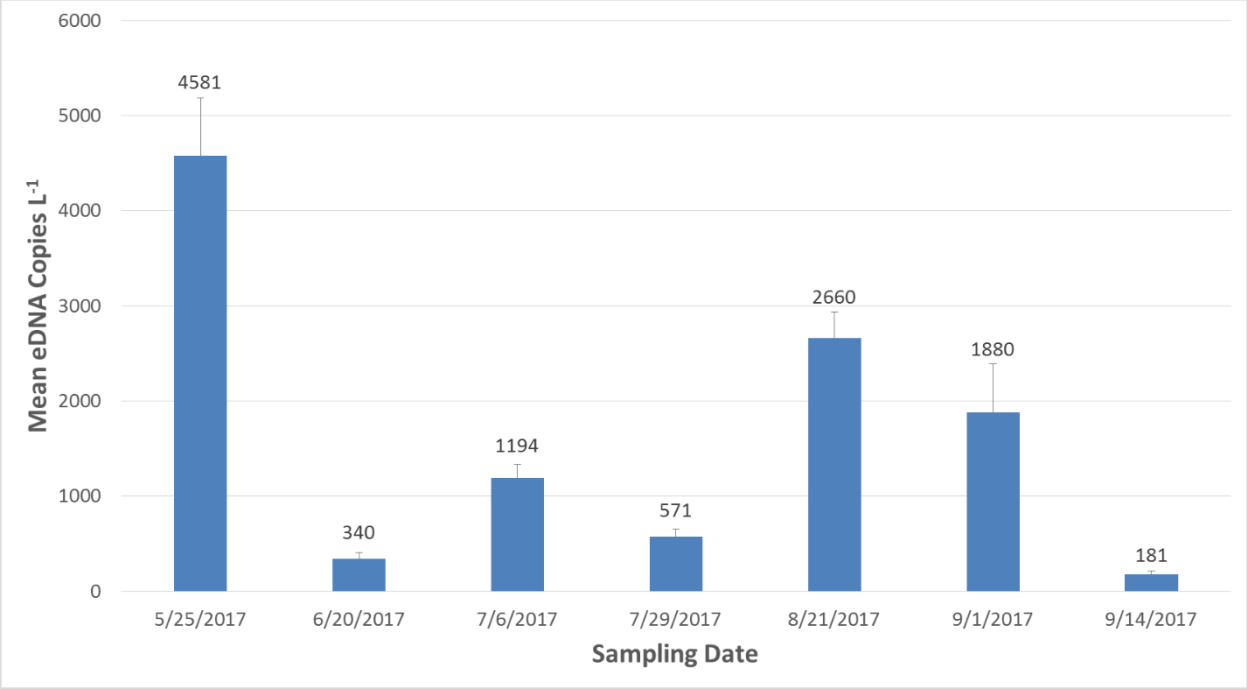

Figure 1. Mean eDNA copies L^{-1} (±SE) of Arctic grayling detected by qPCR at the Kuparuk River road crossing during the 2017 sampling period. Mean values are plotted for each time point of any positive PCR replicates, based on two field replicates and a total of eight PCR replicates.

COLLABORATING PROJECTS:

The Arctic LTER Streams initiative collaborates with and helps to support (with data and field assistance) the following stream-related projects:

FISHSCAPE II: Adaptability of a key Arctic freshwater species to climate change Urban, Deegan (NSF-OPP)

The main goal of this project is to predict the adaptability and persistence of a key Arctic species, the Arctic Grayling (*Thymallus arcticus*) to changing climate and hydrology. The NSF-OPP grant for this project ended in 2017; however, the LTER contributed field support during the 2018 season to continue the project's dataset, as it is integral to the LTER's fish population monitoring efforts. This included:

- Maintaining RFID reader antennae on the Kuparuk River (3 sites) and Oksrukuyik Creek (4 sites) to track movement of tagged Arctic Grayling throughout the summer.
- Deploying and retrieving temperature loggers in the Kuparuk, Oksrukuyik, and I-minus watersheds to help predict timing of Arctic Grayling migration and to detect flow intermittency.
- A brief sampling campaign at Greek Cabin Lake to collect samples for genomic analysis from individuals with prolific movement records in the antenna data.

The LTER intends to continue this limited support of the project until further funding is secured.

Growth of Two Arctic Mayfly Taxa Across Temperature
Atkinson

This project focuses on growth of Baetis and Cingymula mayflies across a temperature gradient created in mesocosms using lake water. In addition, in situ field growth experiments were conducted in a stream near Galbraith Lake, the stream in which the mayflies originated. These data are currently being worked up to examine growth rates of Baetis mayflies across Arctic (Toolik), temperate (Colorado), and tropical (Ecuador) stream ecosystems and Cingymula between the Arctic (Toolik) and temperate (Colorado) stream ecosystems. Further, these preliminary data will be used to plan future reciprocal transplant experiments to examine population differences in growth. Populations that inhabit high-altitude environments experience lower temperatures and shorter activity periods than their low-altitude neighbors and offer an excellent opportunity to assess how survival is facilitated in environments where growth is constrained. This data will be used to determine if high elevation (colder) populations have a higher metabolic rate at a given temperature than those at low elevations to compensate for metabolic rate and activity at varying temperatures within and across populations. Results from these experiments will help us explore the potential implications of a warming climate on aquatic invertebrates.

Dissolved Organic Matter in Arctic and Boreal Streams
Zarnestke, Abbott

Synoptic campaigns: We resampled the 123 sites across our three study watersheds for water chemistry in early (June) and late (August) season to test our spatial structure and synchrony hypotheses for different thaw depths. We measured anions and cations (for geologic tracing and testing sensitivity of distributed mass balance method); nutrients including DOC, NO3, NH4, SRP (for carbon and nutrient source and transport dynamics); and DOC optical properties (absorbance spectra, EEMs). The repeated sampling allowed us to interpret seasonal trends in spatial variance collapse, ecosystem leverage, and spatial stability of dissolved constituents using the approach published in Abbott et al. (2018) (Figure 2).

- *Net nutrient behavior varied across season and by catchment:* Generally, DOC behaved conservatively across all seasons and among catchments. Nitrate was more variable: we found early net production and late net removal signals in our lake-dominated Oksrukuyik catchment, net removal across seasons in the Kuparuk, and net conservation across seasons in alpine Trevor Creek.
- *Variance collapse determined controlling spatial scales across catchments and between seasons:* Across seasons, controls for DOC and nitrate in lake and alpine landscapes operate at smaller scales than for tundra landscapes where lakes influence are absent.
- *Overall spatial instability of nutrients between early and late season samplings:* We observed general instability of landscape processes controlling DOC and nitrate between early and late season in our 2017 sampling. However, we note spatial stability between late 2016 and late 2017 samplings, suggesting strong seasonal drivers that operate during the thaw season that are "reset" every year.
- *Other noteworthy findings:* Imnaviat Creek tended to be an outlier for DOC (net removal), nitrate (net production), and soluble reactive phosphorus (net removal) concentrations.

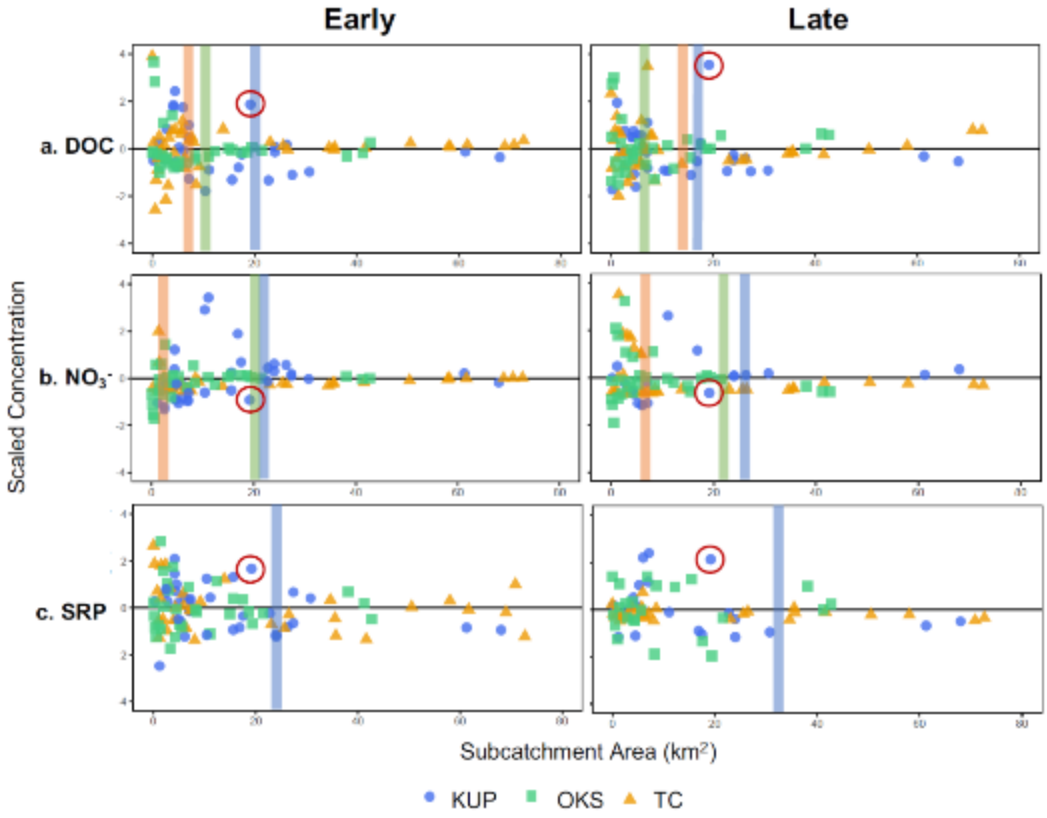

Figure 2. Variability in concentration for subcatchments of differing sizes in Kuparuk (blue circles), Oksrukuyik (orange triangles), and Trevor Creek (green squares) for early and late season. Points represent scaled mean values for a. dissolved organic carbon (DOC), b. nitrate (NO_3^-) and c. soluble reactive phosphorus (SRP). The colored vertical lines represent statistical changes in spatial variance among subcatchments based on change point analysis implemented for each catchment.

Continuous Monitoring: We continued high-frequency monitoring of water flow, DOC, nitrate, turbidity, conductivity, and dissolved oxygen at three catchment outlets (Kuparuk, Oksrukuyik, Trevor Creek) to quantify a) nutrient budgets across the sampling season and b) how hysteretic response to storm pulses changes as thaw depth increases.

- Preliminary high-frequency data from the Kuparuk demonstrate that DOM flux from upland tundra fundamentally shifts from source-limited (dilutes with flow) to transport-limited (increases with flow) as the thaw season progresses (Figure 3).
- Using concurrent nutrient and discharge measurements, we have estimated nitrogen and carbon budgets from June 15-September 1 for each catchment. Across all study catchments, the majority of carbon mass was exported during the period between July 15 and August 15, corresponding with higher precipitation.

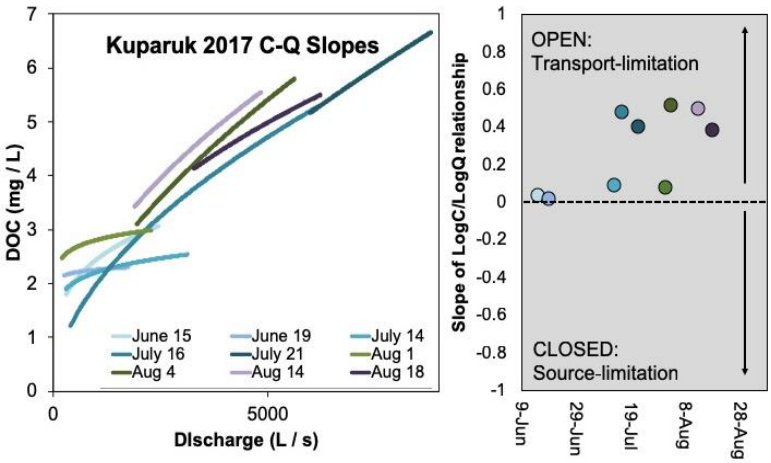

Figure 3. Left panel: Concentration-Discharge relationships for dissolved organic carbon (DOC) across the 2017 summer season in the Kuparuk River. Right Panel: Slope of the C-Q relationships, indicating a shift from chemostatic to transport-limited behavior across the thaw season.

Lakes

Key outcomes or other achievements:

Covered under Significant Results

What opportunities for training and professional development has the project provided?

- **REU:** The LTER core budget supported two REU students in 2018, one examining stream processes (Allie Pankoff) and one examining fish and lake processes (Ryan West).
- The LTER and affiliated projects have many undergraduate, graduate, and post-doctoral students (listed as participants) who make use of our long-term experiments or benefit either directly through salaries or through user days, travel and other logistics. Many of these students now interact with several projects because of their PIs association with the LTER and many attend our winter meeting in Woods Hole. In addition to interactions with a diverse array of scientists while at the Toolik Field Station, they participate in poster sessions/Toolik Talking Shop where students present their results at the end of the summer.
- **Research Experience for Teachers:** Supported 2 Teachers (Pokyzywinski and Tichenor) and the LTER Education Representative (Morrison) assisted in data collection and processing of plant and fauna sampling at Toolik field station for 10 days at Toolik Field Station. Research was led by Adrian Rocca and John Moore.
    - Both teachers have been working to develop curriculum related to their summer research experience at Toolik Field Station and we anticipate classroom implementation by June 2019.

    - The RET team also collaborated with Dr. Bret-Harte's PolarTREC teacher, Svea Anderson, of Arizona, throughout the Fall 2018 semester, engaging she and her students in the tardigrade student research project.
- **Meetings:** Ed Rastetter and Rose Cory attended the LTER Science Council meeting, Madison, WI, May 2018: Ed Rastetter, Alex Huryn, and Jennie McLaren attended the LTER All-Scientists meeting Pacific Grove, CA October 2018 along with post docs Heidi Golden, and Megan Machmuller, graduate student Adiranna Trusiak, our Education Coordinator Amanda Morrison, and our Information Manager James Laundre.
- **LTER Schoolyard Ecology:** Amanda worked to make connections with other LTER Education Representatives in an effort to work together on various projects – Schoolyard Book series, collaboration with other LTER sites to plan how to bring polar research data in schools, and collaboration with other Alaska LTERs in an effort to collaborate with the North Slope Borough. Amanda attended monthly LTER Education meetings throughout the year as well as the All Scientist Meeting. Amanda also worked throughout the fall 2018 semester with the Summer 2018 teachers to develop K-12 curricula around Tardigrades (to be completed in Spring 2019).

How have the results been disseminated to communities of interest?

Yes through journal publications and press reports listed below under products

What do you plan to do during the next reporting period to accomplish the goals?

Terrestrial: In the next field season, we will continue to monitor plant community composition and timing of plant green-up in our long-term experimental plots in multiple plant communities including moist acidic tussock, moist non-acidic tussock, dry heath, wet sedge, and shrub. This includes our newly established artificial warming experiments that create new opportunities to understand the response of tundra communities to increased air temperatures. We will continue interacting with collaborating projects as detailed in the proposal and continue to assemble datasets for web publication as well as results for dissemination.

Land-water Interactions. During the winter months we will continue to analyze the chemistry of the samples collected in the first summer of the research. We will update the data products files and begin assembling results into publications. In the next field season, we will continue with maintaining the long-term data collections from our LTER monitoring sites, and we will continue with the research and sample collection according to the program goals and the specifics outlined in the proposal.

Streams: We will continue to monitor discharge, nutrients, benthic algae, benthic macroinvertebrates, fish, and whole-stream metabolism during the open-water season in the primary long-term river study sites: Kuparuk River and Oksrukuyik Creek. We will continue to monitor the state (cover and nutrient content) of the bryophyte community in the reach of the Kuparuk River that was enriched with phosphorus from 1983 until 2016, to follow the trajectory of ecosystem recovery after the enrichment ceased in 2018. We will continue to explore the use of eDNA techniques to identify spatial patterns of key fish species in streams in the region and we will conduct additional synoptic sampling events in selected watersheds (mountain, tundra,

and tentatively coastal plain) to assess spatial patterns of solute variability in the context of river network structure and the landscape context.

Lakes. During the winter months we will continue to analyze limnological and fish data and analyze zooplankton and invertebrate samples collected in the first summer of the research. We will update the data products files, and begin assembling results into publications. In the next field season we will continue with maintaining the long-term data collections from our LTER monitoring sites, and we will continue with the research and sample collection according to the program goals and the specifics outlined in the proposal.

Products:

Within the Products section, you can list any products resulting from your project during the specified reporting period, such as:

Journal articles:

Gough, L. and Johnson, D.R. 2018. Mammalian herbivory exacerbates plant community responses to increased soil nutrients in two Alaskan tundra plant communities. *Arctic Science.* DOI: 10.1139/AS-2017-0025

Krause, J., J. Pérez, H. Chmura, S. Meddle, K. Hunt, L. Gough, N. Boelman, and J. Wingfield. 2018. Weathering the storm: Do arctic blizzards cause repeatable changes in stress physiology and body condition in breeding songbirds? *General and Comparative Endocrinology* DOI: 10.1016/j.ygcen.2018.07.004

Chmura, H., J. Krause, J. Pérez, A. Asmus, S. Sweet, K. Hunt, S. Meddle, R. McElreath, N. Boelman, L. Gough and J. Wingfield. 2018. Snowfall decreases offspring survival in two migratory arctic-breeding songbird species. *Journal of Avian Biology* DOI: 10.1111/jav.01712.

Asmus, A.L., H.E. Chmura, T.T. Høye, J.S. Krause, S.K. Sweet, J.H. Pérez, N.T. Boelman, J.C. Wingfield, and L. Gough. 2018. Shrub shading moderates the effects of weather on arthropod activity in arctic tundra. *Ecological Entomology* DOI: 10.1111/een.12644.

Oliver, R. D. Ellis, H. Chmura, L. Gough, J. Krause, J. Pérez, S. Sweet, J. Wingfield, and N. Boelman. 2018. Eavesdropping on the Arctic: Automated bioacoustics reveal dynamics in songbird breeding phenology. *Science Advances* DOI: 10.1126/sciadv.aaq1084.

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Liu, X., K. Koba, L.A. Koyama, S.E. Hobbie, M.S. Weiss, Y. Inagaki, G.R. Shaver, A.E. Giblin, S. Hobara, K.J. Nadelhoffer, M. Sommerkorn, E.B. Rastetter, G.W. Kling, J.A. Laundre, Y. Yano, A. Makabe, M. Yano, C. Liu. 2018. Nitrate is an important nitrogen source for arctic plants. Proc. National Academy of Sciences 115:3398-. *doi.org/10.1073/pnas.1715382115*

Trusiak, A., L. A. Treibergs, G. W. Kling, and R. M. Cory. 2018. The role of iron and reactive oxygen species in the production of CO_2 in arctic soil waters. Geochimica et Cosmochimica Acta 224: 80–95. doi.org/10.1016/j.gca.2017.12.022

Cory, R. M. and G. W. Kling. 2018. Controls on DOM degradation along the aquatic continuum: the influence of interactions between light, chemistry, and biology. Limnology and Oceanography Letters 3(3):102-116. *doi: 10.1002/lol2.10060*

King, T. V., B. T. Neilson, M. T. Rasmussen. 2018. "Estimating discharge in low order rivers with high resolution aerial imagery." Water Resources Research 54, 863-878. *doi:10.1002/2017WR021868*

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Kendrick M.R., A.D. Huryn, W.B. Bowden, L.A. Deegan, R.H. Findlay, A.E. Hershey, B.J. Peterson, J.P. Beneš, and E.B. Schuett. 2018. Linking permafrost thaw to shifting biogeochemistry and food web resources in an arctic river. Global Change Biology 24(12): 5738-5750. https://doi.org/10.1111/gcb.14448

Kendrick, M.R., A.E. Hershey, and A.D. Huryn. 2018. Disturbance, nutrients, and antecedent flow conditions affect macroinvertebrate community structure and productivity in an arctic river. Limnology and Oceanography Special Issue: Long-term Perspectives in Aquatic Research. https://doi.org/10.1002/lno.10942

Parker, S.P., W.B. Bowden, M.B. Flinn, C.D. Giles, K.A. Arndt, J.P. Beneš, and D.G. Jent. 2018. Effect of particle size and heterogeneity on sediment biofilm metabolism and nutrient uptake scaled using two approaches. Ecosphere 9(3):e02137. 10.1002/ecs2.2137

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Euskirchen, E.S., A.L. Breen, K. Timm, S. Gray, T.S. Rupp, P. Martin, J. Reynolds, A. Sesser, K. Murphy, J.S. Littell, A.Bennett, W.R. Bolton, T. Carman, H. Genet, B. Griffith, T. Kurkowski, M.J. Lara, S.Marchenko, D. Nicolsky, S. Panda, V. Romanovsky, R. Rutter, C.L. Tucker, A.D. McGuire. In press. Co-production of knowledge: Developing the

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Books:

Book chapters:

van Gestel, Natalie, S., W. Andriuzzi, F.S. Chapin III, J.C. Moore, Y. Pressler, V. Salmon, T. Schuur, G. Shaver, R.T. Simpson, D. Wall. 2019. Long-term warming research in high-latitude ecosystems: Responses from polar ecosystems and implications for future climate. In: Ecosystem consequences of soil warming: Microbes, vegetation, fauna, and soil biogeochemistry, J. Mohan (Ed), Elsevier.

Thesis/Dissertations:

Hendrickson, P.J. 2018. *Ecological characterization of the Kuparuk River aufeis field, North Slope Alaska* (Master's thesis). Available from ProQuest Dissertations and Theses database. (UMI No. 10809582)

King, Tyler V. 2018. Quantifying Dominant Heat Fluxes in an Arctic Alaskan River with Mechanistic River Temperature Modeling (PhD Dissertation) https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=8333&context=etd

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Other conference Presentations/papers:

Moore, J.C., P. Budy, L. Gough, A. Huryn, A. Koltz, S.M. Parker, Y. Pressler, G.R. Shaver, and S. Simpson. The Different Responses of Arctic Terrestrial and Aquatic Food Webs to Long-term Nutrient Additions. American Geophysical Union Annual Meeting, Washington, DC, December 2018.

Gough, L. and J.R. McLaren. Long-term nutrient addition in arctic tundra alters decomposition rates through multiple mechanisms. Ecological Society of America Annual Meeting, New Orleans, LA, August 2018 (poster).

Fetcher, Ned. Ecotypic variation in an Arctic sedge and its consequences in a changing climate.Invited Talk given at Kent State University, Kent, Ohio 2 February 2018

Carey, JC, Thomas C. Parker, Ned Fetcher, and Jianwu Tang. Poster: Biogenic silica accumulation varies across tussock tundra plant functional type. Toolik Field Station All-Scientists Meeting. Portland, OR, 27-28 January 2018

Fetcher, Ned., Thomas C. Parker, Jessica L. Schedlbauer, Elizabeth Stunz, Michael L. Moody, Jianwu (Jim) Tang, James B. Mcgraw, Sal Curasi. Talk: Ecotypic variation in Eriophorum vaginatum: physiology and genetics. Oral Presentation at the 19th ITEX Meeting Integrating Tundra Structure, Function and Change. 25-27 April 2018, Stirling, Scotland, UK

Fetcher, Ned., Thomas C. Parker, James B. Mcgraw, Michael L. Moody, Jianwu (Jim) Tang, Elizabeth Stunz,. Poster: The effects of local adaptation on ecosystem response to climate change. II Joint Congress on Evolutionary Biology. 18-22 August 2018 Montpellier 2018, France

Fetcher, Ned, Thomas C. Parker, Jianwu Tang, Michael M. Moody, James B. McGraw, Jessica L. Schedlbauer, Cynthia C. Bennington, Salvatore Curasi. (2018). Probing the Panglossian Paradigm: Local adaptation in *Eriophorum vaginatum* and its relation to functional traits. Abstract [B11E-2183] presented at 2018 Fall Meeting, AGU, Washington, D.C., 10-14 Dec.

Curasi, Salvatore Rex, Thomas C. Parker, Adrian V. Rocha, Michael M. Moody, Jianwu Tang, Ned Fetcher. (2018). Ecotypes impact GPP in Eriophorum vaginatum L. with implications for the Arctic C cycle. Abstract [B12C-02] presented at 2018 Fall Meeting, AGU, Washington, D.C., 10-14 Dec.

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Parker, TC, Jianwu Tang, Mahalia Clark, Michael L. Moody, Ned Fetcher. Poster: Ecotypic differences in the phenology of the tundra species *Eriophorum vaginatum* reflect sites of origin. Toolik Field Station All-Scientists Meeting. Portland, OR, 27-28 January 2018

Fetcher, Ned. Climate change research in Alaska. Talk presented to Community Connections to Our Watershed Environmental Forum at Wilkes University, 11 January 2018.

Kling, G. W., G. Shaver, J. Hobbie, A. Giblin, V. Romanovsky, E. Rastetter. 2018. Causes of Multi-decadal Environmental Change near Toolik Lake, Arctic Alaska. POLAR 2018, IASC-SCAR 15-26 June, Davos, #2141.

Crump, B., G. Kling. 2018. Dispersal of microbes in aquatic systems: a decade of research using high-throughput DNA sequencing. Association for the Sciences of Limnology and Oceanography, Summer Meeting, 10-15 June, Victoria, B.C., p. 33.

Cardenas, M. B., B. Neilson, M. O'Connor[2], M. Rasmussen, T. King, G. Kling. 2018. Groundwater Exchanges on the Land Surface Control Stream Chemistry in Permafrost. POLAR 2018, IASC-SCAR 15-26 June, Davos, #1543.

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O'Connor, M.T., K.D. Nicholaides, M.B. Cardenas, B.T. Neilson, G.W. Kling. 2018. "Predictability of variable arctic soil hydraulic and thermal properties, and implications of such variability on future thaw." 2018 Fall Meeting, American Geophysical Union, December 10-14, 2018. Abstract C43C-1812. Washington, D.C.

King, T.V., B.T. Neilson. 2018. "Characterization of Spatial Heterogeneity in River Temperatures in a Tundra River Using Thermal Infrared Imagery." 2018 Fall Meeting, American Geophysical Union, December 10-14, 2018. Abstract H21L-1828. Washington, D.C.

O'Connor, M.T., K.D. Nicholaides, S.B. Ferencz, M.B. Cardenas, B.T. Neilson, A. Jan, E.T. Coon, G.W. Kling. 2018. "Impact of a depth-variable organic mat on thaw and groundwater flow in continuous permafrost" November 2018, Geological Society of America Annual Meeting. Indianapolis, IN.

King, T.V., B.T. Neilson. 2018. "Identifying source areas for flow and heat in the Kuparuk River, Alaska" November 2018, Geological Society of America Annual Meeting. Indianapolis, Indiana.

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Abbott, B.W., S. Natali, and J. Zarnetske. Break-out session on Outreach and Activism at the Permafrost Carbon Network meeting, December 9th, 2018, Washington D.C.

Abbott, B.W., E. Wologo, S. Textor, S. Shakil, S. Zolkos, S. Ewing, R. Spencer, M. Baker, S. Tank, J. O'Donnell, K.P. Wickland, J. Lee-Cullin, J.P. Zarnetske, F. Liu, Y. Yang, P. Kortelainen, J. Kolehmainen, J. Dean, J. Vonk, R.M. Holmes, G. Pinay, P.J. Mann, S. Cottingham. Could priming and nutrient effects from degrading permafrost alter dissolved organic matter dynamics in permafrost rivers? European Conference On Permafrost (EUCOP5), Chamonix, France, Jun. 2018.

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Golden, H.E., L.A. Deegan, M.C. Urban, and C.J.A. MacKenzie. March 23, 2018. FishScape: Tracking fish movement through space and time. University of New Haven, New Haven, CT.

Golden, H.E., C.J.A. MacKenzie, L.A. Deegan, and M.C. Urban. June 28, 2018. Spawning displacement predicts fine-scale genetic differentiation. American Fisheries Society Southern New England Chapter (SNEC AFS). Narragansett, RI.

Golden, H.E., L.A. Deegan, M.C. Urban, and C.J.A. MacKenzie. October 3, 2018. Arctic Grayling as foundation species in oligotrophic freshwater systems. Long-Term Ecological Research Network All Scientists Meeting (LTER-ASM). Pacific Grove, CA.

Golden, H.E., L.A. Deegan, and M.C. Urban. December 5, 2018. Using genetics to inform management decisions for climate change. Northeast Climate Adaptation Science Center. Amherst, MA.

Gooseff, M.N., P.J. Hendrickson, A.D. Huryn, M.A. Briggs & N. Terry. Arctic aufeis fields host the large hyporheic zones that serve as winter oases**.** American Geophysical Union, Washington, D.C., 10-14 December 2018.

Urban, M.C. Evolutionary refugia for climate change. Climate refugia workshop, Bordeaux, France.

Urban, M.C. October 4, 2018. Improving the forecast for biodiversity in the global heat age. Invited seminar, Pathobiology, UConn, Storrs, CT.

Zarnetske, J.P., B. Abbott, G. Pinay, G. Gruau, W.B. Bowden, A.J. Shogren, F. Iannucci. On the value of collecting long-term, periodic, synoptic water chemistry data in stream networks: Revealing structure and stability of headwater conditions. Fall 2018 Meeting of the American Geophysical Union, Washington DC, Dec. 2018.

Rastetter, EB. October 1-4, 2018. Climate change at the Arctic LTER (workshop presentation). Long-Term Ecological Research Network All Scientists Meeting (LTER-ASM). Pacific Grove, CA

Rastetter, EB, WB Bowden, P Budy, A Giblin, L Gough, and GW Kling. October 1-4, 2018. Arctic LTER: The Role of Biogeochemical and Community Openness in Governing Response to Climate Change and Disturbance (Site Poster). Long-Term Ecological Research Network All Scientists Meeting (LTER-ASM). Pacific Grove, CA.

Shaver, GR. Forty years of change in composition and structure of monitored and manipulated Alaskan tundra ecosystems. Talk presented at the 22nd ITEX Meeting on Integrating Tundra Structure, Function and Change, 25-27 April 2018, University of Stirling, Scotland

Sheppy, J., M. Suchocki, M. Muller-Girard and L. Gough. 2018. The effects of fertilization on plant community structure and tundra vole activity in moist acidic tundra. Poster presented at Biology Research Symposium, Towson University, December 2018.

Pressler, Y., Simpson, R., Yepa, F., Koltz, A., Rocha, A., Moore, J.C. 2019. Arctic tundra soil food web structure, function, and stability one after wildfire. Soil Science Society of America, San Diego CA, January 2019.

Yepa, F., Salter, M., Simpson, R., Pressler, Y., Moore, J.C. 2018. Soil food web analysis of trophic interactions and nutrient dynamics under Arctic shrub and tussock Tundra ecosystems. LTER All Scientist Meeting, Asilomar, CA, September 2018.

Dunleavy, H. and Mack, M.C. (2018), The role of ectomycorrhizae in Arctic shrub expansion: Opposing effects of warming and fertilization on fungal community and function. presented at 2018 Fall Meeting, AGU, Washington, DC, 10-14 Dec.

Stuart, Julia M., Holland Moritz, Hannah, Mack, Michelle C., Lewis, Lily R, Fierer, Noah, McDaniels, Stuart F., Ponciano, José Miguel, Lewis, Lily R., and Mack, Michelle C. Quantifying moss associated nitrogen fixation in Alaska. Oral presentation delivered at the International Molecular Moss Science Society annual meeting, St. Petersburg, FL, June 2018.

Stuart, Julia M., Lewis, Lily R., and Mack, Michelle C. Rate variation in moss associated N fixation across a diverse group of host species in Alaska is driven by moss type and latitudinal location. Invited eLightning presentation, American Geophysical Union fall meeting, Washington, D.C., December 2018.

Stuart, Julia M., and Mack, Michelle C. Moss associated N fixation rates in Alaska are uncorrelated with the photosynthetic activity of the natural abundance 15N signature of host mosses. Accepted for oral presentation, American Geophysical Union fall meeting, Washington, D.C., December 2018.

Hewitt, R. E., H. Genet, D. L. Taylor, A. D. McGuire, and M.C. Mack. The effects of deep nitrogen and root traits on Arctic vegetation dynamics. Polar 2018, Davos, Switzerland, June 2018.

Hewitt, R. E., H. Genet, D. L. Taylor, A. D. McGuire, and M.C. Mack. The roles of plant roots, mycorrhizal fungi, and uptake of deep nitrogen in the permafrost carbon feedback to a warming climate. Center for Ecosystem Science and Society, Northern Arizona University, Flagstaff, Arizona, March 2018

Euskirchen, E.S. 2018. Long-term release of carbon dioxide from tundra ecosystems in northern Alaska. U.S. – China Carbon Consortium. Jiujiang, China. Invited.

Euskirchen, E.S. 2018. Integrating plant trait data across high latitude ecosystems to inform dynamic vegetation models. LTER-NEON-CZO Workshop. Boulder CO.

West, R. 2019. Feeding ecology and diet overlap of coexisting lake trout and arctic grayling in two open and connected arctic lakes. *To be* presented at the Utah Chapter of the American Fisheries Society meeting, March 12-14, Provo, UT.

Other publications:

News articles or publications about your work at Toolik:

Nash, J. Madeleine. Feb 19, 2018. An unfrozen North. High Country News. http://www.hcn.org/issues/50.3/an-unfrozen-north

Lindsey, Kelsey. Mar 16 2018. What does 'shrubification' mean for the Arctic? Arctic Today. https://www.arctictoday.com/shrubification-mean-arctic/

Rozell, Ned. 2019. Overflow ice becomes a northern oasis. The Arctic Sounder. http://www.thearcticsounder.com/article/1814overflow_ice_becomes_a_northern_oasis_1

National Science Foundation Science 360 Video. Science Now: Episode 56. Based on findings from King et al. 2018 (https://doi.org/10.1002/2017WR021868). https://science360.gov/obj/video/6702b596-2feb-4919-869b-3d2b11f245a4/nsf-science-now-episode-56

Environmental Molecular Sciences Laboratory (EMSL): Sunlight stimulates microbial respiration of organic carbon. https://www.emsl.pnnl.gov/emslweb/news/sunlight-stimulates-microbial-respiration-organic-carbon, https://phys.org/news/2017-10-sunlight-microbial-respiration-carbon.html

Abbott et al. 2018 (Ecology Letters) Press Release in MSU Today "Streams can be sensors", Dec. 29, 2017. https://msutoday.msu.edu/news/2017/streams-can-be-sensors/

The Environmental Report "Small streams tell us a lot about our ecosystems. But are we listening?", Jan. 4 2018. http://www.michiganradio.org/post/small-streams-tell-us-lot-about-our-ecosystems-are-we-listening

Zarnetske et al. 2018 (GRL) Press Release in MSU Today "Carbon Goes with the Flow", Nov. 13, 2018. https://msutoday.msu.edu/news/2018/carbon-goes-with-the-flow/

Zarnetske and Shogren interview for the MSU Canadian Studies Center Arctic Research Platform, Nov. 2018 https://canadianstudies.isp.msu.edu/initiatives/arctic-research-platform/

Technologies or techniques:
Patents:
Inventions:
Licenses:
Websites:
http://arc-lter.ecosystems.mbl.edu/
http://www.k-state.edu/ecoforecasting/SCALER/
http://www.usu.edu/fel/research/arctic-lake-ecosystems/

Other Products:

Participants:
What individuals have worked on the project?
PIs

First Name: Edward
Last Name: Rastetter
Email address: erastetter@mbl.edu
Most senior project role: PI
Nearest person month worked: 3
Contribution to LTER Project: coordinate project, prepare these reports, simulation modeling, chairs ARC LTER Executive Committee
Funding Support: this grant & Marine Biological laboratory

First Name: Laura
Last Name: Gough
Email address: lgough@towson.edu
Most senior project role: co-PI
Nearest person month worked: 1
Contribution to LTER Project: coordinate terrestrial research program, serves on ARC LTER Executive Committee
Funding Support: this grant & Towson University

First Name: George
Last Name: Kling
Email address: gwk@umich.edu
Most senior project role: Principle investigator
Nearest person month worked: 1
Contribution to Project:
George Kling, University of Michigan, is co-PI on the LTER project responsible for coordinating the "land-water research" activities.
Funding Support: this grant & University of Michigan

First Name: William
Last Name: Bowden
Email address: wbowden@uvm.edu
Most senior project role: co-PI
Nearest person month worked: 1
Contribution to LTER Project: Leads the Streams component, serves on ARC LTER Executive Committee
Funding Support: This grant, University of Vermont
Form of LTER Support: User days, travel

First Name: Phaedra
Last Name: Budy
Email address: phaedra.budy@usu.edu
Most senior project role: Co-PI

Nearest person month worked: 2
Contribution to LTER Project: supervises fish and limnological measurements on lakes, serves on ARC LTER Executive Committee
Funding Support: The Ecology Center at Utah State University

Faculty Associates

First Name: Anne
Last Name: Giblin
Email address: agiblin@mbl.edu
Most senior project role: Faculty Associate
Nearest person month worked: 2
Contribution to LTER Project: supervises biogeochemical measurements in lakes, serves on ARC LTER Executive Committee
Funding Support: This grant & Marine Biological laboratory

First Name: Byron
Last Name: Crump
Email address: bcrump@coas.oregonstate.edu
Most senior project role: Faculty associate
Nearest person month worked: 1
Contribution to Project:
Supervises microbiological measurements in lakes and streams, serves on ARC LTER Executive Committee.
Funding Support: NSF, Oregon State University

First Name: Gaius
Last Name: Shaver
Email address: gshaver@mbl.edu
Most senior project role: PI Emeritus
Nearest person month worked: 4
Contribution to LTER Project: Data analysis and synthesis, management advice
Funding Support (this or other projects)**:** Travel to field site and ITEX meeting
Form of LTER support (e.g., user days, travel, use of experimental plots, &c)**:** Travel expenses and user days

First Name: Rose
Last Name: Cory
Email address: rmcory@umich.edu
Most senior project role: Faculty associate
Nearest person month worked: 1
Contribution to Project:

Supervises photochemical and organic carbon measurements supporting our LTER project.
Funding Support: NSF, University of Michigan

First Name: Linda
Last Name: Deegan
Email address: ldeegan@whrc.org
Most senior project role: Faculty Associate
Nearest person month worked: 1
Contribution to LTER Project: Dr. Deegan is a collaborator on the Streams component of the ArcLTER project, and a co-PI on the Fishscape project. She is the primary coordinator of LTER Streams' fish population monitoring efforts.
Funding Support: NSF-OPP, Woods Hole Research Center
Form of LTER support: Field equipment maintenance

First Name: Ned
Last Name: Fetcher
Email address: ned.fetcher@wilkes.edu
Most senior project role: PI
Nearest person month worked: 2
Contribution to LTER Project: Prepared Manuscripts, Visited Tussock Transplant Site
Funding Support (this or other projects)**: PLR-1418010**
Form of LTER support (e.g., user days, travel, use of experimental plots, &c)**: User Days**

First Name: Bethany
Last Name: Neilson
Email address: bethany.neilson@usu.edu
Most senior project role: Faculty associate
Nearest person month worked: 1
Contribution to Project:
Contributes to hydrological measurements and modeling supporting our LTER project. **Funding Support:** Utah State University

First Name: Bayani
Last Name: Cardenas
Email address: Cardenas@jsg.utexas.edu
Most senior project role: Faculty associate
Nearest person month worked: 1
Contribution to Project:
Contributes to hydrological measurements and modeling supporting our LTER project. **Funding Support:** NSF, University of Texas

First Name: John
Last Name: Moore
Email address: john.moore@colostate.edu
Most senior project role: Faculty Associate
Nearest person month worked: 2
Contribution to LTER Project: Hosts our teachers program and studies soil food webs
Funding Support: **Colorado State University**

First Name: Alex
Last Name: Huryn
Email address: huryn@ua.edu
Most senior project role: Faculty Associate
Nearest person month worked: 1
Contribution to LTER Project: Dr. Huryn is a collaborator on the Streams component of the ArcLTER project, and the PI on the NSF-OPP Aufeis project. He is the primary coordinator of LTER Streams' monitoring of benthic macroinvertebrates.
Funding Support: NSF-OPP, University of Alabama
Form of LTER support: Field assistance

First Name: Carla
Last Name: Atkinson
Email address: carla.l.atkinson@ua.edu
Most senior project role: Collaborator
Nearest person month worked: 1
Contribution to LTER Project: Dr. Atkinson is the lead investigator on the "Growth of Two Arctic Mayfly Taxa Across Temperature" project. She has also provided field assistance to the Arctic LTER Streams effort while at TFS.
Funding Support: LTER
Form of LTER support: Field assistance, use of historic data to aid study design, user days, travel

First Name: Jay
Last Name: Zarnetske
Email address: jpz@msu.edu
Most senior project role: Collaborator
Nearest person month worked: 1
Contribution to LTER Project: Dr. Zarnetske is a co-PI on the "Dissolved Organic Matter in Arctic and Boreal Streams" project. Along with Dr. Abbott, he collaborates on the Arctic LTER Streams' synoptic nutrient sampling efforts.
Funding Support: LTER, Michigan State University

Form of LTER support: User days, travel, helicopter support, field assistance, sample analysis

First Name: Ben
Last Name: Abbott
Email address: benabbott@byu.edu
Most senior project role: Collaborator
Nearest person month worked: 1
Contribution to LTER Project: Dr. Abbott is a co-PI on the "Dissolved Organic Matter in Arctic and Boreal Streams" project. Along with Dr. Zarnetske, he collaborates on the Arctic LTER Streams' synoptic nutrient sampling efforts.
Funding Support: LTER, Brigham Young University
Form of LTER support: User days, travel, helicopter support, field assistance, sample analysis

First Name: Mark
Last Name: Urban
Email address: mark.urban@uconn.edu
Most senior project role: Collaborator
Nearest person month worked: 1
Contribution to LTER Project: Dr. Urban is the lead PI on the Fishscape project, and a collaborator on the Streams component of the ArcLTER project. Along with Dr. Deegan, he coordinates LTER Streams' fish population monitoring efforts.
Funding Support: NSF-OPP: Adaptability of a key arctic freshwater species to climate change
Form of LTER support: Maintenance of field equipment

First Name: Michelle
Last Name: Mack
Email address: michelle.mack@nau.edu
Most senior project role: Collaborator
Nearest person month worked: 2
Contribution to LTER Project: worked on three projects: Deep Roots, Snow-shrub, and Moss Dimensions. Deep Roots and Snow-shrub used the long-term warming and fertilization experiments. Snow-shrub and Moss Dimensions used the snow fences and species removal.
Funding Support (this or other projects)**: NSF Polar, NSF DEB Ecosystems, and State of Arizona**
Form of LTER support (e.g., user days, travel, use of experimental plots, &c)**: use of experimental plots and lab space**

First Name: Eugénie
Last Name: Euskirchen
Email address: seeuskirchen@alaska.edu

Most senior project role: Collaborator
Nearest person month worked: 2
Contribution to LTER Project: data collection and analysis
Funding Support (this or other projects)**: NASA, NSF-AON**
Form of LTER support (e.g., user days, travel, use of experimental plots, &c)**:**

First Name: Natalie
Last Name: Boelman
Email address: nboelman@ldeo.columbia.edu
Most senior project role: Collaborator
Nearest person month worked: 3
Contribution to LTER Project: analyzing data from LTER experimental plots
Funding Support (this or other projects): 1603777
Form of LTER support (e.g., user days, travel, use of experimental plots, &c): use of experimental plots

First Name: Kevin
Last Name: Griffin
Email address: griff@ldeo.columbia.edu
Most senior project role: Collaborator
Nearest person month worked: 1
Contribution to LTER Project: analyzing data from LTER experimental plots
Funding Support (this or other projects): 1603777
Form of LTER support (e.g., user days, travel, use of experimental plots, &c): use of experimental plots

First Name: Jennie
Last Name: McLaren
Email address: jrmclaren@utep.edu
Most senior project role: Collaborator
Nearest person month worked: 1
Contribution to LTER Project: processing samples and analyzing data from LTER experimental plots
Funding Support (this or other projects): 1603677
Form of LTER support (e.g., user days, travel, use of experimental plots, &c): use of experimental plots

First Name: Rebecca
Last Name: Rowe
Email address: Rebecca.Rowe@unh.edu
Most senior project role: Collaborator
Nearest person month worked: 1
Contribution to LTER Project: analyzing data from LTER experimental plots and AR burn sites

Funding Support (this or other projects): 1603654
Form of LTER support (e.g., user days, travel, use of experimental plots, &c): use of experimental plots, helicopter time to visit AR burn sites

First Name: Adrian
Last Name: Rocha
Email address: arocha1@nd.edu
Most senior project role: Collaborator
Nearest person month worked: 1
Contribution to LTER Project: eddy covariance at AR burn sites
Funding Support: University of Notre Dame
Form of LTER support: user days, travel, use of experimental plots, helicopter time to visit AR burn sites

First Name: Syndonia
Last Name: Bret-Harte
Email address: msbretharte@alaska.edu
Most senior project role: Collaborator
Nearest person month worked: 3
Contribution to LTER Project: plant community ecology
Funding Support: University of Alaska
Form of LTER support: use of experimental plots

OTHER PROFFESSIONALs

First Name: James
Last Name: Laundre
Email address: jlaundre@mbl.edu
Most senior project role: Other Professional
Nearest person month worked: 12
Contribution to Project: lead technician supervising work on LTER terrestrial research, data management, web site maintenance,
Funding Support: this grant

First Name: Jason
Last Name: Dobkowski
Email address: jdobkow@umich.edu
Most senior project role: Technician
Nearest person month worked: 12
Contribution to Project:
Jason Dobkowski assumed the responsibility of the senior technician on the Land-Water Interactions part of the LTER project in Fall 2013, and has continued working in that capacity until present.

Funding Support: NSF (this grant)

First Name: Frances
Last Name: Iannucci
Email address: fiannucc@uvm.edu
Most senior project role: Other Professional
Nearest person month worked: 12
Contribution to Project: Ms. Iannucci is the senior RA for the Streams component of the Arctic LTER. She is responsible for coordinating field efforts, sample analyses and data management for Arctic LTER Streams.**Funding Support: LTER, University of Vermont**

First Name: Daniel
Last Name: White
Email address: dwhite@mbl.edu
Most senior project role: Other Professional
Nearest person month worked: 12
Contribution to Project: lead technician supervising work on LTER lake research
Funding Support: this grant

First Name: Bonnie
Last Name: Kwiatkowski
Email address: bkwiatkowski@mbl.edu
Most senior project role: Other Professional
Nearest person month worked: 6
Contribution to Project: Technician working on LTER data management, simulation modeling
Funding Support: this grant,

First Name: Ruby
Last Name: An
Email address: rubyan@uchicago.edu
Most senior project role: Other Professional
Nearest person month worked: 3
Contribution to Project: summer technician working on LTER terrestrial research
Funding Support: this grant

First Name: Christopher
Last Name: Cook
Email address: chlcook@umich.edu
Most senior project role: Technician
Nearest person month worked: 6
Contribution to Project:

Chris Cook started working as a technician on this grant in June 2014 as a research assistant at the Toolik Field station in Alaska. He has continued working on the project as a technician starting in Fall 2014 at the University of Michigan.
Funding Support: NSF (this grant)

First Name: Johanna
Last Name: Albrigtsen
Email address: joal5806@colorado.edu
Most senior project role: Technician
Nearest person month worked: 4
Contribution to Project:
Johanna Albrigtsen worked as a technician on this grant from June-August 2018 as a research assistant at the Toolik Field station in Alaska.
Funding Support: NSF (this grant)

First Name: Sam
Last Name: Finnerty
Email address: finne203@umn.edu
Most senior project role: Other Professional
Nearest person month worked: 3
Contribution to Project: summer technician working on LTER Lakes
Funding Support: NSF (this grant)

First Name: Kyle
Last Name: Zollo-Veneck
Email address: kylezollo@gmail.com
Most senior project role: Other Professional
Nearest person month worked: 3
Contribution to Project: summer technician working on nutrient analyses
Funding Support: LTER (this grant)

First Name: Cameron
Last Name: MacKenzie
Email address: cmackenzie@atwaterresources.com
Most senior project role: Technician
Nearest person month worked: 1
Contribution to Project: Mr. MacKenzie is a technician for the Fishscape project. He is closely involved with Arctic LTER Streams' fish population monitoring efforts.
Funding Support: NSF-OPP: Adaptability of a key arctic freshwater species to climate change

First Name: Becca
Last Name: Frei

Email address: beccafrei@gmail.com
Most senior project role: Technician
Nearest person month worked: 3
Contribution to Project: Ms. Frei is the lab manager for Dr. Abbott's lab at BYU. She has been closely involved in the management and analysis of samples from Artic LTER Streams' synoptic nutrient sampling efforts.
Funding Support: Brigham Young University

First Name: Megan
Last Name: Muller-Girard
Email address: meg.mg216@gmail.com
Most senior project role: research assistant
Nearest person month worked: 3
Contribution to Project: helped collect data in the field
Funding Support: 1603760 and this award

(teachers)
First Name: Amanda
Last Name: Morrison
Email address: Amanda.j.morrison@colostate.edu
Most senior project role: Other Professional
Nearest person month worked: 2
Contribution to LTER Project: Coordinates educational activities for the Arctic LTER
Funding Support: Colorado State University, This grant

First Name: Andrea
Last Name: Pokrzywinski
Email address: andrea_pokrzywinski@lksd.org
Most senior project role: Other Professional
Nearest person month worked: 1
Contribution to Project: Bethel, AK High School teacher gaining research experience on schoolyard fund supplemented by the MBL; Assisted in food web data collection and in pluck field and lab work; curriculum development
Funding Support: This grant

First Name: Maureen
Last Name: Tichenor
Email address: mtichenor@falmouth.k12.ma.us>
Most senior project role: Other Professional
Nearest person month worked: 1
Contribution to Project: Falmouth, MA Elementary School teacher gaining research experience on schoolyard fund supplemented by the MBL; Assisted

in food web data collection and in pluck field and lab work; curriculum development
Funding Support: This grant

Postdoctoral associates

First Name: Thomas C
Last Name: Parker
Email address: t.c.parker@stir.ac.uk
Most senior project role: Post-doc
Nearest person month worked: 1
Contribution to Project: Prepared Manuscripts
Funding Support: University of Stirling, UK
Form of LTER support: Weather Data

First Name: Rodney
Last Name: Simpson
Email address: Rodney.simpson@colostate.edu
Most senior project role: Postdoctoral associate
Nearest person month worked: 2
Contribution to Project: Sampling and processing, Analysis and synthesis
Funding Support:
Form of LTER support: travel, user days

First Name: Heidi
Last Name: Golden
Email address: heidi.golden@uconn.edu
Most senior project role: Post-doc
Nearest person month worked: 1
Contribution to Project: Dr. Golden is the post-doc for the Fishscape project. She assists the Arctic LTER Streams efforts in fish population monitoring, and she has been particularly involved in the implementation of new environmental DNA sampling techniques as part of this effort.
Funding Support: NSF-OPP: Adaptability of a key arctic freshwater species to climate change
Form of LTER support: Field assistance, helicopter support for LTER-related activities, user days, travel

First Name: Arial
Last Name: Shogren
Email address: shogrena@msu.edu
Most senior project role: Post-doc
Nearest person month worked: 7

Contribution to Project: Dr. Shogren is the post-doc for the "Dissolved Organic Matter in Arctic and Boreal Streams" project. She assists the Arctic LTER Streams' synoptic nutrient sampling efforts, and processes much of the data from these sampling campaigns.
Funding Support: Michigan State University
Form of LTER support: Field assistance, use of field equipment, helicopter support for LTER-related activities, user days, travel

First Name: Rebecca
Last Name: Hewitt
Email address: Rebecca.hewitt@nau.edu
Most senior project role: Postdoctoral researcher
Nearest person month worked: 12
Contribution to Project: worked on Deep Roots and Snow-shrub.
Funding Support: NSF Polar
Form of LTER support: used experimental plots and lab space

Graduate students

First Name: Salvatore
Last Name: Curasi
Email address: Salvatore.R.Curasi.1@nd.edu
Most senior project role: Graduate Student
Nearest person month worked: 1
Contribution to Project: Prepared Manuscripts
Funding Support: University of Notre Dame

First Name: Stephen
Last Name: Klobucar
Email address: stephen.klobucar@gmail.com
Most senior project role: Graduate Student
Nearest person month worked: 12
Contribution to Project: Research and publications, supervising technicians in field and lab.
Funding Support: The Ecology Center at Utah State University

First Name: Karl
Last Name: Romanowicz
Email address: kjromano@umich.edu
Most senior project role: Graduate student
Nearest person month worked: 3

Contribution to Project:
Karl Romanowicz started working in Dr. George Kling's lab in 2017 and spent the 2018 field season at Toolik Lake beginning his PhD studies.
Funding Support: NSF, University of Michigan

First Name: Adrianna
Last Name: Trusiak
Email address: atrusiak@umich.edu
Most senior project role: Graduate student
Nearest person month worked: 3
Contribution to Project:
Adrianna Trusiak started in Dr. Rose Cory's lab in Fall 2014, and worked in part on the LTER project during the summers of 2014-2017 at Toolik Lake.
Funding Support: University of Michigan

First Name: Tyler
Last Name: King
Email address: tylerking@aggiemail.usu.edu
Most senior project role: Graduate student
Nearest person month worked: 3
Contribution to Project:
Tyler King started in Dr. Beth Neilson's lab at Utah State University and has worked in part on the LTER project during the summers of 2015-2017 at Toolik Lake. He defended his PhD dissertation in August 2018.
Funding Support: NSF, Utah State University

First Name: Jennifer
Last Name: Bowen
Email address: bowenjc@umich.edu
Most senior project role: Graduate student
Nearest person month worked: 3
Contribution to Project:
Jennifer Bowen started in Dr. Rose Cory's lab in Fall 2015, and worked in part on the LTER project during the summer of 2018 at Toolik Lake.
Funding Support: NSF, University of Michigan

First Name: Yue (Sophy)
Last Name: Wu
Email address: sophywu@utexas.edu
Most senior project role: Graduate student
Nearest person month worked: 3
Contribution to Project:
Sophy Wu started in Dr. Ann Chen's lab in Fall 2017, and worked in part on the LTER project during the summer of 2018 at Toolik Lake.
Funding Support: NSF, University of Texas

First Name: Michael
Last Name: O'Connor
Email address: mtoconnor12@gmail.com
Most senior project role: Graduate student
Nearest person month worked: 3
Contribution to Project:
Michael O'Connor started in Dr. Bayani Cardenas's lab at University of Texas and has worked in part on the LTER project during the summers of 2015-2018 at Toolik Lake.
Funding Support: NSF, University of Texas

First Name: Natasha
Last Name: Christman
Email address: christmn@oregonstate.edu
Most senior project role: Graduate student
Nearest person month worked: 3
Contribution to Project:
Natasha Christman started in Dr. Byron Crump's lab at Oregon State University and has worked in part on the LTER project during the summers of 2017 and 2018 at Toolik Lake.
Funding Support: NSF, Oregon State University

First Name: Austin
Last Name: Roy
Email address: anroy4@miners.utep.edu
Most senior project role: grad student
Nearest person month worked: 1
Contribution to Project: processing samples and analyzing data from LTER experimental plots
Funding Support: 1603760

First Name: Matthew
Last Name: Suchocki
Email address: msucho1@students.towson.edu
Most senior project role: grad student
Nearest person month worked: 1
Contribution to Project: coordinated Towson data collection, collected new data from LTER experimental plots
Funding Support: 1603760

First Name: Yamina
Last Name: Pressler
Email address: Yamina.pressler@colostat.edu
Most senior project role: Resercher and Lab Coordinator
Nearest person month worked: 2
Contribution to Project: Soil food web research, modeling

Funding Support (this or other projects)**: Arctic LTER, NSF LTREB, CSU**
Form of LTER support (e.g., user days, travel, use of experimental plots, &c)**: user days and use of experimental plots**

First Name: Haley
Last Name: Dunleavy
Email address: hd255@nau.edu
Most senior project role: Graduate student
Nearest person month worked: 12
Contribution to Project: Measured root-associated enzyme activity in the long-term fertilization gradient experiment (LMAT) and assisted in the tussock snow fence harvest
Funding Support: NSF DEB and State of Arizona
Form of LTER support: used experimental plots and lab space

First Name: Julia
Last Name: Stuart
Email address: jms2435@nau.edu
Most senior project role: Graduate student
Nearest person month worked: 12
Contribution to Project: Measured moss associated N-fixation; conducted moss transplant experiment
Funding Support: NSF Dimensions and State of Arizona
Form of LTER support: used lab space

First Name: Jessica
Last Name: Steketee
Email address: jess.steketee13@gmail.com
Most senior project role: grad student
Nearest person month worked: 3
Contribution to Project: coordinated small mammal trapping efforts, trapped at AR burn
Funding Support: 1603654

First Name: Elizabeth
Last Name: Min
Email address: ekm2130@columbia.edu
Most senior project role: grad student
Nearest person month worked: 3
Contribution to Project: small mammal project
Funding Support: 1603654

Undergraduate students

First Name: Mary

Last Name: Baddoo
Email address: mary.baddoo@wilkes.edu
Most senior project role: Research Assistant
Nearest person month worked: 0.5
Contribution to Project: Collected data on flies that live in flowers of Eriophorum vaginatum
Funding Support: PLR-1418010
Year of schooling completed: 3
Home Institution: Wilkes University
Fiscal year(s) REU Participant supported:

First Name: Nicholas
Last Name: Warren
Email address: ntwarren@uvm.edu
Most senior project role: Undergraduate student
Nearest person month worked: 5
Contribution to Project: Mr. Warren works as an assistant lab technician in Dr. Bowden's lab at UVM**. He assists Ms. Iannucci with sample analysis and data management.**
Funding Support: LTER
Year of schooling completed: Senior
Home Institution: University of Vermont
Fiscal year(s) REU Participant supported: 2018

First Name: Natasha
Last Name: Griffin
Email address: natasha.a.griffin@gmail.com
Most senior project role: Lab technician
Nearest person month worked: 6
Contribution to Project: Ms. Griffin worked as a lab technician in Dr. Abbott's lab at BYU, processing samples and data from the "Dissolved Organic Matter in Arctic and Boreal Streams" project and Arctic LTER Streams' synoptic sampling efforts.
Funding Support: Brigham Young University
Year of schooling completed: Senior
Home Institution: Brigham Young University
Fiscal year(s) REU Participant supported: 2018/2019

First Name: Allie
Last Name: Pankoff
Email address: appankoff@gmail.com
Most senior project role: Summer REU student
Nearest person month worked: 3

Contribution to Project: Ms. Pankoff was an REU student working with Arctic LTER Streams during the summer field season. She assisted with LTER Streams field sampling and conducted an independent research project contributing to LTER research goals.
Funding Support: LTER
Year of schooling completed: Junior
Home Institution: University of Vermont
Fiscal year(s) REU Participant supported: 2018

First Name: Mercedes
Last Name: Horn
Email address: mhorn@uvm.edu
Most senior project role: Technician
Nearest person month worked: 2
Contribution to Project: Ms. Horn works as an assistant lab technician in Dr. Bowden's lab at UVM. She assists Ms. Iannucci with sample analysis and data management.
Funding Support: LTER
Year of schooling completed: First Year
Home Institution: University of Vermont
Fiscal year(s) REU Participant supported: 2018/2019

First Name: Anna
Last Name: Hildebrand
Email address: Anna.Hildebrand@uvm.edu
Most senior project role: Technician
Nearest person month worked: 2
Contribution to Project: Ms. Hildebrand works as an assistant lab technician in Dr. Bowden's lab at UVM. She assists Ms. Iannucci with sample analysis and data management.
Funding Support: LTER
Year of schooling completed: Sophomore
Home Institution: University of Vermont
Fiscal year(s) REU Participant supported: 2018/2019

First Name: Sam
Last Name: Bratsman
Email address: sbratsmanx@gmail.com
Most senior project role: Technician
Nearest person month worked: 6
Contribution to Project: Mr. Bratsman worked as a field assistant for the "Dissolved Organic Matter in Arctic and Boreal Streams" project, participating in Arctic LTER Streams' synoptic sampling efforts. He also worked as a lab technician in Dr. Abbott's lab at BYU.
Funding Support: Brigham Young University
Year of schooling completed: Junior

Home Institution: Brigham Young University
Fiscal year(s) REU Participant supported: 2018/2019

First Name: Rachel
Last Name: Watts
Email address: miss.rachelwatts64@gmail.com
Most senior project role: Technician
Nearest person month worked: 6
Contribution to Project: Ms. Watts worked as a field assistant for the "Dissolved Organic Matter in Arctic and Boreal Streams" project, participating in Arctic LTER Streams' synoptic sampling efforts. She also worked as a lab technician in Dr. Abbott's lab at BYU.
Funding Support: Brigham Young University
Year of schooling completed: Senior
Home Institution: Brigham Young University
Fiscal year(s) REU Participant supported: 2018/2019

First Name: Sam
Last Name: Cairns
Email address: cairnss1@msu.edu
Most senior project role: Technician
Nearest person month worked: 1
Contribution to Project: Mr. Cairns worked as a lab technician in Dr. Zarnetske's lab at MSU, processing data for the "Dissolved Organic Matter in Arctic and Boreal Streams" project and Arctic LTER Streams' synoptic sampling efforts.
Funding Support: Michigan State University
Year of schooling completed: Senior
Home Institution: Michigan State University
Fiscal year(s) REU Participant supported: 2018/2019

First Name: Megan
Last Name: Duda
Email address: dudamega@msu.edu
Most senior project role: Technician
Nearest person month worked: 1
Contribution to Project: Ms. Duda worked as a lab technician in Dr. Zarnetske's lab at MSU, processing data for the "Dissolved Organic Matter in Arctic and Boreal Streams" project and Arctic LTER Streams' synoptic sampling efforts.
Funding Support: Michigan State University
Year of schooling completed: Senior
Home Institution: Michigan State University
Fiscal year(s) REU Participant supported: 2018/2019

First Name: Justin

Last Name: Kilmer
Email address: justin.kilmer27@gmail.com
Most senior project role: Undergraduate Student
Nearest person month worked: 3
Contribution to Project: Justin assisted with laboratory analysis of zooplankton and data analysis concerning fish distributions
Funding Support: Budy LTER NSF

First Name: Daison
Last Name: Weedop
Email address: daisonweedop@gmail.com
Most senior project role: Undergraduate Student
Nearest person month worked: 3
Contribution to Project: Daison has assisted with laboratory analysis of macroinvertebrates
Funding Support: Budy LTER NSF

First Name: Will
Last Name: Sutor
Email address: fsutor@uvm.edu
Most senior project role: Undergraduate Student
Nearest person month worked: 1
Contribution to Project: Will was an additional summer RA for Arctic LTER Streams during the summer field season. He primarily assisted Meghan Christie with field work in the senior RA's absence.
Funding Support: LTER (this grant)

Name: Meghan
Last Name: Christie
Email address: meghan.j.christie.17@gmail.com
Most senior project role: Undergraduate Student
Nearest person month worked: 3
Contribution to Project: Megnan was the summer RA for Arctic LTER Streams. She assisted the senior RA in field operations, and acted as the lead RA in the senior RA's absence.
Funding Support: LTER

First Name: Tara
Last Name: Larkin
Email address: tara.larkin@aggiemail.usu.edu
Most senior project role: Undergraduate Student
Nearest person month worked: 3

Contribution to Project: Tara assisted with laboratory analysis of zooplankton, invertebrates, and fish diets
Funding Support: LTER (this grant)

First Name: Ryan
Last Name: West
Email address: ranwest1@gmail.com
Most senior project role: Summer REU student
Nearest person month worked: 3
Contribution to Project: Mr. West did the preliminary fish and invertebrate investigations to be prepared for the lake closure experiment on I1 and I2. He collected fish, weighed and tagged them, and collected diets. He analyzed the diets and prepared a poster. He also assisted the graduate student with sculpin warming and feeding experiments.
Funding Support: LTER
Year of schooling completed: Junior
Home Institution: Utah State University
Fiscal year(s) REU Participant supported: 2018

First Name: Julian
Last Name: Sheppy
Email address: j.shepp16@gmail.com
Most senior project role: undergraduate
Nearest person month worked: 3
Contribution to Project: helped collect data in the field and helped in the lab in the fall
Funding Support: 1603760
Year of schooling completed: graduated December 2018
Home Institution: Towson University
Fiscal year(s) REU Participant supported: N/A

First Name: Felix
Last Name: Yepa
Email address: Felix.yepa
Most senior project role:
Nearest person month worked:
Contribution to Project:
Funding Support:
Year of schooling completed:
Home Institution: Colorado State University
Fiscal year(s) REU Participant supported:

First Name: Ceci
Last Name: Silberstein
Email address: csilberste@haverford.edu
Most senior project role: REU

Nearest person month worked: 3
Contribution to Project: Performed ecosystem model simulations for sites in the vicinity of the Arctic LTER
Funding Support: NSF (Part of the UAF REU program: REU Site: Understanding the Arctic as a System)
Year of schooling completed: Junior
Home Institution: Haverford College
Fiscal year(s) REU Participant supported: 2018

What other organizations have been involved as partners?

Type of Partner Organization, Name, Location, Partner's contribution to the project

University, Towson University, Towson, MD 21252, home institution L. Gough
University, University of Michigan, Ann Arbor, MI 48109, home institution G. Kling, R Cory
University, University of Vermont, Burlington, VT 05405, home institution W. Bowden
University, Utah State University, Logan UT 84322, home institution, P. Budy and B. Neilson
University, Oregon State University, Corvallis, OR 97331, home institution B. Crump
University, Colorado State University, Fort Collins, CO 80523, home institution J. Moore
Research, Woods Hole Research Center, Falmouth, MA 02540, home institution, L. Deegan
University, University of Alabama, Tuscaloosa, AL 35487, home institution A. Huryn
University, University of Texas, Austin TX 78712, home institution B. Cardenas and A. Chen

University, Wilkes University, Wilkes-Barre PA 18766, home institution of N Fetcher
University, University of Alabama, Tuscaloosa, AL 35487, home institution of A Huryn, C Atkinson
University, **Michigan State University**, East Lansing MI 48824, home institution of J Zarnetske
University, **Brigham Young University**, Provo UT 84602, home institution of B Abbott
University, University of Connecticut, Storrs, CT 06269, home institution of M Urban
University, Northern Arizona University, Flagstaff AZ 86001, home institution of M Mack
University, University of Alaska, Fairbanks, AK 99775, home institution of MS Bret-Harte, E Euskirchen
University, Colombia University, Palisades NY 10964, home institution of K Griffin & N Boelman
University, University of Texas, El Paso TX 79968, home institution of J McLaren
University, University of New Hampshire, Durham NH 03824, home institution of R Rowe
University, University of Notre Dame, Notre Dame IN 46556, home institution of A Rocha

Have other collaborators or contacts been involved?

Faculty associates on collaborating grants:

Aanderud, Zach: zachary_aanderud@byu.edu, Brigham Young University,
Buckeridge, Kate: kmbuckeridge@gmail.com, Lancaster University, UK
Carey, Joanna: jcarey@babson.edu, Babson College
Natali, Susan: snatali@whrc.org, Woods Hole Research Center

Wallenstein, Matthew: matthew.wallenstein@colostate.edu, Colorado State University

Postdoctoral scientists on collaborating grants:

Machmuller, Megan: megan.machmuller@colostate.edu, Colorado State University, response of below-ground processes to warming and fertilization

Thiede, Gary: gary.thiede@usu.edu, Utah State University, Lake and streams fish populations

Graduate students on collaborating grants:

Baker, Kristina: bakerkri@oregonstate.edu, Oregon State University, monitoring Toolik Lake

Drew, Jackson: jwdrew@alaska.edu, University of Alaska, species removal experiment

Lynch, Laurel: laurellynch@gmail.com, Colorado State University, DOE & NSF soil microbial process projects

Other professionals on collaborating projects:

Frei, Becca: beccafrei@gmail.com, Brigham Young University, "Dissolved Organic Matter in Arctic and Boreal Streams" project.

Huish, Allie: allie.huish.lax@gmail.com, Utah State University, Lake warming project

Ludwig, Sarah: sludwig@whrc.org, Woods Hole Research Center, NASA & ABoVE C cycling projects and MBL-UChicago seed grant

MacKenzie, Cameron: cmackenzie@atwaterresources.com, Water Resources, Fishscape project.

Minions, Christina: cminions@whrc.org, Woods Hole Research Center, NASA & ABoVE C cycling projects

Spann, Sedona: Sedona@nau.edu, Norther Arizona University, root-associated enzyme activity in warming, fertilization, snow fence, and the species removal experiment.

Undergraduates, REUs on collaborating grants:

Griffin, Natasha: natasha.a.griffin@gmail.com, Brigham Young University, "Dissolved Organic Matter in Arctic and Boreal Streams"

Salter, Morgan: Colorado State University, Soil processes

Wilcots, Megan: mew2210@columbia.edu, Columbia University, Team Vole

Yappa, Felix: Colorado State University, Soil processes

Impacts

What is the impact on the development of the principal discipline(s) of the project?

A key indicator of impact is the number and diversity of citations from the ARC LTER. In our proposal we reported that we had over 35,000 citations of the 579 journal publications since 1975 that include contributions from ARC LTER scientists and their collaborators with an overall h-index of 101. In addition, ARC LTER scientists had produced 7 books, 95 book chapters, 35 PhD theses, 66 Master's theses, and 15 honor's theses. This past year we added 35 papers to our publication list, 1 book chapter, and 2 PhD theses. Our project website is regularly used as a source of data, with data downloads averaging 5-10 per week.

The ARC LTER attracts collaborators from all over the world to work at Toolik Lake, make measurements on our long-term manipulations of tundra, streams, and lakes, and make use of our monitoring program and data. Largely because of this leveraging on LTER capabilities, the area around Toolik is the most thoroughly described and studied arctic landscape in the world. Research results from Toolik Lake are often used in comparative studies at other sites. Many of the ideas that drive research in other arctic landscapes were developed from research at Toolik Lake. Examples include the Danish Greenland Ecosystem Monitoring (GEM) programs at Zackenberg and Nuuk, which used the ARC LTER design as a model for their establishment 20 years ago, and which have continued to call on ARC personnel for collaboration and advice (e.g., Hobbie et al. 2017); The International Tundra Experiment (ITEX) is another example, currently using our experience in Alaska to design an international program in ecotypic and within-species genetic adaptations. Examples of impacts outside the Arctic include research to document C losses from surface waters as a component of regional and global C budgets, first pointed out by Kling and colleagues working at Toolik Lake in the 1990s, and the Kuparuk river fertilizer experiment and N isotope experiments, which were the inspiration for the continent-wide STREON experiment.

What is the impact on other disciplines?

None to report

What is the impact on the development of human resources?

This year we provided support and training for two K-12 teachers who apply what they learned in their class rooms and contribute to an ongoing network of previously supported teachers who post curricula and share lesson plans. We also supported two REU students from our core funding and support about 18 more undergraduate students either directly through summer salaries or through user days, travel, and other logistics. There are over 40 graduate students and post-doctoral students that make use of our long-term experiments and/or derive support in the form of user days, travel, and other logistics. In addition the summer research assistants gain training and field experience that they often take with them in the pursuit of higher degrees.

What is the impact on physical resources that form infrastructure?

The Arctic LTER has set up many long term experimental plots, streams, and lakes. We encourage the use of these resources by researchers outside the LTER after review and approval and provide our web site as a data repository (automatically uploaded to EDI site).

What is the impact on institutional resources that form infrastructure?

The Arctic LTER project has played a primary role in the development of Toolik Field Station into the Flagship Arctic Research Station that it now is, including lodging, laboratories, and other services to a wide array of research projects including ARC LTER. The solid foundation of research established by the ARC LTER was a major factor in the choice of Toolik Lake as a NEON site.

What is the impact on the information resources that form infrastructure?

ARC LTER is one of 7 sites using the LTER Drupal Ecological Informational Metadata System (DEIMS) which is based on the open source Drupal content management system (https://www.drupal.org/project/deims). This system provides web presentation/data discovery, dataset management and for the upload of datasets to the LTER network data portal (now the Environmental Data Initiative (EDI) data portal).

The Arctic LTER information manager (IM) actively contributes to the continued development of DEIMS via software enhancements, issue resolutions and discussions with other LTER IMs.

The Arctic LTER web site (http://arc.lternet.edu) currently has 610 datasets from LTER and collaborating projects. All datasets, including metadata and data, are available through the Arctic LTER web site or through the LTER network data portal.

At present 11 associated project's metadata and data are hosted on our web site. (http://arc.lternet.edu/data-collabrating-projects)

What is the impact on society beyond science and technology?

Arctic tundra has inherent value as one of the major biomes of the world, with a unique assemblage of animals and plants. Warming could result in a dramatic decrease in tundra area or the complete loss of the biome as the climatic boundary favorable to tundra moves northward beyond the shores of the Arctic Ocean. It is therefore vital to understand how this ecosystem is responding to current changes in climate.

One of the defining characteristics of arctic tundra is that it is underlain by permafrost. It is estimated that permafrost soils store between 25 and 50% of all the organic carbon currently in soils globally and contains substantially more carbon than is currently in the atmosphere. As the climate warms, the seasonal thaw depth of tundra soils increases and the organic matter currently in deep-freeze storage becomes susceptible to microbial activity. This activity releases the stored carbon to the atmosphere as CO_2, but also releases nutrients into the soil, potentially stimulating plant growth. The net contribution of tundra to atmospheric CO_2 depends on the balance between CO_2 released by microbes in the soil and CO_2 taken up by vegetation and stored in plant biomass. The LTER is striving to understand this balance.

Finally, because the Arctic is warming faster than the rest of the world, it serves as a harbinger for changes to come in ecosystems further south. All ecosystems share a core set of ecological processes like production of plant biomass through photosynthesis, decomposition of dead biomass by microbial activity, cycling of vital elements, among many more. Understanding how these processes change in a rapidly warming Arctic can help in predicting and interpreting future changes in other biomes.

Changes/Problems

Nothing to report