Overview: This proposal represents an integrated research program to study the cross-scale controls over responses of the Alaskan boreal forest to changing climate-disturbance interactions, including the associated consequences for regional feedbacks to the climate system, and to identify vulnerabilities and potential adaptations to social-ecological change with rural Alaskan communities and land management agencies. The program addresses the dynamics of change through the integration of five components. 1) Studying **direct effects of climate change on ecosystems and disturbance regimes** by characterizing controls over the spatial heterogeneity of ecosystems and disturbances, and the sensitivities of these controls to regional climate, and by studying the spatial and temporal synchrony of multiple disturbances to assess which landscapes are most vulnerable to change; 2) Understanding patterns, mechanisms, and consequences for scale-dependent **climate-disturbance interactions** involving current and legacy influences of fire, permafrost, and trophic dynamics as drivers of ecosystem and landscape change; 3) **Linking landscape heterogeneity with regional and global climate feedbacks** by studying and modeling how intermediate-scale patterns and processes influence regional scale ecosystem dynamics and climate feedbacks; 4) Studying how climate variability and change are affecting **coupled social-ecological dynamics** by characterizing variability in changes to ecosystem services across a select group of interior Alaskan communities, and collaborating with communities to find solutions that reduce vulnerability and improve adaptation to social-ecological change; 5) **Integrating LTER science and resource management with regional environmental change through co-production** by developing coordinated science with agencies to fill management knowledge gaps, assessing outcomes of policy decisions, and communicating syntheses to policy makers in meaningful ways.

Intellectual Merit: Alaska has warmed more than twice as rapidly as the contiguous US over the past century, with some of the largest annual air temperature increases occurring in interior boreal forests. This has triggered unprecedented changes in the fire regime and permafrost thaw, species range shifts, major alterations to successional pathways and ecosystem structure and function across the boreal landscape, and changes in the abundance, distribution, and access to ecosystem services by Alaskans. Understanding how linkages and feedbacks across multiple temporal and spatial scales control boreal forest responses to changing disturbance regimes is important for predicting regional change over the next century, and for determining how Alaska will adapt to and manage this change. The intellectual merit of this proposed research derives from a comprehensive program to understand the cross-scale interactive effects of changing climate and disturbance regimes on the Alaska boreal forest, to study associated consequences for regional feedbacks to the climate system, and to identify vulnerabilities and explore adaptation opportunities to social-ecological change with rural Alaskan communities and land management agencies.

Broader Impacts: This proposal expands the BNZ SLTER program by targeting children in urban foster care who face obstacles to participating in science programs, and children in Native villages throughout rural interior Alaska with limited access to high quality science education opportunities and interaction with professional scientists compared to schools along the road system and in Fairbanks. Undergraduate and graduate students participate fully in LTER research, and are engaged in local K-12 education and with Network-wide educational programs. The BNZ LTER integrates arts, humanities and science through outreach and education at the site and Network levels, collaborates closely with agencies to address fire and wildlife management challenges, and partners with tribal entities and subsistence users to characterize changes to ecosystem services and find solutions to reduce vulnerability and improve adaptation to social-ecological change. BNZ contributes to Network syntheses to advance understanding of climate-disturbance interactions, trophic dynamics, resilience and vulnerability science, and modeling that integrates biophysical processes and social phenomena across multiple temporal and spatial scales. Information management emphasizes secure archival of data, promotion of its use in synthesis, and development of web-based databases to facilitate access to and use of data by the scientific community.

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For font size and page formatting specifications, see GPG section II.B.2.

Appendix Items:

*Proposers may select any numbering mechanism for the proposal. The entire proposal however, must be paginated. Complete both columns only if the proposal is numbered consecutively.

Results from Prior Support: Alaska has warmed more than twice as rapidly as the contiguous U.S. over the past century, with some of the largest annual air temperature increases occurring in interior boreal forests [24, 53]. This warmer and drier climate has triggered unprecedented changes in the fire regime and permafrost thaw, species range shifts, major alterations to the structure and functioning of ecosystems across the boreal landscape, and changes in the access and use of ecosystem services by Alaskans. Warming has been driven primarily by anthropogenic emissions of greenhouse gases at the global scale, but is amplified at high latitudes by energy and trace gas feedbacks resulting from wildfire, melting of sea ice and glaciers, lengthening of the snow-free season, and atmospheric losses of previously frozen permafrost C as CO_2 and CH_4 [220].

During our last funding cycle, the BNZ LTER initiated a program to study how interior Alaska as a coupled social-ecological system, is responding to environmental change, focusing on understanding mechanisms that have contributed to resilience for thousands of years, and characterizing current and projected patterns and vulnerabilities to gradual and threshold changes in ecosystems and landscapes. The project was structured around four integrated sections (Fig 1).

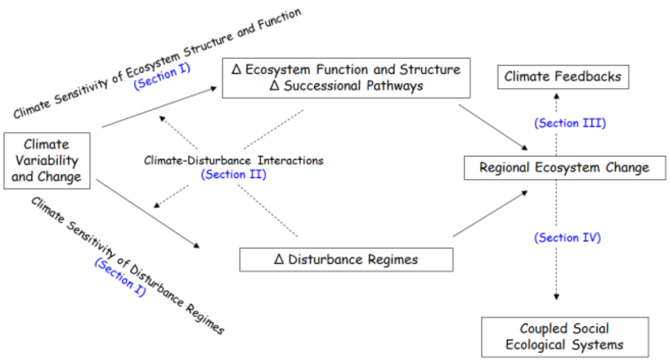


Fig 1. Conceptual model for the 2011 BNZ LTER proposal.

Climate sensitivity: Reduced basal increment growth and $\delta^{13}C$ enrichment of tree rings of white and black spruce over the past 100 years are consistent with satellite-derived declines in productivity and "browning" of the boreal forest throughout interior Alaska, and coincident with a drier, warmer climate with increased evaporative demand [6, 14, 139, 140, 248, 249, 256, 257]. Moreover, the occurrence of thresholds in tree growth indicate that small changes in climate may have disproportionately large effects on forests in interior Alaska [160]. The response of plant life history traits to climate variability and change strongly affects dispersal, recruitment and community dynamics, and ecosystem resilience to multiple disturbances [39, 112, 250]. Increased tree growth in wetter regions of western Alaska [140], coupled with range expansion of conifers into both northern and western tundra regions, and the spread of deciduous forests following fire suggest a regime shift across the boreal forest and boreal-tundra ecotone [12, 14, 167].

Long-term monitoring indicates that as climate warms and the snow-free period increases, native and non-native species both leaf and flower earlier, but during prolonged falls, non-native species extend growth much longer than native species, indicating there is a vacant phenological niche in fall but not in spring, and non-native plants may be able to fill this niche. The reproductive responses of boreal native plants to invasives are likely determined by the identity of new pollinators attracted to invaded sites, the degree of shared pollinators between invasive and native species, and the variation in resource limitation among sites [227, 228]. Given the strong association between woody species and their root symbionts [5, 107, 207, 236], sensitivities of mutualisms to changing climate and disturbance regimes are likely

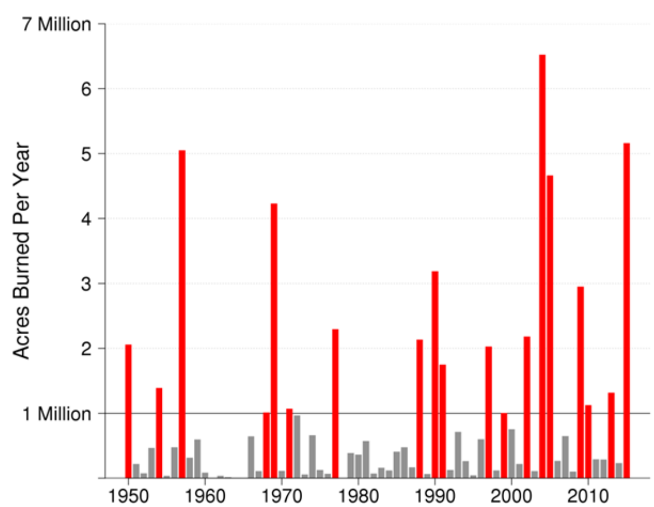


Fig 2. Annual area burned in Alaska has increased dramatically in the past 60 years, notably in the past 15 years. 85% of all Alaskan fires since 1950 have occurred in interior boreal forests (Rupp, TS; *Scenarios Network for Alaska & Arctic Planning*).

an important factors influencing ecosystem-level responses.

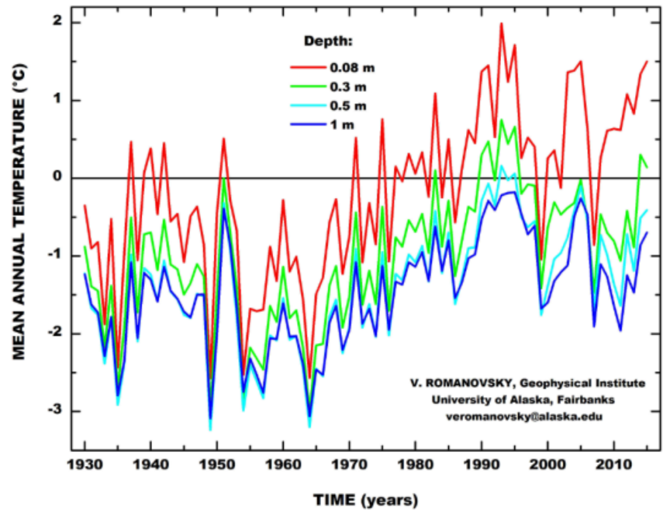


Fig 3. Long-term monitoring indicates that permafrost temperatures in Fairbanks, AK have warmed from the mid1960s – mid1990s during the warm phase of the PDO, then cooled slightly due to lower temperatures and less snow, but shown increases over the past decade, interrupted by a late snowfall in 2006, despite the return to a cool PDO phase in the early 2000s (BNZ long-term monitoring data).

A pronounced consequence of climate warming is the recent shift in interior Alaska's fire regime to an increase in fire size and severity, and a decrease in fire return interval [44](Fig 2). Fires are primarily occurring in highly flammable black spruce stands, which constitute 70% of the forested landscape and are characterized by deep organic layers underlain with permafrost. Impeded drainage typically maintains high moisture levels in surface organic layers, preventing deep burning and enabling recovery of vascular and non-vascular plants that survive fire, while providing a favorable seed bed for black spruce reestablishment [112, 128, 223]. However, warmer early-season temperature coupled with prolonged late summer drought are leading to larger fires burning later in the fire season and into deeper soil organic layers [11, 242]. This includes fire spread into black spruce lowlands/peatlands, where associated effects on permafrost and surface hydrology are particularly pronounced [32, 241, 242]. Paleoecological studies indicate that the current fire regime is novel in the context of interior Alaskan fires over the past 10,000 years [144], and projections are that the current fire regime is likely to persist throughout the 21st century [8, 167], although the amount of area burned may stabilize by mid-century due to conversion of the landscape to hardwood forests [261]. This intensified fire regime has substantially increased total C emissions from Alaska black spruce forests [94, 95], and paleodata-informed modeling suggests that such C losses could offset enhanced NPP caused by CO_2 fertilization and a longer growing season, potentially converting the boreal biome from a sink to a source of C over the next century [145, 265].

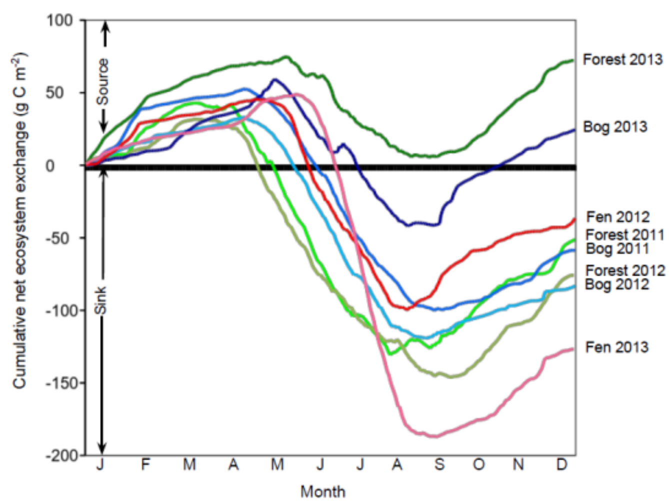


Fig 4. NEE estimates (eddy covariance) showing that the bog and permafrost forest were sensitive to the hot/ dry conditions in 2013, turning from C sinks to sources, while the fen with no surface permafrost remained buffered from these conditions and remained a C sink (Euskirchen et al. 2014).

Globally, permafrost constitutes a C pool that is approximately twice that of the atmosphere, a significant fraction of which is vulnerable to microbial decomposition over decades to centuries as northern regions continue to warm [215, 220, 240]. Long-term monitoring indicates that permafrost temperature near Fairbanks warmed considerably from the mid1960s to mid1990s, then cooled slightly due to lower temperatures and less snow, but have shown increases over the past decade, interrupted by a late snowfall in 2006 (Fig 3). Field studies and monitoring emphasize the importance of landscape heterogeneity (topography, vegetation, drainage, ice content) in controlling the sensitivity of permafrost to warming and to a changing fire regime (which removes surface insulation), and the nature and magnitude of ecosystem responses post thaw [95, 100, 137, 241]. For example, abrupt permafrost thaw in ice-rich lowlands/peatlands has resulted in thermokarst bogs and wetland succession [157], while thaw in well-drained areas where permafrost is discontinuous and/or of lower ice content has led to widespread surface drying and lake drainage [137, 203, 204]. Changes in hydrology accompanying permafrost thaw determine the balance of CO_2 and CH_4 emissions [184, 185, 220, 243], with ombrotrophic thermokarst collapse scar bogs and intact permafrost forests showing greater sensitivity to hot and dry conditions than oligotrophic fens with no surface permafrost [78] (Fig 4). Transient numerical modeling incorporating the role of snow, soil organic layer thickness, water saturation and thermal properties in controlling thaw vulnerabilities [121, 122] to assess and map climate sensitivity of permafrost thaw for Alaska over the next century predicts that sensitivity to climate warming is strongly influenced by fire severity [32, 123].

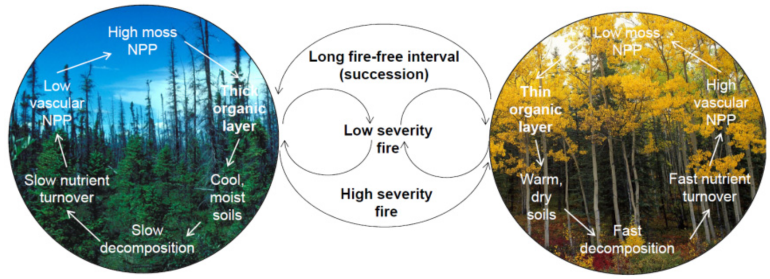


Fig 5. Soil organic layer dynamics across fire and successional cycles representing alternative stability domains. In the thick organic layer domain (left circle), the accumulation of soil organic layers in mesic-to-moist sites is associated with feedbacks among cool, moist soils, low rates of decomposition and nutrient cycling, and high moss productivity. Alternatively, in the thick organic layer domain (right circle), shallow organic layers in mesic-to-dry sites are associated with feedbacks among warm, dry soils, high rates of decomposition, high rates of nutrient cycling, and high vascular plant productivity that smothers mosses with deciduous leaf fall (adapted from Johnstone et al. (2010)).

Climate-Disturbance Interactions: One of the most rapid pathways by which climate warming alters the C balance of high northern latitude ecosystems is through intensification of wildfires [54, 101, 115, 142, 146, 165, 242]. The majority of organic C sequestered in boreal coniferous forest and peatlands resides in thick soil organic layers (SOL) that can be thousands of years old, and a C legacy of past fire cycles [101]. Combustion of the SOL dominates C emissions during fire [25, 142], and more intense fires result in deeper burning [242]. Because rates of soil C accumulation vary across the landscape [110], deeper burning may not always combust legacy C. But deeper burning that does combust legacy C could rapidly shift ecosystems across a C cycling threshold: from net accumulation of C from the atmosphere over multiple fire cycles to net loss.

Disturbances that impact the SOL can also persistently alter both physical and biological controls over C cycling (Fig 5). Reduction or loss of the SOL decreases ground insulation [137, 224], warming permafrost soils and exposing organic matter that has been frozen for hundreds to thousands of years to microbial decomposition, mineralization, and atmospheric release of greenhouse gases [219]. Degradation of permafrost can also increase or decrease soil drainage, leading to threshold changes in soil moisture regimes that impact both decomposition and production [137, 221]. Loss of the SOL also exposes mineral

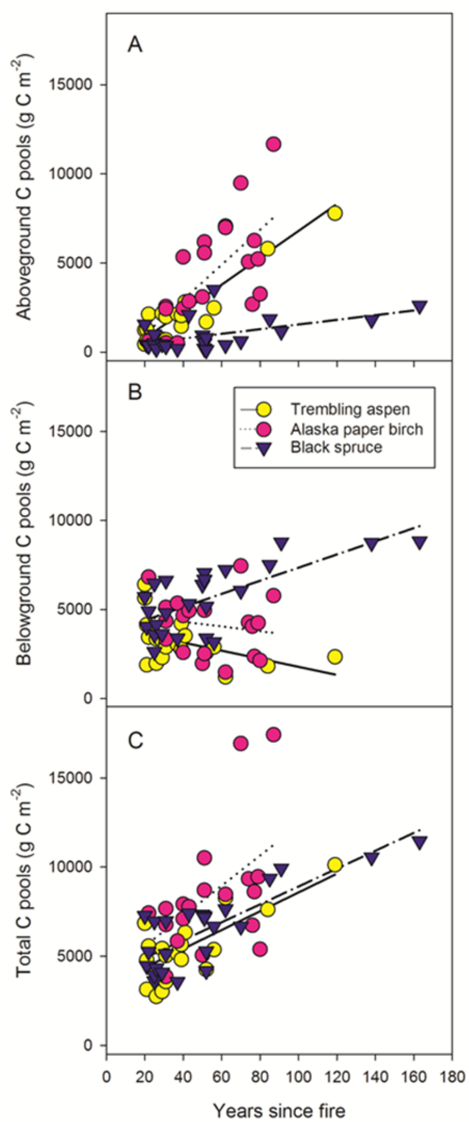


Fig 6. Changes in (A) aboveground, (B) belowground, and (C) total C pools with 'years since fire' in stands undergoing trembling aspen, Alaska paper birch, and black spruce successional trajectories within interior Alaska. High severity fires in black spruce lead to hardwoods with high AGNPP but accumulate little C in soils due to high litter quality and soil conditions favoring rapid decomposition rates. Low severity fires that return to dominance by black spruce, have low AGNPP, low litter quality, and slow decomposition rates. The net result is similar rates of C storage in hardwood vs black spruce stands, but in very different pools (AG vs BG) (Alexander and Mack 2015).

soil seedbeds [125, 127] leading to recruitment of deciduous tree species that do not establish on organic soil [129] and can shift post-fire vegetation to alternate successional trajectories [128]. Indeed, model projections suggest that Alaskan forests may soon cross a tipping point, where recent increases in fire activity have made deciduous stands as abundant as spruce stands on the landscape [167]. Plant-soil-microbial feedbacks within new vegetation types determine long-term trajectories of nutrient dynamics [172], ecosystem C storage [3, 128] and resultant climate feedbacks, and shifts to deciduous trajectories with very different rates and partitioning of NPP and patterns of C storage (Fig 6).

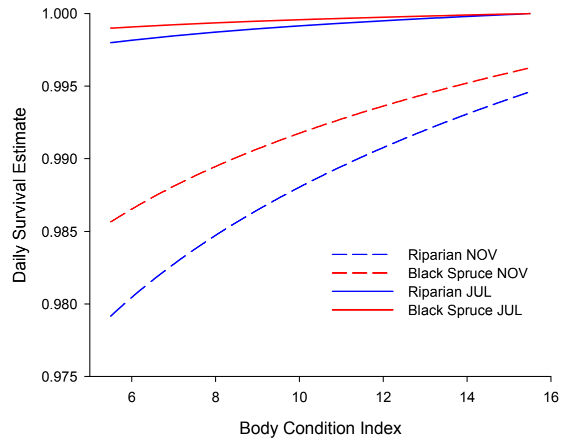


Fig 7. Our long-term mark-recapture study indicates that interactions among season, body condition and habitat are the primary controls over survival in snow-shoe hares (Feierabend and Kielland 2015).

Vegetation changes resulting from warming and altered disturbance regimes are influencing vertebrate herbivore populations, including caribou [133, 134], moose [31, 161, 234], ptarmigan [57] and snowshoe hares [150, 233]. Plant-herbivore interactions strongly influence plant growth, and community composition [35, 56, 58, 86, 181], and feedback to control herbivore fecundity through impacts on forage quality and abundance [187, 222]. The decadal population cycle of snowshoe hares in interior Alaska represents a 20-fold variation in hare density [150], which is accompanied by strong demographic effects on their mammalian and avian predators. Hare populations appear to be controlled by an interaction of food supply and predation [82] as evidenced by survival being best explained by body condition superimposed on season and habitat use [84](Fig 7). Population dynamics of snowshoe hares along the auroral oval sweeping north-west from central Canada into Alaska are hypothesized to be driven by a traveling wave of predators [155], and the amplitude of the hare cycle is inversely correlated with the rate of lynx increase from the previous low [154]. However, the moderate change in survival of adult hares across the increase, peak, and decline phases of the cycle suggest that the population crash is controlled by additional demographic variables such as reduced fecundity, and/or lower leveret/juvenile survival [84].

Stream hydrology and chemistry are tightly coupled to fire frequency and severity, and the distribution of permafrost, which influences watershed flowpaths through catchments. Streams draining watersheds with extensive permafrost have flashier and greater variation in stream flow than streams draining watersheds lacking permafrost [136]. Moreover, based on stream flow data collected from BNZ watersheds since 1978, stream flows have become less responsive to rain storms, presumably due to loss of permafrost and the effects on water routing to streams. Stream water chemistry is similarly strongly affected by permafrost in catchments, as well as landscape topography and landscape features. For example, DOC concentrations vary by an order of magnitude between glacially fed streams and lowland streams draining soil with extensive peat deposits [182]. Moreover, the chemical composition of stream DOC is variable with higher C:N and greater proportion of recalcitrant organic matter in lowland streams. Wildfires also control

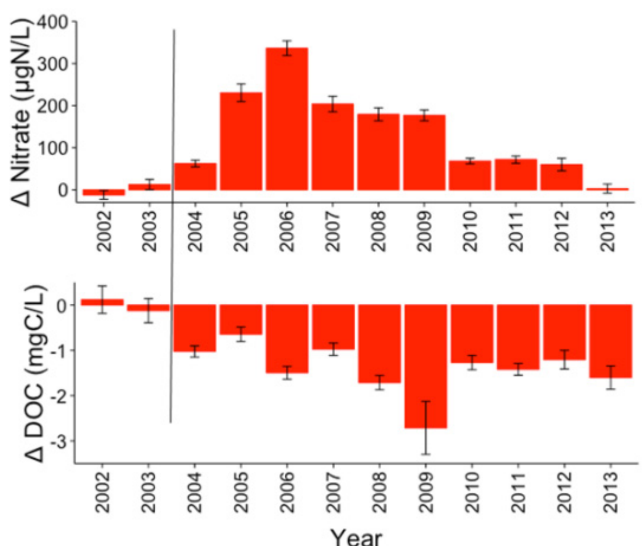


Fig 8. Following a fire in 2004, stream NO_3^- and DOC concentrations increased and decreased, respectively, persisting for the next decade with a slow return to pre-fire conditions (BNZ LTER monitoring).

stream water chemistry across landscapes and over time (Fig 8), increasing the proportion of black C (molecules formed as combustion products) in stream DOC compared with temperate biomes [124], with black C accounting for 2-7 % of stream water DOC [67]. The riparian zone is metabolically active with the potential to assimilate DOC and DIN rapidly, with uptake rates directly related to hydrologic residence time [102, 202]. Net NO_3^- uptake declines sharply following snowmelt, whereas peak denitrification rates occur during summer, indicating a large capacity for N retention in organic soil horizons. However, continued deepening of the active layer due to permafrost degradation following fire may promote DIN export as the active layer deepens and catchment flow paths bypass organic soils, but reduce DOC export due to sorption within mineral soil horizons.

Long-term experimental snow additions to boreal tundra soil using snow-fences have warmed winter soil temperature by 4-8 °C. This temperature difference disappears in the early spring when the snow pack is removed, but results in a persistent difference in the depth of thaw throughout the growing season into fall, indicating that accumulated winter heat persists for an entire season [173-175]. Experimental soil warming has triggered permafrost degradation and increased losses of old, previously-frozen permafrost C through microbial respiration, but has also led to a two-fold increase in net ecosystem C uptake during the growing season, due to greater increases in NPP resulting from higher soil N availability [197], in line with decadal trends of ‘greening’ across the region. However, experimental warming has also enhanced winter soil respiration, which offsets growing season C gains [175]. These results highlight the importance of winter processes in determining whether boreal ecosystems acts as a C source or sink, and demonstrate the potential magnitude of C release from the permafrost zone that might be expected in a warmer climate.

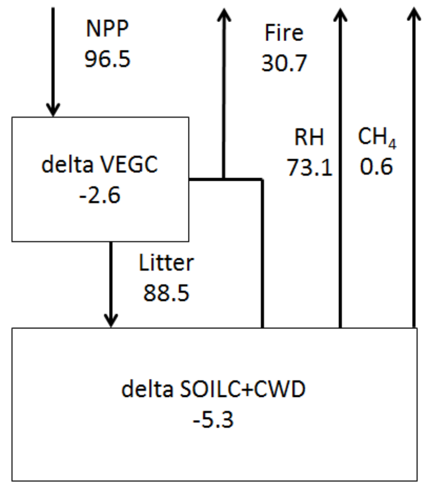
Regional Ecosystem Dynamics and Climate feedbacks: An assessment of C dynamics for the northern boreal region of Alaska was conducted [169, 170, 266] to address the following questions: 1) what are the magnitudes of C pools and fluxes of soil and biomass?; 2) how are changes in fire regime and permafrost dynamics influencing C balance?; 3) how might sources and sinks of CO_2 and CH_4 change in response to projected changes in climate, fire regime, and permafrost dynamics?; and 4) how might energy feedback to the climate system change in response to projected changes in climate, fire regime, and permafrost dynamics? The assessment used the Alaska Frame-Based Ecosystem Code (ALFRESCO) [213, 214] to simulate changes in fire regime and vegetation distribution from 2010 to 2099. The dynamic organic soil version of the Terrestrial Ecosystem Model (DOS-TEM; [95, 262, 263, 265] used input data on soil texture, land cover, historical climate, historical fire, and model projections of future climate and fire disturbance to estimate changes in ecosystem pools and fluxes for upland and wetland ecosystems of boreal Alaska. The CH_4 dynamics module of DOS-TEM [267, 268] was used to estimate CH_4 consumption in upland ecosystems [94] and both CH_4 consumption and emissions in wetland ecosystems [103].

Uncertainty in the simulation results that contributed to this assessment were evaluated in several ways. First, each set of ALFRESCO simulations included an ensemble of 200 simulations to evaluate parameter-based uncertainty in the estimated changes in wildfire activity and vegetation distribution. Uncertainty with respect to model responses to future climate and atmospheric CO_2 concentration was assessed by conducting six sets of simulations based on the CCCMA and ECHAM climate model projections for B1, A1B, A2 SRES emission scenarios. The CCCMA and ECHAM climates spanned the range of future wildfire sensitivity in ALFRESCO simulations, and the three emission scenarios essentially span the range of uncertainty in future atmospheric CO_2 concentrations. Because changes in C storage simulated by DOS-TEM are most sensitive to the level of CO_2 fertilization, we also conducted simulations without changes in CO_2 concentration for each of the six climate-emission scenario combinations to quantify DOS-TEM uncertainty.

Between 1950 and 2009, approximately 85% of fire activity in Alaska occurred in the northern boreal region [261], and the number of fires averaged 32 yr^{-1}, ranging as high as 137 in 2005. The annual area burned averaged 3,262 km^2/yr (0.7%) in northern boreal Alaska. The interannual variability in area burned is substantial and ranged as high as 26,684 km^2/yr (6%) in the northern boreal region in 2004. For the CCCMA climate, which indicates less warming than ECHAM, the median simulation resulted in increases in areas burned across the 3 emission scenarios (ranged from 1% to 48%). For the ECHAM climate, the distribution of area burned for the A1B and A2 scenarios showed general increases, but the B1 showed a decrease in the median simulation. The distribution of area burned for the A1B scenario exhibited the largest change (+44%) in the median simulation.

ALFRESCO simulations indicate that both white and black spruce in the northern boreal region would decrease substantially under both the CCCMA and ECHAM climates (ranging from 8% to 44%), except for the B1 emissions scenario, which resulted in minimal increases of approximately 3%.

Between 1950 and 2009, DOS-TEM estimates that the northern boreal region of Alaska was a C source of 7.9 TgC/yr because of large C losses from wildfire, specifically during large fire years in 1956, 1969, 1977, and in the 1990s and 2000s [94, 103](Fig 9). CH_4 emissions were estimated to be 0.6 Tg C-CH_4/yr [103]. Vegetation C stocks were projected to increase throughout the 21st century for the six climate scenarios for the northern boreal region of Alaska because of responses to longer growing seasons, increased soil N availability, and atmospheric CO_2 fertilization. DOS-TEM estimates that increased inputs to the soil from projected increases in NPP more than offset C losses from thawing permafrost so that soil C increases in all scenarios. CH_4 emissions ranged from little change to a tripling across climate scenarios, so that there was variability across scenarios as to whether the northern boreal region of Alaska would enhance or mitigate greenhouse gas forcing of the climate system.



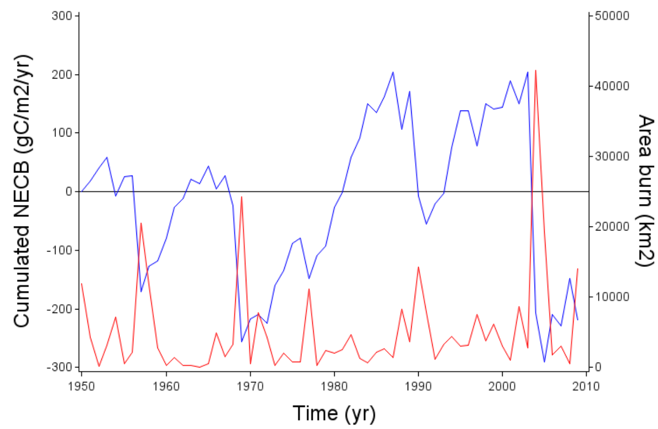


Fig 9. Cumulative net ecosystem C balance in TgC/yr simulated by DOS-TEM between 1950-2009 for the northern boreal region of AK (top), showing large C losses during high fire years (bottom) (Genet et al. 2016).

Social-Ecological Dynamics: BNZ LTER study of social-ecological system (SES) dynamics focuses on how changing landscapes and disturbance regimes are affecting the abundance, distribution and access to ecosystem services, and the capacity of rural communities to adapt and/or transform in response to both environmental and socio-economic change. We've advanced resilience science through partnerships in knowledge co-production and the development of an agent-based model (ABM) that projects future interactions and trade-offs at the household and community levels. Over the past several years, we initiated a community-based long-term monitoring program in partnership with villagers that complements LTER science and is relevant to decision makers [51]. We conducted interviews with active harvesters and elders from Nenana (on-the-road system village, pop. 378, 41% Alaska Native) that included participatory mapping to collect ecological, demographic, and social data (Fig 10). Predominant observations on landscape change include widespread river bank erosion, lake drying, and increases in the frequency and intensity of fires, social-ecological findings that correspond strongly to biophysical measurements made over the past 50 years. Harvesters report changes in fish and wildlife (fewer waterfowl, and muskrats; smaller, fewer King salmon) and social changes (fewer villagers involved in subsistence; an overall increase in non-local hunters in their area). These results demonstrate the richness of local knowledge and also how it provides insights into social-ecological interactions at a local scale [183]. We recently innovated methods of community-based ecological monitoring by issuing camera-equipped GPS units to subsistence harvesters in six interior Alaskan subsistence communities. Harvesters documented their observations of landscape change, with images and locations posted online using "Storybook" software [232]. Of particular interest is how landscape changes are affecting harvesters' access to traditional-use areas.

We have also studied historic changes in community engagement in subsistence [41], developed a framework for empirically measuring adaptive capacity (AC) and used it to compare AC among Alaskan communities [18], and modeled tradeoffs of subsistence resource sharing, job employment, and resource scarcity using the Rural Alaska Social-Ecological Model, an ABM parameterized with recent and historic household socioeconomic and social network data, and a series of biophysical base layers. Model scenarios investigated the effects of iterative changes on household access to wild foods and equity outcomes [40]. We found that the mixed economy that has persisted through time in spite of greater engagement in the cash economy is built on a basic tradeoff that re-distributes wild foods from successful hunters to the broader community. Under modelled employment and resource perturbations, manipulation of connectedness exerted stronger positive effects on household provisioning than did the magnitude of sharing among households. While the distribution tradeoff was robust to some perturbations, it was less robust as perturbations accumulated. Household-scale sharing and cooperation norms are shaped by an indigenous worldview, and these cultural norms introduce an important non-economic perspective on tradeoffs.

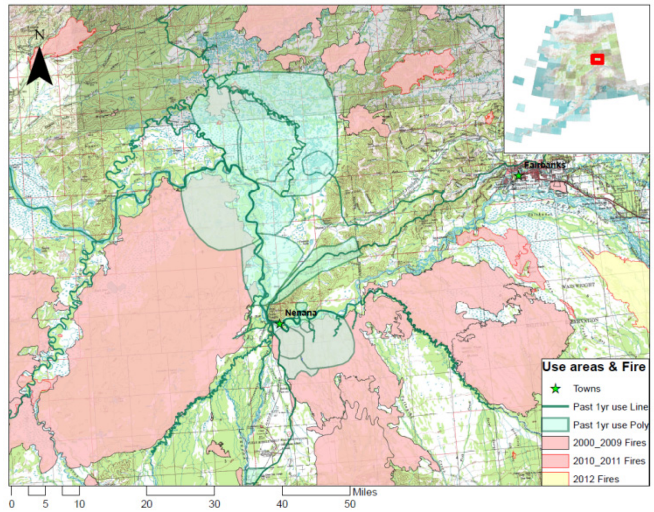


Fig10. Interviews with harvesters using participatory maps defining subsistence use areas for the previous 12 months, showing that access to traditional hunting grounds are often blocked because of downed trees in recent burns.

Proposed Research

Introduction: The regional landscape of interior Alaska is heterogeneous, dominated by a mosaic of wetlands, floodplains, and upland forests in varying stages of successional development adapted to and controlled by climatic extremes, cryospheric processes, and fire [49, 138]. Interactions between ecosystem dynamics and disturbance regimes across the region have remained resilient to climate fluctuations since black spruce spread to dominate the forest approximately 6,000 years ago [108, 114, 144]. For thousands of years, this shifting landscape mosaic has been influenced by nomadic populations of herbivores, large carnivores and humans, entraining a trophic cascade that remains relatively intact [118, 176, 179]. However, rapid climate change over the past century has altered linkages and feedbacks among biophysical, ecological and socio-economic drivers to substantially transform the regional landscape [53]. Understanding how linkages and feedbacks across multiple temporal and spatial scales control boreal forest responses to changing disturbance regimes is important for predicting regional change over the next century, and for determining how Alaska will adapt to and manage this change [29, 48, 151, 239]. The guiding research question of the Bonanza Creek LTER is: ***How is the boreal biome responding to climate change and what are the local, regional, and global impacts of those responses?*** This question is of timely relevance for several reasons. (1) Since 1950, interior Alaska has warmed twice as fast as the contiguous U.S., leading to landscape shifts resulting in pronounced changes in atmospheric feedbacks of C, water, and energy [24, 78, 95, 230]. These feedbacks are globally significant because the boreal forest covers 12 million km^2 of the Northern Hemisphere and stores a massive pool of soil C which is vulnerable to atmospheric exchange [117, 215, 220]. (2) Climate warming has radically changed the nature and interaction among disturbance regimes, notably fire frequency, size and severity [44], rate of permafrost thaw, surface hydrology [32, 203], and the outbreak behavior of insects and pathogens [209, 247], resulting in threshold changes in biogeochemical cycling, successional trajectories, and landscape heterogeneity and function [3, 130-132, 137]. (3) Subsistence traditions of interior Alaskan communities are coupled to the influences of regional gradients in climate and disturbance regimes on the temporal and spatial distributions of subsistence resources [118, 176, 179]. Urban, rural, and subsistence Native communities remain closely reliant on wild food harvested from the boreal forest [162]; however, economic, social, and ecological changes are affecting human-ecological interactions, cultural traditions, and the distribution, abundance, and access to ecosystem services by Alaskans [26, 98, 99, 171]. ***Here we outline a program to understand the cross-scale interactive effects of changing climate and disturbance regimes on the Alaska boreal forest, study associated consequences for regional feedbacks to the climate system, and identify vulnerabilities and explore adaptation opportunities to social-ecological change with rural Alaskan communities and land management agencies.*** Knowledge and relationships established by the BNZ LTER over our previous funding cycle uniquely positions us to broaden the spatial and temporal contexts over which we study these complex changes, and work collaboratively with stakeholders to identify solution pathways for challenges facing boreal forest managers and policy makers.

Research across the LTER Network is drawing increasingly on theoretical frameworks of resilience (the capacity of a system to absorb disturbance and reorganize while undergoing change so as to retain essentially the same structure, function, and feedbacks [88, 253]) and vulnerability (the degree to which a system is likely to change in response to exposure of some stress or hazard [48]). Both frameworks offer insights into the functionality and management of complex systems undergoing rapid change, and contribute to policy strategies for environmental stewardship, sustainability science, and adaptive governance [52, 88, 218, 253]. Feedbacks contributing to resilience operate across multiple temporal and spatial scales [111], and research from diverse biomes highlights the importance of understanding how changes in such cross-scale dynamics determine vulnerabilities to environmental change, and often trigger non-linear or threshold changes in ecosystem structure and function [21, 46, 71, 106, 128, 193, 195, 196, 199, 200, 216]. Understanding the complexities of these cross-scale feedbacks is the defining focus of macrosystems ecology, and a key objective of the BNZ LTER as we seek to characterize how changing disturbance regimes are modifying the connectivity within and across local, landscape, regional, and global scales to affect the vulnerability of Alaska's boreal forest to environmental and social change [15, 96, 105, 226].

BNZ LTER research has characterized feedbacks that contribute to boreal forest resilience, and demonstrated how climate-driven changes in disturbance regimes are disrupting these feedbacks and leading to regime shifts in successional pathways and landscape structure and function [3, 112, 128, 132, 160]. Warming trends throughout the Alaskan boreal forest are expected to continue over the next century, exacerbating multiple vulnerabilities including drier landscapes with increased wildfire, permafrost thaw, and altered wildlife habitat, driving both positive and negative climate feedbacks at local to global scales [24, 53, 63, 145, 167]. Recent and projected trends in the interactions between changing climate and disturbance regimes are also having dramatic impacts on Alaska's subsistence, rural, and urban communities, which differ in their exposure, sensitivity, and capacity to adapt to environmental and socioeconomic change [239]. Alaska Native communities are particularly vulnerable given the high cost of living in remote villages off the road system, and the threats to cultural traditions, lifestyles, and economies that have a high reliance on ecosystem services [26, 99, 152]. There is a strong consensus within Alaska that understanding the complex interactions among ecological, economic, political and cultural dynamics is critical for developing and implementing adaptive co-management strategies in response to rapid social-ecological change [52, 60, 151]. The BNZ LTER is uniquely positioned to serve as a bridge institution that fosters knowledge networks for the development of these strategies.

Conceptual Framework and Research Design: The BNZ LTER program was established to study patterns and mechanisms of boreal forest succession following fluvial and fire disturbance, and for the first few decades, our monitoring program, long-term experiments and process studies focused on state factor and interactive controls over succession, trophic dynamics, and ecosystem function of floodplain and upland chronosequences. During the mid 2000s, we began studying gradual and abrupt changes to climate warming, and what new landscape patterns and dynamics were emerging. During our last funding cycle, we developed a more integrated conceptual framework focusing on how the interactive effects of climate warming and altered disturbance regimes are influencing key sources of ecological resilience, leading to threshold shifts in landscape structure with regional and global consequences for climate feedbacks, and impacts to ecosystem services on which Alaskan communities depend. That research framework was the first to more explicitly consider the Alaskan boreal forest as a coupled social-ecological system, and showed how variables with slow responses

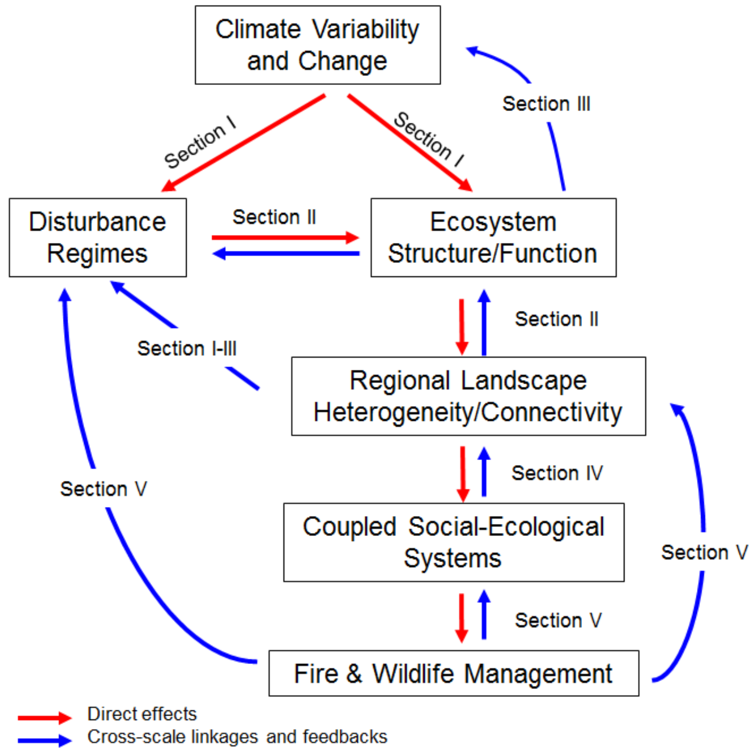


Fig 11. Conceptual model showing relationships among research Sections for current proposal.

and legacies of prior conditions, events, and institutions contributing to the resilience of boreal forests and northern communities for thousands of years are changing dramatically in response to climate warming [50]. These include geophysical (fire regime, permafrost distribution, landscape hydrology), biological (soil C and nutrient stores, regional biota), and social (cultural beliefs and practices, stakeholder groups, economic and political institutions) variables that have shaped histories to past disturbances, but are now changing to affect sensitivities of variables such as fire behavior, successional pathways, NPP, trophic dynamics, and subsistence harvest, which operate on daily, seasonal, and interannual timescales [137]. Here, we extend this framework to focus on how spatial heterogeneity in landscape structure, disturbance regimes and disturbance legacies, and cultural traditions at intermediate scales affect cross-scale interactions between local- and regional-scale social-ecological dynamics to influence vulnerability and adaptation to change.

Our proposed framework for studying social-ecological resilience and vulnerability to change is organized around 5 interconnected sections (Fig 11).

I. Direct effects of climate change on ecosystems and disturbance regimes. Rapid warming of interior Alaska's boreal forest over the past 80 years has both lengthened and dried the growing season, leading to reduced NPP in drought-stressed habitats, an increase in the incidence of large, high-severity fires, changes in the outbreak behaviors of native and invasive pests and pathogens, and an accelerated rate of permafrost thaw [24, 44, 140, 143, 247]. Positive high-latitude climate feedbacks resulting primarily from loss of sea ice, seasonal snowpack, and permafrost are amplifying this warming, and are expected to impact the boreal forest landscape over the next century [23, 53, 76, 95, 220]. We extend our study of the direct effects of climate variability and change on ecosystems and disturbance regimes by characterizing controls over the spatial heterogeneity of ecosystems and disturbance regimes, the sensitivities of these controls to climate change across the region, and by assessing the spatial and temporal synchrony of multiple disturbances to determine what landscapes are most vulnerable to change. Results will be integrated with studies on mechanisms and consequences of change to model climate sensitivity of ecological communities (plant and animal species, plant functional types, community structure), ecosystem processes (NPP, biogeochemical cycling), landscape structure and heterogeneity, and the severity and distribution of disturbance regimes (fire, permafrost thaw, insect/pathogen outbreaks).

II. Scale-dependent climate-disturbance interactions as drivers of ecosystem and landscape change: The age, composition, and spatial patterning of ecosystem types across the boreal landscape influence the severity, extent, and climate sensitivity of disturbances, which, in turn, govern ecosystem responses to climate variability and change. Warmer drier summers are increasing fire severity in black spruce forests and favoring the establishment of hardwood species, which are less flammable, provide higher quality forage to herbivores, and have strikingly different patterns and rates of C and N accumulation and storage [3]. We have begun to understand the underlying mechanisms for these feedbacks at local scales, but what are the patterns and controls over burn severity within and among burn scars, and how does this heterogeneity affect species movements and associated controls over successional dynamics? Critical thresholds in ecosystem and landscape structure and function derive from the interaction of multiple disturbances across complex scales. For example, high severity fires are increasing the sensitivity of permafrost thaw to warming temperatures in both uplands and lowlands [32, 123], but how and where these interactions influence within-site variation in surface wetness, or ultimately push ecosystems to drier or wetter states is poorly understood.

III. Linking landscape heterogeneity with regional and global climate feedbacks: Changing climate-disturbance interactions are affecting exchanges of trace gases, water, and energy between the boreal forest and the atmosphere, and are predicted to strongly influence feedbacks to regional and global climate over the next century. Positive feedbacks to climate warming include decreases in albedo due to changes in snow cover, and releases of CO_2 and CH_4 from thawing permafrost. Negative feedbacks include increases in surface albedo due to a shift to a deciduous forest canopy, and increased vegetation C uptake resulting from an extended growing season. BNZ LTER research indicates that ecosystem processes affecting net annual exchange of heat and trace gasses vary at seasonal to century time scales [78, 137], and that regional climate feedbacks will depend on the characteristic responses and distributions of uplands and wetlands to changing climate-disturbance interactions across the landscape [173, 242]. Our continued study of climate feedbacks uses retrospective and prospective modeling [77, 95, 123] to integrate data from long-term monitoring and field experiments with a regional assessment of the mechanisms and spatial heterogeneity of change in upland and wetland ecosystem structure and function.

IV. Coupled social ecological dynamics of interior Alaska: Changes in biophysical drivers are altering the abundance and distribution of subsistence resources (e.g. plants, animals and fuel wood) on which urban, rural, and subsistence Native communities depend, and affecting social-ecological interactions that link people to the land throughout interior Alaska [31, 98, 99]. Moreover, access to these resources is increasingly limited by changes in snow cover, wildlife behavior, river navigability, extent and timing of river and lake freeze-up and thaw, high fuel costs, and logistic challenges associated with disturbance [26, 217]. Social, economic and institutional structures of urban, rural and subsistence communities account for differences in sensitivity to changes in the availability of subsistence resources, and influence the capacity of individuals and communities to adapt to environmental change. Reliance on the harvesting and sharing of subsistence foods is integral to the sustainability of interior Native communities; however, rapid environmental change and escalating energy costs, coupled with limited employment opportunities, conflicts between rural and urban hunters, and a governance structure for resource management driven by urban values are posing serious threats to the rural subsistence lifestyle. We now broaden our partnerships with tribal entities and subsistence users to characterize variability in changes to ecosystem services across interior Alaskan communities, and to collaborate with communities to find solutions that reduce vulnerability and improve adaptation to social-ecological change.

V. Integrating LTER science and resource management with regional environmental change through co-production: The BNZ LTER has a long history of collaboration with state and federal agencies regarding forest and wildlife management since it was jointly funded by NSF and the USFS in 1987. While much of what is known about forest ecosystem dynamics and response to environmental change in Alaska's boreal forest derives from BNZ LTER research, our findings have not informed forest, wildfire, or wildlife management policies to the extent that is possible. There is a growing consensus that collaboratively co-produced science that directly addresses stakeholder needs and strengthens science literacy and communication will be increasingly required to address environmental challenges, and that LTER sites are uniquely positioned to serve as bridge institutions to foster these interactions [70, 91, 151, 158, 229]. Here we initiate a new collaborative program with wildfire and wildlife management institutions within Alaska to 1) pursue coordinated science with stakeholders to fill management knowledge gaps, 2) assess the outcomes of policy decisions with models that incorporate cross-scale feedbacks in the context of regional ecosystem dynamics, and 3) communicate syntheses of these activities to policy makers in meaningful ways. By fostering collaboration across diverse interests, sectors and institutional arrangements, we seek to contribute to a developing ecosystem stewardship framework that guides Alaskans to identify pathways of social-ecological change that enhance ecosystem resilience and long-term community wellbeing [16, 47, 52, 218].

Our research program integrates these 5 themes across ***multiple temporal and spatial scales***. Long-term monitoring of climate, vegetation, populations, ecosystem function, and disturbance regimes using permanent plots and satellite imagery allows us to document change at seasonal, interannual, and decadal scales, while chronosequence, dendrochronological, and paleoecological studies provide a historical context for climate-disturbance interactions over centuries to millennia. Process studies and experiments investigate the influence of time lags and legacies on contemporary cross-scale feedbacks. For example, this includes understanding how lags in the response of plant species, traits or functional types, or trophic dynamics affect ecosystem response to environmental change, or how legacies of past fires, including organic matter thickness or soil N and C stocks, influence ecosystem response to a changing fire regime. We project consequences of current and future landscape heterogeneity and change using both retrospective and prospective modeling. This includes terrestrial ecosystem models that couple plant succession, biogeochemical cycling, and soil thermal/moisture dynamics to project disturbance and climate impacts on ecosystem distributions and associated components of C balance for the boreal forest, and to understand energy and trace gas feedbacks to high latitude regions and the Earth's climate system. We also use state-and-transition successional models to project regional scenarios for future climate-disturbance interactions to understand threshold responses of these dynamics, and to address outcomes of fire and wildlife management options of interest to agencies and the public.

We include in our study design the key ***landscape types*** found throughout interior Alaska. These are uplands, floodplains, boreal tundra, and wetlands/peatlands, which differ in geomorphology, biophysical drivers, ecosystem dynamics, and sensitivity to changing climate-disturbance interactions. For over 25 years, BNZ LTER research and long-term monitoring was concentrated in two study areas: (1) the BNZ Experimental Forest, where we have maintained permanent plots across floodplain and upland successional sequences since 1989, and (2) the Caribou-Poker Creeks Research Watersheds (CPCRW), where we monitor stream flow and chemistry (since 1978), and now study hydrological responses to natural and experimental fires in upland catchments across watersheds with varying amounts of permafrost (since 1999). More recently, we added a snow manipulation experiment to induce permafrost thaw in boreal tundra [175], an experiment manipulating water-table height and summer air temperature in wetlands [141], and a suite of process studies, including eddy covariance, across a thermokarst forest-bog chronosequence [78].

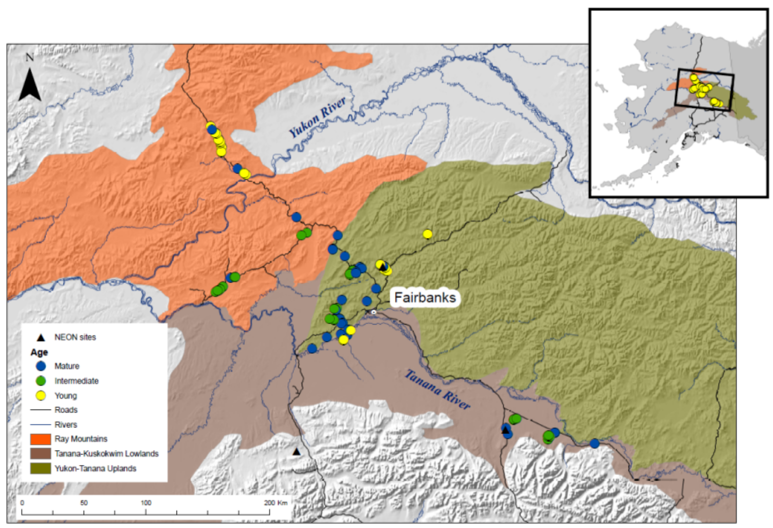


Fig 12. Locations of young, intermediate-age, and mature sites within the recently-established BNZ LTER Regional Site Network, distributed across 3 Ecoregions in interior Alaska [201].

To study and monitor how changing climate-disturbance interactions are influencing heterogeneity and cross-scale dynamics within and among these various landscape types at the regional scale, we recently completed a restructuring of the BNZ LTER monitoring program around a network of 94 long-term study sites distributed across three of the Ecoregions of interior Alaska (~50,000 km^2 area), designated the Regional Site Network (RSN)[201] (Fig 12). Focusing on how Alaska's changing fire regime (and associated permafrost thaw) is altering successional pathways and transforming landscape structure and function, we selected stands of 3 broad age classes representing time since the last fire; young stands (<15 yr), intermediate-age stands (40-60 yr), and mature stands (> 80 yr) stands. All stands were black spruce prior to being burned, but many of the young stands in particular, have lost permafrost and transitioned to hardwoods following the increase in high severity fires over the past 15 years. Variation among stands within age classes captures heterogeneity within and among burn scars in a number of interrelated factors, including landscape type and structure, burn severity, topography, site moisture, organic matter thickness, hardwood:conifer dominance, and herbivory (Fig 13) [3]. Vegetation composition and biomass, and tree insect/pathogen abundances have been inventoried for all stands, and a full soil characterization is underway, which will allow us to assess fire and permafrost history, model effects of disturbance on changes in C & N stocks, and construct water budgets across the network. A core suite of sites chosen to represent the full range of variability will be monitored more intensively for climate, litterfall, decomposition rates, seed fall, vertebrate herbivory, seasonal tree growth (dendrometers), recruitment, understory composition, and pests and pathogens. We maintain monitoring across the original LTER plots established in 1989 (many of which are in the RSN), but have scaled-back sampling frequency based on analyses of long-term vegetation data [113, 168, 206]. The RSN provides the foundation for monitoring and studying population, community, and ecosystem dynamics and change in response to changing climate-disturbance interactions at the regional scale for the next several decades, and is the most extensive regional network of its kind anywhere in the boreal biome.

The BNZ LTER ***research strategy*** has been to a) assemble a team of highly talented boreal scientists who collaborate effectively, b) provide them with a research infrastructure consisting of logistic and personnel support, long-term measurements on permanent plots and experiments, and data/information management, c) provide enough base funding for investigators to initiate studies on the long-term ecological dynamic of their focal interest, and d) encourage/require investigators to seek external funding for process studies that explore the underlying mechanisms. Tasks described below constitute the long-term research funded by the NSF and the direct USDA Forest Service support for the LTER. We list in the Project Management Plan other projects on which the BNZ LTER research plan relies.

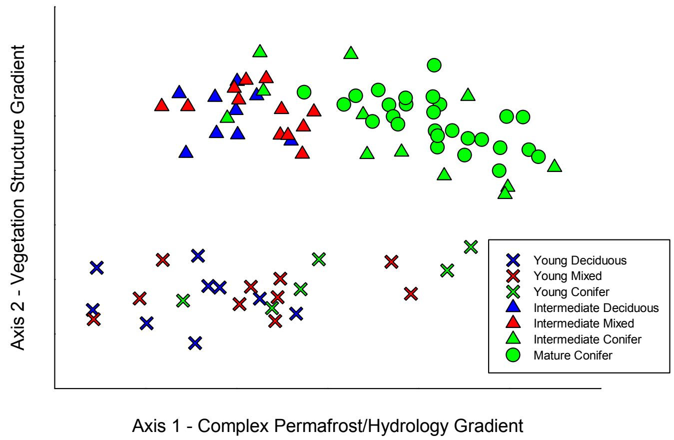


Fig 13. NMDS ordination of the RSN sites, based vascular and nonvascular species composition. Sites closer together in ordination space are more similar in species composition. Axis 1 was correlated with environmental variables including active layer depth, drainage, and soil moisture, and represents a complex permafrost /hydrology gradient. Axis 2 was correlated with vegetation characteristics such as % tree canopy, vegetation height, and % moss, all of which are often associated with “time since fire”. There is a distinct break in the ordination indicating similar species composition across young sites with a few notable exceptions in very wet or shallow-permafrost areas. The ordination indicates the large variability in species composition across sites classified as “conifer” stands, and in particular intermediate conifer stands.

Section I. Direct effects of climate change on ecosystems and disturbance regimes.

BNZ LTER research indicates that responses of ecosystems and disturbance regimes to climate variability and change in interior Alaska are controlled more by indirect and interactive effects than by the direct effects of climate warming alone. These responses are modulated by strong feedback controls of ecosystem structure on disturbance regimes, and the interaction of multiple disturbances across the landscape. For example, sensitivity of NPP to warming appears to be more a function of soil moisture [140, 256, 257] and soil nutrient availability [197], than to temperature *per se*. Vegetation has strong influences on soil moisture and thermal properties that regulate permafrost stability [123, 137], interactions that affect and are affected by fire frequency and severity [32, 95]. We continue our research on climate sensitivity to further understand the interactions and feedbacks among climate, vegetation, and disturbance and to characterize how spatial heterogeneity of ecosystems and disturbances influences the vulnerability of landscapes to change. Inventories across the RSN have quantified the large, and somewhat surprising, variability in biophysical parameters and disturbance regimes both within and among ecosystems of varying ages across the landscape, while reinforcing our understanding of the driving role of landscape position and biological legacies on both. To expand our current understanding, we will focus on quantifying patterns in the response of both ecosystems and disturbance regimes to climate change that are apparent across spatial and temporal scales. First, we will examine the spatial variability in species diversity, functional and life history traits, and productivity across the RSN, as these community/ecosystem characteristics link across spatial scales. Second, we will examine temporal and spatial evidence for the widespread browning that has been documented via remote-sensing. Third, we will assess landscape vulnerability to change by quantifying the current spatial heterogeneity of disturbance regimes (fire and permafrost), and the temporal legacies, current severity, and distribution of these disturbances.

Hypothesis 1a: Climate change influences ecosystem structure and function at multiple temporal scales through effects on site conditions, key species and vegetation community types, transforming landscape structure and heterogeneity. (Lead = Hollingsworth)

Task C1: Quantify the climate sensitivities of vegetation communities across multiple temporal and spatial scales, with an emphasis on relationships among plant species diversity, life history and functional traits, and productivity (Hollingsworth, Verbyla, Mulder). Alaska's boreal forest constitutes the northern extent of the range for many species, and ongoing and future climate change across Alaska's boreal forest is expected to influence the growth and interactions among species. Directional changes in mean climate or increases in climatic variation will likely have major implications for vegetation communities and ecosystem processes, resulting in loss or addition of species, shifts in phenology, and/or changes in community dynamics and productivity. The RSN provides a hierarchical framework for long-term monitoring of community processes, their sensitivity to changing climate, and their effects on ecosystem function across spatial and temporal scales. We will first use the RSN to test the hypothesis that diversity increases resilience to perturbation at some spatial scales but may decrease resilience at other scales, and explore the role of non-vascular plants in driving these relationships. Non-vascular plants comprise large components of species diversity and productivity in boreal ecosystems but they are difficult to identify and are seldom included in community- or trait-based studies. We have complete vascular, and non-vascular diversity data at all RSN sites. NPP will be measured at a variety of scales using both field and remote sensing techniques. Second, we will monitor the phenology of approximately 70 plant species across multiple sites, including recently introduced species, and combine these measurements with historical records based on herbarium specimens to evaluate how individual species will respond to changes in climate such as changes in season length, mean temperature, and amount and timing of precipitation. Third, we will quantify a suite of plant functional traits to provide a mechanistic framework for explaining shifts in phenology and community processes across environmental conditions captured by the RSN.

Task C2: Determine the direct and interactive effects of climate sensitivity vs. intrinsic factors on wide-spread patterns of browning in the boreal forest (Johnstone, Mack, Goetz, Ruess). Widespread declines in NDVI and other satellite indicators of productivity have fueled concerns about the health and carbon sink strength of boreal forests in Alaska [14] and the circumpolar North [19]. These signals of changing forest productivity are consistent with BNZ observations of declining radial growth of tree species in interior Alaska [14, 139, 256]. Radioisotopes in tree wood link declines in Alaskan tree growth to recent climate warming across a surprisingly broad spectrum of the forest landscape [9, 256]. Forest inventory records in Canada suggest a wide range of boreal forests are vulnerable to increasing rates of tree mortality caused by drought stress [192], an emerging pattern in forests worldwide [4]. However, patterns of tree mortality are also shaped by the autogenic processes of stand development through succession. Confounding intrinsic processes of succession with impacts of external drivers is likely to cause biased estimates of climate effects on mortality, including both overestimates [237] and underestimates [163]. Here we will combine long-term records of tree growth and mortality from BNZ plots and other State-wide data sets in productive, floodplain forests with our recently initiated RSN in upland forests to disentangle intrinsic vs. extrinsic drivers of forest productivity. Our approach will integrate monitoring data with tree ring records and demographic reconstruction of stand mortality to provide a basis for interpreting satellite records of changing forest productivity.

Hypothesis 1b: Disturbance regimes that have shaped the boreal forest for millennia are changing due to increases in mean annual temperature, the length of the snow-free period, and the incidence of drought. (Lead = Hollingsworth)

Task C3: Examine the relationship between climate and the spatial heterogeneity of fires (variation in burn area and severity, fragmentation of burn scars, composition of unburned islands) and determine what parts of the landscape are most vulnerable to reburn and vegetation change (Hollingsworth, Verbyla, Turetsky). Plot-level data, satellite-based analyses and modeling studies suggest that recent changes in Alaska's fire regime are promoting a shift towards a more deciduous forest [13, 112, 128, 160]. However, we have little information concerning how the conifer:hardwood ratio has shifted across the landscape due to changes in fire regime, which areas are most and least vulnerable to change, and the extent to which recent patterns of vegetation change are due to changes in fire regime characteristics other than burn severity. Our goal is to better understand where and when Alaskan conifer forests are vulnerable to conversion to deciduous forest following wildfire by examining the role of a suite of fire regime characteristics, including past and current forest fragmentation, topographic position, fire seasonality, and fire-return interval. Landscape fragmentation is a legacy of past disturbance (both wildfire and human-caused), but also influences current fire behavior and the spatial heterogeneity of vegetation trajectories we see on the landscape today. LANDSAT imagery from the 1980s to present will be used to examine how post-fire vegetation has been driven by various components of the fire regime [64, 74]. We will use daily MODIS hot spot locations [59] to examine how seasonality within a burn perimeter influences post-fire vegetation on similar landscape types. We will use plot-level data from two very different large fire years (2004, that burned late in the growing season and 2015, that burned early in the growing season) along with archived post-fire plot-level data dating back to 1950, to ground-truth pre- to post-fire conifer:hardwood ratios and assess whether there was significant change in post-fire vegetation that cannot be explained by topography and relay succession, indicating a true state-change as a result of climate-induced changes to the fire regime. Based on information from field and remote-sensing data, we will create maps of landscape vulnerability and determine the landscape components most susceptible to change.

Task C4: Examine how interactions among climate, fire severity, and landscape characteristics govern patterns of permafrost thaw and subsequent recovery (Turetsky, Romanovsky, Schuur). Discontinuous permafrost in interior Alaska is heterogeneous at multiple scales (i.e., broad variations in permafrost thickness, finer scale distributions of ice content and closed and open taliks), and our ability to predict changes in permafrost regimes requires more information on this heterogeneity and how it interacts with ecological and hydrological systems. We will use a combination of vertical ground temperature monitoring, electrical resistivity tomography (ERT), seasonal thaw depth measurements, and permafrost coring to investigate spatial variation in permafrost thickness, spatial extent, and soil properties and ice content across a subset of RSN sites encompassing a range in vegetation cover, fire history, soil type, and geomorphology. Of primary interest is how fire severity influences both short- and long-term rates of thaw. We will include sites that burned during the extreme fire seasons of 2015 and 2004, using a space-for-time substitution to examine the spatial variation in thaw depth and subsidence following fire. These data will be analyzed using understanding gained from Task C3. Within a single location, repeat ERT measurements can provide insight into the sustained impact of climatic variation, fire disturbance, and post-fire vegetation recovery on permafrost stability and dynamics [109]. We will also use these approaches to monitor changes in permafrost structure that occurred following a record flood in 2014 that led to large increases in active layer thickness. Together, the proposed research will allow us to understand where and when permafrost is most vulnerable to degradation, what landscape characteristics (vegetation, substrate composition and properties, geomorphology, aspects of ground or stream hydrology) have the potential to alter the sensitivity of permafrost to climate, as well as what controls the spatial nature of permafrost recovery following disturbance. We will then use the thermal and geophysical data in combination with GIS techniques to analyze permafrost distributions and identify which areas are most vulnerable to thaw and thermokarst development. Overlays with fire perimeter maps will allow us to make inferences about relationships between fire history and contemporary permafrost regimes.

Section II. Scale-dependent climate-disturbance interactions as drivers of ecosystem and landscape change

Hypothesis 2a: Climate-driven changes in fire regime affect ecosystem structure and function through interactions between fire characteristics and vegetation or permafrost that alter the spatial connectivity of biophysical processes and the influence of past material legacies on present ecosystems. (Leader = Mack).

A central focus of our previous LTER funding cycle was to develop a mechanistic understanding of the long-term ecological consequences of climate-driven increases in fire severity and its impacts on ecosystem structure and function (Fig 5). We will continue to develop this work through ongoing ecosystem-scale studies of post-fire permafrost dynamics, tree seedling establishment, and plant-soil-microbial feedbacks that control C sequestration over succession. As we established the RSN, however, we discovered that our mechanistic model, largely ecosystem-scale in perspective, does not account for the surprising variability in ecosystem properties that we see across the landscape. Catastrophic events such as wildfires share characteristic non-linear behaviors that are often generated by cross-scale interactions and feedbacks among system elements [194]. We suspect that these types of processes are creating surprises across the RSN: patterns that cannot easily be predicted based on information obtained at a single spatial or temporal scale. Our proposed research will expand beyond the ecosystem-scale to focus on when and where cross-scale phenomena shape post-fire ecosystem structure, function, and spatial distributions.

Our research points towards four key cross-scale interactions or feedbacks we hypothesize to be important controls over ecological impacts of an intensifying fire regime at the landscape scale (Fig 14). First is the negative feedback between fire severity and flammability of dominant tree species, an effect that could dampen or even decouple the relationship between climate warming and fire [95](see *Task CP1* below). Second is the cross-scale interaction between patterns of fire severity and plant seed or mycorrhizal spore sources; increasing fire severity could decrease local seed and spore sources, making post-fire recruitment dependent upon long-distance dispersal, as well as seedbed characteristics [30]. We expect that patterns of long-distance dispersal are highly sensitive to the spatial configuration of unburned stands on the landscape. Third is the population dynamics and movements of browsing animals; at a decadal time- scale, browsing of deciduous tree species could deflect severely burned ecosystems from deciduous successional trajectories, even if deciduous seedlings dominate in the first decade after fire. Fourth is the post-fire degradation of permafrost; in sites where permafrost temperature is a legacy of past climate, loss of the organic layer could lead to loss of permafrost, altering site drainage and coupling current C and nutrient dynamics to the material legacy of past ecosystems.

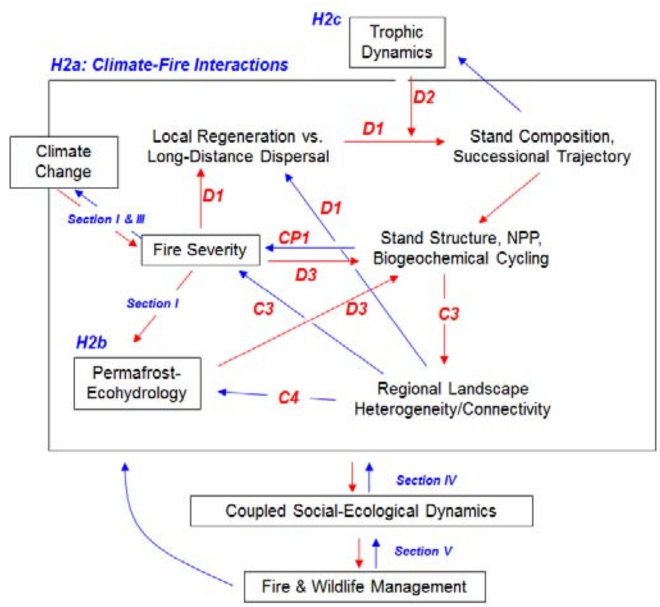


Fig 14. Diagram showing how Tasks (notations in red) link components pertaining to climate-fire interactions directly (red arrows) and via feedbacks (blue arrows), and how H2a is tied to the other proposal sections.

Task D1: Examine the effects of plant and microbial propagule dispersion on post-fire establishment of key plant species and successional trajectories, and determine how propagule availability will respond to an altered fire regime (Johnstone, Hollingsworth, Ruess, Taylor, Mack). As fire severity increases, dominant regeneration strategies of trees and understory species shift from local resprouting and re-seeding to long-distance dispersal [112, 130]. Boreal species show a high reliance on ectomycorrhizal

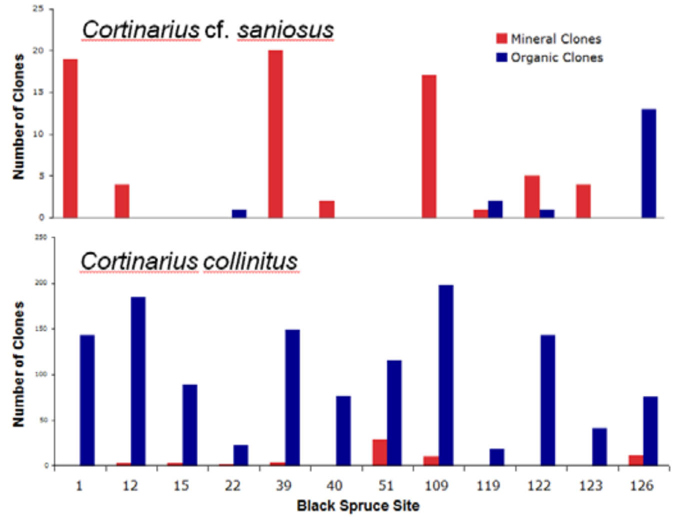


Fig 15. The fungus to plant ratio in black spruce forest soils from interior Alaska is at least 17:1 and is regionally stable, with 43% of all top matching OTUs being ectomycorrhizal symbionts (EM). An extrapolation of this ratio suggests 6 million species of fungi globally. Several examples of the same site and horizon sampled in successive years indicate a year-to-year consistency of fungal communities within a site. Strong horizon partitioning of fungal communities illustrated by these EM species indicates that closely related fungi often occupy divergent niches. This pattern is seen in fungi spanning all major functional guilds and four phyla, suggesting a major role of deterministic niche partitioning in community assembly (Taylor et al. 2014).

fungi (Fig 15), and local sources of microbiome inoculants, including mycorrhizae and N-fixing symbionts, are similarly reduced by severe fires [107, 235]. Although microbial spores tend towards spatial ubiquity [85], evidence suggests that in high severity disturbance events or plant range expansions, the availability of microbe propagules can limit establishment and growth of plant hosts [61, 65, 66]. Where fires have reduced the availability of on-site propagules, colonization from source populations is dependent on the spatial configuration of unburned patches [177, 245], although sensitivity may vary by taxa [119]. As regeneration dynamics become more reliant upon long-distance dispersal, we predict that the spatial configuration of fire severity and its history on the landscape should become a dominant control over post-fire community assembly.

In the proposed research, we will explore the relationship between fire severity and the relative importance of local regeneration vs. long-distance dispersal for the assembly of plant communities and their symbiotic microbiomes. We will use information obtained from Task C3 to identify sites with varying distance to unburned and lightly burned seed/spore sources, including unburned islands within a burn scar. We will focus exploratory analysis on RSN sites that have burned within the past 15 years. In particular, we will build on more than a decade of work on our network of 2004 burned sites to explore this relationship by identifying distance to unburned seed/spore source for each site using maps of fire disturbance derived from remote sensing. In these sites, we will focus our efforts on the establishment dynamics of four plant species or physiognomic groups that have key impacts on biogeochemical processes: (1) dominant boreal tree species and their mycorrhizal symbionts, (2) understory vascular species and their mycorrhizal symbionts, (3) mosses and their nitrogen fixing microbiomes, and (4) alders and their N-fixing actinorhyzal symbionts. We will examine plant abundance, indices of growth, and symbiotic microbiomes of each of these groups across our focal sites [5, 236]. Because of the cost of the molecular analyses involved in sampling the symbiotic microbiome, we will restrict this analysis to a subset of sites.

Task D2: Examine the spatial patterning and strength of plant-herbivore interactions across the post-fire landscape in relation to plant growth, species dominance, successional pathway, and biogeochemical cycling (Kielland, Ruess, Genet). With the recent establishment of the RSN, we are poised to extend our >25 years research on plant-herbivore interactions along the Tanana River to understand how vertebrate herbivory influences successional trajectories after fire [31, 161]. This research will complement ongoing studies on wildlife population ecology initiated during the previous funding cycle, and fits well with current efforts to examine linkages between food webs and biogeochemical cycles in relation to climate-disturbance interactions across the region. In particular, we move to examine the coupling of biogeochemical cycling and plant-herbivore interactions in the context of fluctuating browsing pressures (herbivore densities), which has strong feedbacks to plant demography, successional dynamics, and the sustainability of herbivore populations and their predators [84, 161, 187]. We will measure plant responses to herbivory in terms of regrowth, stem/species turnover, and plant 1° and 2° chemistry. Biogeochemical effects will be examined by way of nitrogen supply (PRS probes), soil N composition, and C turnover (soil enzyme activities and litter decomposition). These studies will be conducted across a browsing gradient based on moose and hare densities, and by expanding our long-term network of vertebrate herbivore exclosures within 10 burns scars spanning in age of 15-60 years. This design will help address questions regarding ecological services (sustainability of both plant and animal communities) as well as how plant communities recover from the combined effects of physical (fire) and biotic (herbivory) disturbances.

D3. Determine the consequences of a changing fire regime and fire-driven permafrost thaw for biogeochemical connectivity between past and present ecosystems (Mack, Turetsky, Schuur, Johnstone, Hollingsworth, Taylor, Harms, Genet). Low severity burning of boreal forest and tundra ecosystems leaves a residual soil organic layer that is a biogeochemical legacy of one or more past fire cycles (101). In upland black spruce ecosystems characteristic of our RSN, this legacy can contribute >50% of ecosystem C and nutrient pools. High severity burning, by contrast, erases the surficial legacy of past ecosystems, and exposes permafrost organic matter to decomposition and contemporary biogeochemical cycles. Loss of the organic layer also offers an opportunity for plant community reorganization; plant and microbial species that sequester propagules in the organic layer are killed and novel seedbeds are exposed, shifting the dominant recruitment mode towards long-distance dispersal (112). Increasing severity of burning of the soil organic layer thus catalyzes opposing shifts in the biogeochemical connectivity of past and present ecosystems. Our over-arching goal is to understand the consequences of these shifts for net ecosystem C balance and C cycling feedbacks to climate. Because nutrients such as N strongly limit plant productivity in these ecosystems, we are particularly interested in how N released from thawing permafrost may couple past ecosystems to contemporary patterns of net primary productivity.

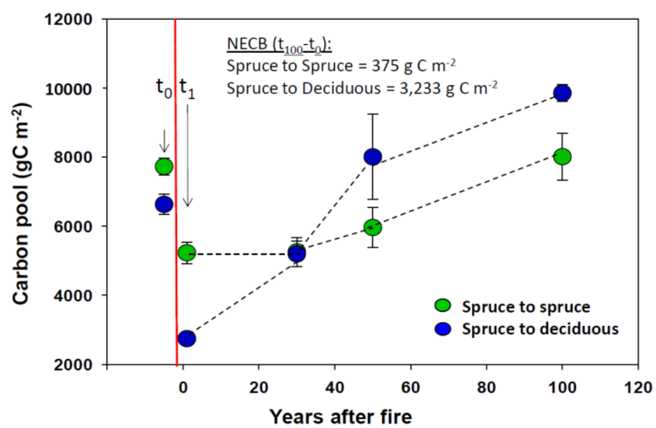


Fig 16. Ecosystem C pools in plants and surface soils and ecosystem carbon balance (NECB) across two successional cycles representing alternative stability domains: black spruce forests that regenerate to spruce dominance after fire, and black spruce forests that regenerate to deciduous (birch and aspen) dominance after fire. t0 shows estimated pre-fire ecosystem carbon pools and t1 shows pools the first year after fire for forest stands that burned in the record 2004 fire year (n=90). Stands were assigned to successional trajectories based on seedling recruitment during the first eight years after fire. Stands >20 years after fire (n=130) were sampled in a similar domain of inference as the 2004 fires.

We will use upland and lowland chronosequences together with mechanistic biogeochemical studies in a subset of sites to address the following questions: (1) How do fire severity, successional trajectory, time after fire, and landscape position affect the relative contribution organic layer vs. newly thawed permafrost C and N to contemporary ecosystem pools? (2) How does decomposition of permafrost soil organic matter contribute to contemporary C cycling, and how does this vary across sites that differ in landscape position? (3) In sites that thaw deeply after fire, do plants acquire N released by thawing permafrost and, if so, how do differences in plant functional traits or landscape position affect their contribution to net primary productivity?

To address question 1, we will continue our work characterizing ecosystem C and N pools across RSN sites that represent chronosequences of ecosystem recovery after fire. By combining these results with our study of recent (2004) fire impacts on C and N pools (25), we will determine the net ecosystem balance of C and N across conifer and deciduous successional trajectories and the contribution of legacy C or N to those balances (Fig 16). We will also develop similar characterizations of C and N pools in the thermokarst chronosequence sites, where succession was similarly initiated by fire. In a subset of upland and lowland sites that are intermediate- and mature-aged, we will use radiocarbon dating of the soil organic layer to confirm or modify mass-balance based estimates of legacy organic matter contributions (172). These data will be key for validation of model performance for post-fire succession (see below).

To address question 2, we will measure seasonal variation in the radiocarbon age of soil respired CO_2 [197] and CH_4 [258] across paired burned and unburned sites that vary in landscape position (ice-rich floodplain, valley bottom toe slope, and well-drained hillslope), where we have continuously monitored soil temperature in the top 1.5 m since 2012. By comparing seasonal change in age of C respired at the surface to depth of thaw in paired burned and unburned sites, we will determine the contribution of permafrost soil C to respiration dynamics. These data will be used to validate modeling of post-fire soil respiration dynamics.

Plant acquisition of N from deep permafrost will be determined by the reach of both plant roots and their mycorrhizae, so to address question 3, we will survey plant root density, functional traits, and mycorrhizal symbiont identity by depth across a subset of young, intermediate, and old sites in both the RSN and thermokarst chronosequence. In replicate plots that are part of the C4 watershed of the CPCRW, where stream N exports are measured (below) as well as deep soil temperature dynamics (above), we will employ an experimental addition of a ^{15}N tracer to determine which plant species are capable of acquiring N from deep in the soil profile, at the face of thawing permafrost. We will also examine partitioning and retention of the tracer in the plant-soil system, and determine the allocation and C:N stoichiometry of plant-acquired tracer. These data will be used for validation of the new depth-stratified rooting and N dynamics in DOS-DVM-TEM.

Hypothesis 2b: Vegetation, landscape setting, and soil drainage characteristics modulate the response of permafrost to climate warming, changes in hydrological connectivity resulting from permafrost thaw, and post-thaw changes in ecosystem function. (Lead = Jones)

Alaska's boreal forest is experiencing broad scale hydrologic changes in the timing and forms of precipitation, frequency of drought, and river discharge. Over the past century, summer drought conditions have become more frequent with the climate shifting towards warmer conditions and reduced precipitation. The effects of changes in the timing and amount of precipitation on ecosystem functioning are modulated by the distribution of permafrost, landscape topography, infiltration rate, soil water holding capacity, and vegetation structure [69, 135]. Permafrost has a dominant control on hydrology by forming an impermeable barrier that restricts subsurface flows to the shallow active layer of soil -- the shallow soil layer above permafrost that freezes and thaws each year [136]. In upland catchments, degradation of permafrost may lead to drying of surface soil and reduced stream flow as the impermeable barrier recedes deeper in the soil profile. In contrast, in lowland ecosystems, the combination of low gradient and subsidence caused by local permafrost degradation, serves to maintain saturated soils and may result in ponding of surface waters. Interactions among changing climate, vegetation, permafrost, and water availability will control ecosystem carbon and nitrogen cycling. In upland landscapes, loss of permafrost and soil drying will likely lead to deepening flow paths through catchments, drying of soil, and increased aeration leading to loss of organic matter stored within soil. In contrast, thawing of lowland permafrost and impounding of water can reduce soil decomposition rate and stimulate production of methane. Lastly, while deepening of the active layer typically occurs gradually, thermokarst in areas of ice rich permafrost can cause abrupt thaw and collapse of the soil profile, which accelerate losses of soil carbon and nitrogen [1]. How will vegetation and permafrost thaw interact with changing

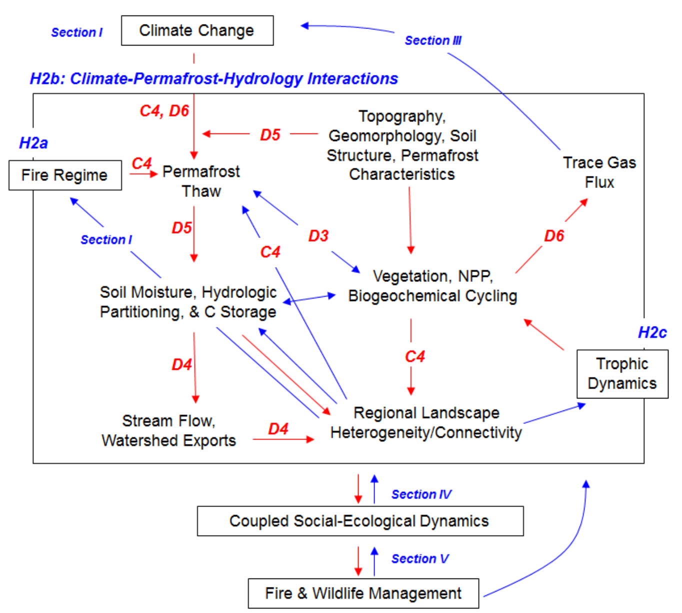


Fig 17. Diagram showing how Tasks (notations in red) link components pertaining to climate-permafrost - hydrology interactions directly (red arrows) and via feedbacks (blue arrows), and how H2b is tied to the other proposal sections.

climate to alter water availability and surface hydrology within and across different landscapes throughout interior Alaska, and what are the feedbacks to landscape connectedness, ecosystem structure and function, and disturbance regimes (Fig 17)?

Task D4: Examine the interactions among changes in climate, permafrost, and vegetation on soil water retention, hydrologic partitioning, and stream export of C and N across upland boreal forest catchments (Jones, Harms). Research examining the coupling among climate, permafrost, soils and vegetation with watershed hydrology and stream solute exports is focused in the CPCRW and builds on ~35+ years of stream flow and climate measurements. The CPCRW is the core site for the taiga domain of NEON and will host a tower and aquatic array, which will provide infrastructure to examine solute fluxes at higher temporal resolution than currently possible. We propose to couple ongoing measurements of stream flow with patterns of summer precipitation using collectors located in sub-catchments of the CPCRW to characterize hydrologic partitioning and develop a model describing change in actual evapotranspiration and stream discharge with timing of precipitation and extent of permafrost. Sub-catchment measures of hydrologic partitioning will be coupled to plot scale measures using wells collecting soil and near-stream water in order to examine how changes in the ecohydrology of boreal forests will affect stream exports of C and N. We also will initiate data collection across the RSN to examine C and NO_3^- production and transport in soil, ground water, and streams. Data collection will focus on concentrations and isotopes of solutes in streams and waters contributing to streamflow, as well as measures of the production of DOC and NO_3^- in soil. Sampling will target locations of contrasting disturbance history, vegetative characteristics, drainages, and permafrost conditions, to provide a broad context for examining effects of vegetation shift from black spruce to deciduous stands. We will apply an existing process and mixing-based model to quantify relative contributions of NO_3^- in precipitation, and rates of nitrification and denitrification.

Task D5: Determine influences of vegetation and permafrost thaw on soil C storage and soil water retention and hydraulic properties (Turetsky, Schuur, Mack). Relationships between carbon storage and hydraulic properties in soils vary with soil organic content, texture, and disturbance history, and have the potential to change as permafrost thaw leads to the gradual deepening of the seasonally thawed active layer. We will evaluate properties of soil hydrology in relation to carbon stocks across a range of plant-water and permafrost-water relationships associated with the RSN. We will quantify depth-dependent soil water infiltration and water retention curves in sites spanning the range of forest cover type, stand age, organic layer thickness, and soil texture offered by the RSN. Subsamples used in our soil hydrology assessments will be analyzed for C and organic matter concentrations. These data also support Task D6, as they will allow us to make predictions regarding how soil saturation and runoff response will vary as a function of disturbance and changing active layer conditions.

Task D6: Use global change experiments situated in contrasting upland and lowland ecosystems to determine ecosystem responses to changes in permafrost extent and surface hydrology (Schuur, Turetsky). We will use two long-term manipulative experiments that have been established in contrasting ecosystem types of the boreal domain: (1) upland tundra at the altitudinal treeline (CiPEHR/DryPEHR), and (2) lowland black spruce forest (APEX). These experiments were established independently, and both manipulate aspects of permafrost and hydrology to understand controls over ecosystem function. Though located in different settings, both represent trajectories of thaw in ice-rich permafrost, and both experiments are focused on similar key questions: (1) Does warming and permafrost degradation cause a net release of C from the ecosystem to the atmosphere, and how does the magnitude change over years, decades, and centuries? (2) What proportion of this C release is derived from old C that comprises the bulk of the soil C pool? (3) How does water table position interact with warming to control old C losses and release of C to the atmosphere? In this round of LTER research, we will integrate datasets to determine whether the partitioning of total C release into CO_2 and CH_4 responds similar to variation in water table position across the two experimental sites. Increasing CH_4:CO_2 ratios should occur as a result of anaerobic decomposition in saturated soils, and can have a significant climate effect because of the much higher greenhouse warming potential of CH_4. Because permafrost thaw can have very different impacts of hydrology dependent on ice content, geomorphology, and soil characteristics, integrating data across all of our experimental treatments will provide information on C flux responses across a wide range of soil moisture conditions.

Hypothesis 2c: Climate- and disturbance-driven changes in trophic dynamics affect the population dynamics of plants and animals and ecosystem function by altering the abundance of key plant species. (Lead = Ruess).

High densities of vertebrate herbivores in Alaska's boreal forest and the associated evolution of chemical defense against browsing are believe to be linked with global variation in climate-driven fire at the end of the Pleistocene, resulting in high forage availability and intensity of selective browsing during winter across the Alaskan landscape [35, 38]. The BNZ LTER has been studying mechanisms and consequences of plant-herbivore interactions for over three decades [33, 34, 36-38, 147-149, 208]. We are now focusing on how changing disturbance regimes are influencing the population dynamics and movement patterns of vertebrate herbivores and their predators across the region, and how plant-browser interactions are shaping regional vegetation responses to environmental change. Changing disturbance regimes are also affecting the complex interactions among vertebrate and invertebrate herbivores and plant pathogens. For example, browsing promotes the dominance of chemically-defended alders (N-fixing species), which influence N cycling [181, 207, 246], but the outbreak of a fungal stem canker on thin-leaf alder (*Valsa melanodiscus*) has led to near-complete alder mortality in some riparian habitats [209]. Quaking aspen, a preferred forage species for moose [222], is predicted to increase in abundance on drying slopes following high severity fires, but the fate of the aspen leaf miner (*Phyllocnistis populiella*, hereafter ALM), which has been at outbreak densities for over a decade in interior Alaska, is uncertain. Other invertebrate herbivores, such as the willow leaf blotch miner (*Micurapteryx salicifolliela)*, can severely impact vertebrate forage species, but we are just beginning to study how moose and plant pests/pathogens interact, including feedbacks that may influence outbreak dynamics, such as whether bark stripping of aspen by moose fosters the spread of aspen cankers (Fig 18).

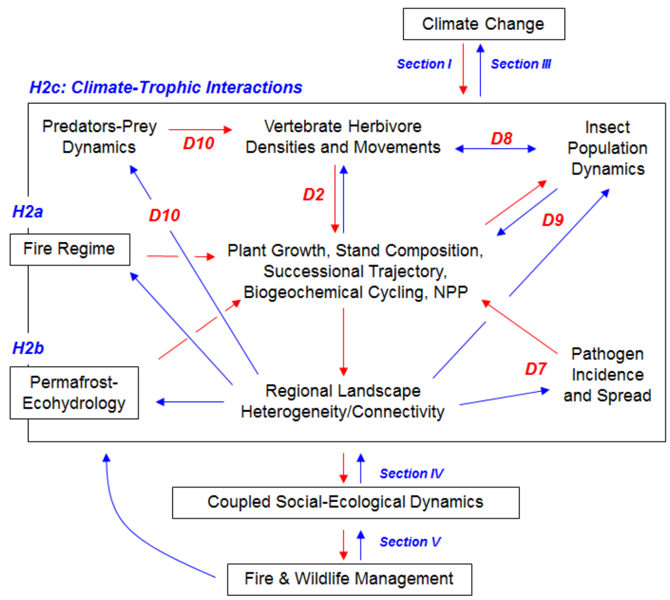


Fig 18. Diagram showing how Tasks (notations in red) link components pertaining to climate-trophic interactions directly (red arrows) and via feedbacks (blue arrows), and how H2c is tied to the other proposal sections.

Task D7: Characterize patterns and drivers of recent changes in regional distributions of key plant pathogens, assess pathogen effects on plant growth, community composition, and successional dynamics, and predict future impacts on ecosystem function at regional scales (Ruess, Wagner, Rupp). We will continue collaborations with USDA State and Private Forestry and utilize State-wide aerial (USFS) and ground-based (USFS & LTER) monitoring efforts to assess how recent warming and associated plant drought stress are affecting key plant pathogens, and coordinate pathogen abundances with measurements of plant growth, community composition and stand structure across LTER and State permanent plots. We will focus on fungal cankers specific to trembling aspen and alder, because of the importance of these hosts in ecosystem function, their critical role in vegetation regime shifts following fire, and the apparent rapid spread of their fungal cankers (Fig 19) [209]. Related stem cankers are now rapidly spreading to infect Siberian, Sitka and red alder throughout the state. We will initiate new monitoring programs for these hosts in collaboration with the USFS, and quantify the effects of canker on N fixation by Siberian alder and associated rates of plant growth and successional patterns of C and N storage [3, 209]. We will help coordinate a new effort to study and monitor the identities, distributions, and impacts of the suite of fungal cankers that are now increasing on aspen [205], and incorporate results into models that forecast regional impacts on herbivores, stand production dynamics, and climate feedbacks [212, 261].

Task D8: Examine the direct and interactive effects of insect herbivores and vertebrate browsers on plant growth, biogeochemical cycling, and vegetation development in early successional stands (Wagner, Kielland, Ruess). This task is motivated by the desire to better understand the impact of insect herbivory within natural communities on the foraging of mammalian species highly valued as a subsistence resource. While vertebrate browsers clearly have strong direct effects on plant community structure and biogeochemical cycling in the boreal forest [147], the long-term impacts of insect herbivores are less well understood. In addition to direct effects on plant performance, which can be substantial during outbreaks [252], insect herbivores may indirectly affect patterns of browsing by mammals by reducing plant quality and slowing growth, leading to underappreciated interactive effects. Conversely, winter browsing by mammals appears to improve leaf quality [33, 148], which could in turn have positive effects on insect herbivores. We will continue a manipulative experiment begun in 2012, in which mammal exclusion (via fencing) is crossed with insect suppression (via annual insecticide application). Dependent variables are plant community composition, cover, shrub growth, litter production, decomposition, and soil chemical and physical variables. The work builds on a history of LTER-related research that seeks to understand the influence of herbivores on boreal communities and ecosystems.

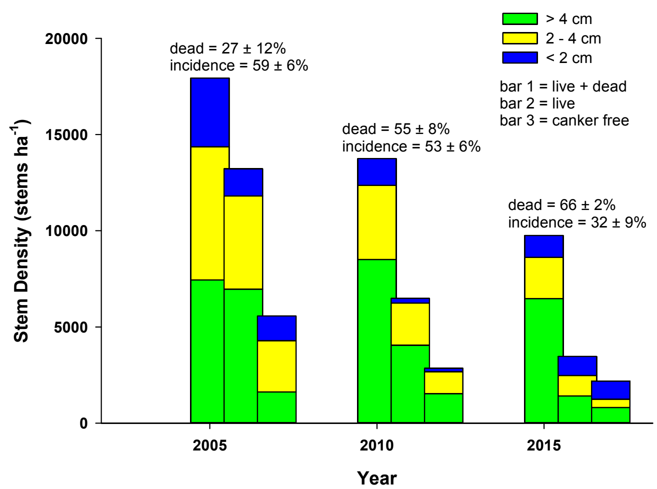


Fig 19. Stem density of thin-leaf alder showing incidence and mortality from alder stem canker in early successional stands (n=3) along the Tanana River. Declines in N-fixation inputs to these ecosystems parallel canker infection (Ruess et al. 2009). Dense shade in the understory prevents alder seedling recruitment, but scattered balsam poplar recruited at T0 suggests these stands will eventually transition to balsam poplar. However, if, when, and how alder will recruit back into these stands to develop into the mid-successional stands we see on the landscape today is unclear, as are the long-term impacts to biogeochemical cycling due to the loss of N fixation inputs (LTER Long-Term Monitoring Program).

Task D9: Determine how post-fire stand age and area influence aspen's susceptibility to insect herbivory and impact the population dynamics of an outbreak insect herbivore (Doak, Wagner). The ALM feeds on epidermal leaf tissues, disrupting photosynthesis, reducing growth, and causing dieback of it primary host, quaking aspen [251, 252]. Although it is not unusual for ALM populations to remain at high density for decades [62], the mechanisms sustaining such outbreaks are poorly understood [68]. Between 2002 and 2011, the ALM maintained high densities throughout interior Alaska [247]. Damage declined in 2011, then rebounded in many areas in 2014, creating a patchwork of high and low density populations across interior Alaska. The current pattern of spatial variation in ALM density is ideal for the investigation of environmental factors fostering ALM outbreaks. We plan to expand an ongoing, long-term field study of ALM populations near Fairbanks to a regional scale in order to relate variation in ALM oviposition, survivorship, fecundity, and leaf damage to environmental and host characteristics across stands ranging in age from <5 to 80 years. A central hypothesis is that ALM survivorship and fitness increase with aspen stand age. The expression of both direct (chemical) and indirect (predator-mediated) defenses declines as aspen trees mature [264], and preliminary data indicate that the leaves of mature aspen trees produce more ALM survivors of higher mass than the leaves of young trees. Larger-scale temporal and spatial patterns of outbreak timing and distribution will be investigated using data from annual aerial forest damage surveys conducted by the state of Alaska. A better understanding of the relationship between stand age and ALM outbreak will assist in predicting future outbreaks. As the climate warms and wildfires increase in extent and intensity, pre-fire black spruce stands are predicted to convert to post-fire deciduous stands with increasing frequency [112]. Large, aging stands of poorly defended trees could produce disproportionate numbers of ALM individuals, fueling additional widespread outbreaks.

Task D10: Examine population dynamics of snowshoe hares and their spatial synchrony across a latitudinal boreal transect in relation to the abundance and space use of their primary mammalian predators (Kielland). Recently we have demonstrated the importance of predation and habitat structure as controls over snowshoe hare survival [82, 84], and that their primary predator (Canada lynx) is capable of traversing vast distances and significant dispersal barriers [83]. This observation corroborates the idea that a “travelling wave” of predator abundance could affect the spatial synchrony of hare population dynamics [155]. Populations of snowshoe hares are being actively monitored via annual pellet counts or biannually by capture-mark-recapture techniques [150] in 4 areas: Tetlin National Wildlife Refuge (Tok), BCEF (Fairbanks), Koyukuk/Nowitna NWR (Galena), and Gates of the Arctic NP (Wiseman), representing a ~700km latitudinal gradient from the Canadian border to the central Brooks Range of Alaska. Across this gradient we also live-capture lynx using cage traps and modified foot snares [82]. We collect morphometric and genetic data on each animal and outfit the animals with 350 g GPS2110L Iridium transmitters. The transmitter fix schedule can be controlled remotely which allows us to obtain detailed information on habitat use, travel rates, and activity patterns. We are currently expanding this effort to include additional wildlife refuges (Yukon Flats and Kanuti NWR), as well coordinated capture efforts with researchers in Yukon Territory, Canada. These efforts also involve cooperation with residents of rural communities across interior Alaska.

Section III. Linking landscape heterogeneity with regional and global climate feedbacks

Overarching Question: How do intermediate-scale patterns and processes (sub-kilometer resolution) of upland and wetland ecosystems influence regional scale ecosystem dynamics and climate feedbacks?

Hypothesis 3a: Responses of boreal ecosystems in interior Alaska to projected changes in climate and disturbance regimes will directionally shift vegetation distribution towards more deciduous forest cover in uplands because of increased fire frequency and severity, and towards more wetland cover in lowlands because of increased thermokarst disturbance. The rate and degree of these shifts will be influenced by intermediate-scale patterns and processes in upland ecosystems (e.g., the effect of landscape patterns on flammability, seed availability, and post-fire regeneration) and in lowland ecosystems (e.g., the effect of landscape patterns on the thaw of ice-rich permafrost ecosystem transitions associated with thermokarst disturbance). (Lead = Rupp).

During the previous phase of the BNZ LTER, we made substantial progress in developing the modeling framework that will constitute the starting point for this research on regional ecosystem dynamics and climate feedbacks. The framework is Generation 2 of the integrated ecosystem model (IEM) for Alaska and Northwest Canada (Fig 20) [120]. This model is a synchronous coupling of ALFRESCO [98, 132, 167, 211-214], the dynamic organic soil model-dynamic vegetation model-version of the Terrestrial Ecosystem Model (DOS-DVM-TEM) [76, 78], and the Geophysical Institute Permafrost Lab (GIPL) regional permafrost model [121-123, 180]. Model applications to date have primarily focused on simulating interactions among wildfire, vegetation distribution, C dynamics, and top-down permafrost thaw at 1-km resolution in the northern boreal region of Alaska. ALFRESCO currently models the relationship between monthly climate variables and flammability of a given 1-km grid cell, and fires are stochastically ignited and then burned recursively at that resolution. We have recently modified ALFRESCO so that it considers the effects of spatially explicit fire management zones in Alaska (limited, modified, full, and critical) by modifying the flammability in these zones [44]. DOS-DVM-TEM includes interactions among soil thermal dynamics, multiple vegetation pools (leaf, wood, and roots), and a dynamic vegetation component. The dynamic vegetation component includes multiple plant functional types (such as moss, deciduous trees, black spruce, white spruce, and shrubs) that compete for water, light, and N in the context of a dynamic organic soil that can be altered by fire disturbance and alternate successional trajectories. The GIPL model uses the effect of snow layer, moss, and subsurface soil thermal properties to simulate ground temperatures and active layer thickness by solving the 1D heat diffusion equation with phase change. The GIPL model has been successfully validated using ground temperature measurements in shallow boreholes across Alaska [180].

A number of Section I & II tasks will inform the further development of the IEM that will operate at 1-km resolution (i.e., tasks C1, C2, C4, and D3). This information will be used to parameterize, calibrate, and verify model dynamics prior to the regional applications in Task CF1 (see below). For example, we will use information on C and N dynamics associated with alternate successional trajectories from the RSN as well as past and ongoing research on this topic [3, 172]. This model development will also result in improvements with respect to representing ecosystem processes at less than 1-km resolution. In Task CF1 below we focus on Section I & II tasks that will be informative to representing landscape heterogeneity and cross-scale processes at sub 1-km resolution.

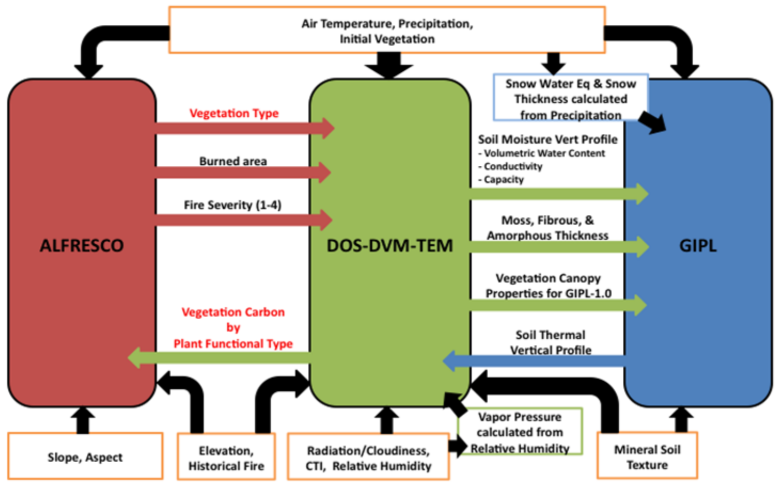


Fig 20. The Integrated Ecosystem Model (IEM) for AK and NW Canada is a synchronously coupled model of the Alaska Frame-Based Ecosystem Code (ALFRESCO), the dynamic organic soil dynamic vegetation version of the Terrestrial Ecosystem Model (DOS-DVM-TEM), and the Geophysical Institute Permafrost Lab (GIPL) Model.

Although the regional version and applications of the IEM framework will not directly consider information for a number of tasks (e.g., D2, D4, D7, D8, D9, and D10), we do intend to conduct exploratory studies with the IEM framework to examine issues considered by these tasks. For example, we anticipate conducting exploratory model development and application on issues of vertebrate herbivory, insect disturbance, and land-water interactions of the C and N cycles.

Task CF1: Modify the integrated model framework of fire regime and ecosystem structure and function to incorporate information developed from Sections I & II to the effects of intermediate-scale patterning and processes. Compare retrospective analyses of disturbance regime and landcover change between applications of the modeling framework that do and do not consider intermediate-scale patterning and processes (Rupp, McGuire, Genet, Turetsky, Romanovsky). We will modify the IEM so that it represents changes in wetland distribution associated with thermokarst disturbance through development and incorporation of the Alaska Thermokarst Model (ATM) into the modeling framework (Fig 21). Because wetlands are generally not dominant at 1-km resolution, this will require the ATM to track wetland distribution within 1-km resolution. We will use a data set of wetland distribution in Alaska developed from the National Wetland Inventory [103] to define the initial wetland distribution for the northern boreal region in 1950, since the National Wetland Inventory for Alaska was derived from aerial photography largely

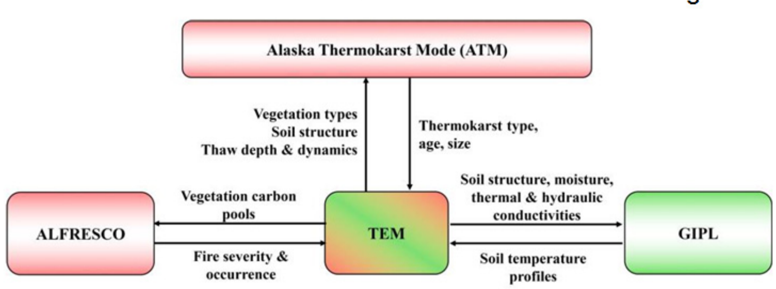


Fig 21. The Alaska Thermokarst Model (ATM) will be incorporated into the IEM (ALFRESCO-TEM-GIPL) to model vegetation transitions associated with thermokarst disturbance.

collected in the 1950s. The ATM is being designed as a state-and-transition model that predicts the transition of permafrost plateau forest to thermokarst features in boreal region (Fig 22). This model is being developed using field and remote sensing data collected in the Tanana Flats and the Yukon Flats NWR [157, 203]. Research in tasks C4 and D3 (effects of climate and fire on permafrost thaw and degradation) will also inform the development of ATM. Thus, the direct effects of climate and the indirect effects via changing fire regime will be represented in ATM.

The tracking of sub-grid cell variability in wetland distribution also requires us to modify ALFRESCO so that it simulates fire and tracks stand-age distribution within 1-km resolution. Research in tasks C3 (climate and spatial heterogeneity of fires), and D1 (species spatial dispersion and fire characteristics) will inform the modification of ALFRESCO.

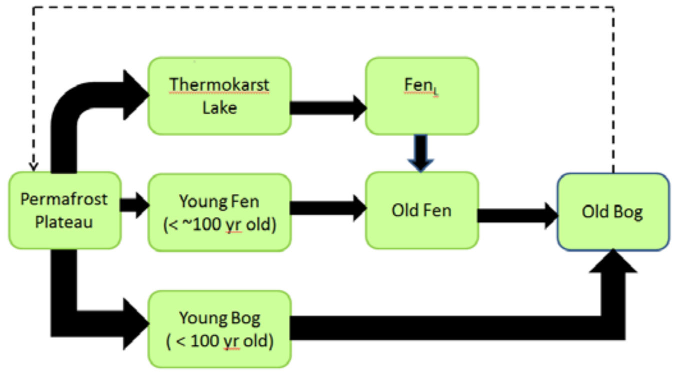


Fig 22. Wetland land cover transitions in interior Alaska associated with thermokarst disturbance.

We will also further develop and incorporate peatland biogeochemical dynamics into DVM-DOS-TEM based on progress made with Peatland DOS-DVM-TEM in collapse-scar fens and bogs [81] to estimate the dynamics of CO_2 and CH_4 of established wetlands as well as those dynamics associated with thermokarst disturbance. Research from tasks D3, D5, and D6 will inform this further development.

For tasks CF2, CF3, CF4, and CF5, we will conduct a set of simulation experiments with both the reference IEM that operates at 1-km resolution and the new IEM that operates at sub- 1-km resolution for the northern boreal region of Alaska. These simulations will be run from year (1) 1000 - 1900 to condition the IEM to disturbance regimes, (2) 1901 - 2009 to represent historical climate and disturbance, and (3) 2010 - 2100 to represent future projections of climate and disturbance. We have conducted these types of simulations in recent assessments [94, 103, 169, 170, 210, 266]. The future projections will include at least two climate models and at least two representative concentration pathways (RCPs). We have recently prepared and downscaled the climate data from the top five ranked climate models for the Alaska region and several RCPs [225]. We will choose two climate models that differ substantially in their sensitivity of warming to changes in greenhouse forcing, and will likely use the RCP 4.5 (intermediate mitigation effort) and 8.5 (business as usual) simulations for each of these climate models. The four scenarios are intended to bracket the plausible uncertainty in responses of the IEM. For each of these scenarios, we will conduct 200 simulations, as we did in the Alaska Carbon Assessment, to evaluate within vs. across scenario uncertainties.

Task CF2: Compare changes in ecosystem structure estimated by the new integrated model framework for future scenarios of climate for interior Alaska to applications of the integrated model framework that do not consider intermediate-scale patterning and processes (Rupp, Euskirchen, Genet, Turetsky, McGuire, Romanovsky). Aspects of the retrospective model simulations for northern boreal Alaska to be evaluated by both versions of the IEM include area burned, fire size distribution, the composition and distribution of vegetation types, stand-age distribution, the statistical distributions of vegetation C and soil organic matter, and the spatial distribution of permafrost. Area burned of the model simulation will be compared with two data sets. The first (1950-2015) is derived from the Alaska Large Fire Database. The second (1860-1949) is derived from a modified version of a statistical model [72]. The composition and distribution of vegetation types in 2009 (the end of the historical simulation period) will be compared with the 2011 landcover in interior Alaska obtained from the National Land Cover Database [178]. A key analysis in this comparison is to evaluate the ratio of coniferous to deciduous vegetation across the landscape, which is an integrated metric of the ability to simulate both fire disturbance and shifting successional trajectories through time. Stand-age distribution will be evaluated with data from available forest inventory surveys in interior Alaska. Analyses of changes in wetland distribution simulated by the ATM in the new version of the IEM will be evaluated/verified with information available for wetland dynamics in the Tanana Flats and the Yukon Flats NWR [157, 203].

Vegetation C stocks simulated by the IEM will be compared with estimates from forest inventories conducted by the Cooperative Alaska Forest Inventory [159, 166]. Several data sets based on the National Soil Carbon Network database for Alaska, which was developed in collaboration with the BNZ LTER, will be used to validate IEM estimates of soil carbon stocks[126, 261]. We will also evaluate vegetation and soil C stocks with information from the RSN. Permafrost distribution in the northern boreal region will be evaluated by comparisons with several synthetic data sets of permafrost spatial distribution that have recently been developed for Alaska [190, 191, 261].

Future vegetation, fire, wetland, and permafrost dynamics simulated by the two versions of the IEM will be analyzed for the four climate model-RCP scenario combinations. Analyses of vegetation change will primarily focus on changes in deciduous and conifer forest cover in uplands and changes in permafrost plateau forests and wetland cover in lowlands. We will conduct additional attribution simulations with and without changes in fire regime, with and without changes in permafrost top-down thaw, and with and without changes in wetland distribution to evaluate the relative contributions of changes in fire regime, permafrost top-down thaw, and wetland distribution to these dynamics.

Task CF3: Evaluate if simulated future changes in boreal ecosystems are unprecedented in the context of natural variability at decadal to millennial timescales (Hu, Rupp, McGuire, and Mack). The present understanding of boreal ecosystem change is largely based on several decades of observational studies and satellite data. These records are of limited use for understanding ongoing and future changes in these ecosystems because fire return intervals and successional cycles in the boreal forest occur over decadal-centennial timescales. Paleorecords spanning a broad range of environmental conditions and temporal scales are required to understand vegetation feedbacks that may attenuate the climate-fire relationship or override the direct impact of climate change [144]. We will evaluate projected future changes in the context of Holocene variability. Specifically, we will (1) synthesize fire records spanning the past 10,000 years from across Alaska to decipher the spatiotemporal variability of fire regimes [10, 108, 114, 144, 164]; (2) conduct high-resolution pollen analysis to estimate deciduous vs. conifer forest cover and elucidate vegetation feedback to fire-regime shifts, with a focus on past warm periods such as the Medieval Climate Anomaly [116, 144, 238]; and (3) obtain paleoecological and geochemical records to infer fire-permafrost interactions in relation to climate and vegetation [55]. We will conduct simulations with the IEM framework that incorporate information from these analyses to determine if the simulated fire regime and C dynamics differ quantitatively from those simulations conducted as part of Task CF2 to evaluate if considerations of past variations influences ecosystem resilience and threshold change in the regional boreal forest of Alaska. This analysis will spatially and temporally extend an analysis we conducted for a restricted region in the Yukon Flats National Wildlife Refuge [146].

Hypothesis 3b: Responses of water and energy exchange associated with changes in climate (i.e., changes in snow cover), fire frequency and severity, and permafrost thaw throughout the 21st Century will result in 1) net positive feedbacks to climate warming during the shoulder seasons due to decreases in snow cover, and 2) net negative climate feedbacks during summer due to vegetation shifts. However, this will result in net positive feedbacks over the annual cycle since positive feedbacks related to changes in snow cover will exceed negative feedbacks associated with vegetation cover. The consideration of intermediate-scale patterns and processes of upland (e.g., higher albedo associated with failure of tree regeneration in some successional trajectories) and wetland ecosystems (e.g., higher albedo associated with wetland ecosystems in comparison with conifer permafrost plateau forest) will enhance negative water and energy feedbacks to the climate system during the summer and shoulder seasons. (Lead = Euskirchen)

Task CF4: Analyze water and energy feedbacks to future change in climate for interior Alaska between applications of the model that do and do not consider intermediate-scale patterning and processes (Euskirchen, Turetsky, Genet, Rupp, McGuire, Romanovsky). We have developed a methodology to compute changes in atmospheric heating due to changes in post-fire vegetation and snow cover [75, 76, 79, 80]. This methodology takes into account information pertaining to air temperature, precipitation, latent heat, sensible heat, short- and long-wave radiation as well as information pertaining to vegetation cover for a given year. To evaluate H3b, we will analyze vegetation and stand-age distributions simulated by the two versions of the IEM from the simulations conducted under Task CF2 of H3a, as well as solar radiation information (based on cloudiness) to estimate atmospheric heating for the years 2010-2100 for the 4 future climate-RCP scenarios. Both remotely-sensed and field-based estimates of albedo will be used. We will also analyze the attribution simulations conducted in Task CF2 to evaluate the relative contributions of changes in fire regime, permafrost top-down thaw, and wetland distribution to changes in water and energy feedbacks.

Hypothesis 3c: Upland boreal ecosystems of interior Alaska will lose soil C mainly as CO_2 to the atmosphere as a result of increased disturbance frequency and severity and increased decomposition because of warming and permafrost thaw. This C loss will be partially offset by increased NPP at the intermediate-scale associated with increased deciduous and mixed forest cover resulting from increased disturbance severity. In boreal wetlands, intermediate-scale CH_4 emissions will change due to warming-induced increases in methanogenesis and drainage-induced decreases in methanogenesis (the former response dominating the overall flux). In the new IEM framework, the consideration of intermediate scale patterns and processes in uplands and wetlands will enhance C feedbacks to the climate system more than simulations that do not consider these intermediate-scale patterns and processes. (Lead = Genet)

Task CF5: Analyze C feedbacks to the climate system to future change in climate for interior Alaska. Compare applications of the modeling framework that do and do-not consider intermediate-scale patterning and processes (Genet, Turetsky, McGuire, Romanovsky). The application of the two versions of the IEM for the historical period and for the future climate-RCP scenarios in Task CF1 will provide spatially and temporally explicit estimates of CH_4 and CO_2 exchange through 2100 for the full suite of variables used to drive those simulations. We will calculate cumulative greenhouse gas forcing from 1950 – 2100 for each simulation [92]. We will also analyze the attribution simulations conducted in Task CF2 to evaluate the relative contributions of changes in fire regime, permafrost top-down thaw, and wetland distribution to changes in C feedbacks.

Section IV. Coupled Social-Ecological Dynamics for Interior Alaska

Our study of social-ecological change in Interior Alaska focuses at the household, community and regional scales. Interior Alaska has few roads and a scattering of human settlements with only one urban center of moderate size, Fairbanks and the North Star Borough (pop size ~101,000). Rural settlements fall into two categories, those located on the road system, and smaller villages off the road system (Fig 23). Off-road rural villages are primarily situated on rivers and populated by Athabaskan Indians. On-the-road communities have more mixed ethnicity. Harvestable resources are particularly important to all rural communities for food security and cultural identity associated with subsistence. These same resources are also of value to many urban residents who harvest wildlife and fish for food and recreation. Moose, caribou, salmon, and waterfowl are particularly important, as is timber as a source of fuelwood. The diversity of human settlements and their respective cultural perspectives on harvesting resources makes for significant contrasts in social-ecological conditions. For example, annual per capita harvest of wildlife in the Fairbanks area is ~10 kg whereas harvest by villagers of rural Interior Alaska is 206 kg [259]. This contrast creates challenges for policy makers when allocating resources for harvesting, regulating access to hunting grounds and harvesting seasons, and managing land-

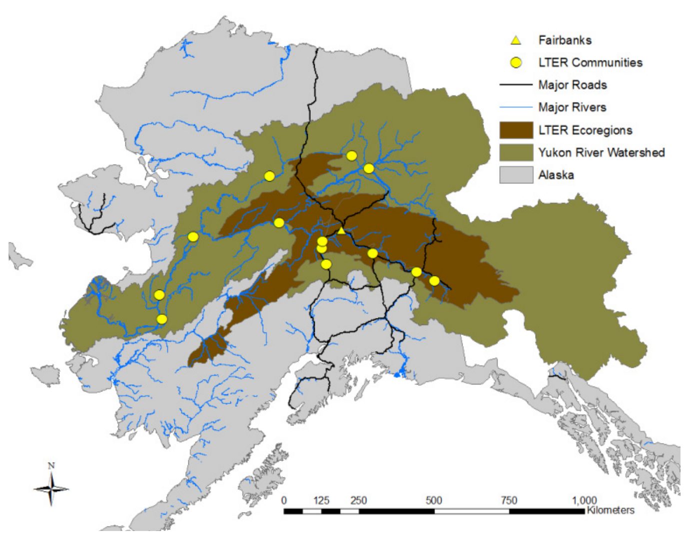


Fig 23. Locations of rural communities that are actively engaged in building research partnerships with LTER scientists.

use changes that potentially alter ecosystems, demographics, and economic systems. The complexity of changes in climate and disturbance regimes to the landscape adds to the challenge of resource management. For example, the increase in fire frequency alters wildlife habitat and timber resources and creates smoke conditions that have human health implications. The degradation of permafrost and timing of precipitation affects river levels, hinders travel and access to hunting grounds, and affects subsistence species in aquatic and terrestrial ecosystems. BNZ LTER social-ecological systems research builds on our past focus on select study communities of interior Alaska to examine contrasting conditions of the region with comparative studies to consider both the effects of changes on different types of communities as well as communities' respective capacity to adapt and or transform in the face of these changes.

Task SES1: Build and evaluate partnerships between LTER scientists and rural communities to increase two-way communication, develop metrics to assess impact, and ultimately expand the utility of LTER research to local stakeholders (Brinkman, Hollingsworth). Our approach focuses on development of a community engagement strategy [42, 104] that integrates local research priorities and activities (e.g., citizen science) into long-term monitoring efforts. Our community engagement framework is a multistep process that includes contacting relevant communities that may be interested in collaboration, formalizing partnership agreements following local protocols and customs, ranking and assessing the feasibility of local research priorities, and co-designing and implementing LTER research agendas that address local needs. Although involving communities in the research will strengthen bottom-up planning, the outcomes of research plans will need to be carefully evaluated to determine effectiveness. We will develop an evaluation assessment survey to collect perceptions of both communities and LTER scientists on the extent of satisfaction or dissatisfaction with each step of the engagement process and the outcomes of the research partnership. Independent of the survey, we will create metrics to quantify local utility of LTER data. For example, the frequency that LTER data are used by communities to advance their interests will be an index of community benefit. Research partnerships also may benefit scientists through 1) exposure to new epistemologies that foster novel research questions, 2) enhanced awareness of societal consequences of research, and 3) insight on cross-scale (local-regional-national) social-ecological interactions [51]. A key deliverable of this task will be a community engagement model that can be applied and tested across the LTER network.

Task SES2: Advance the practice of community-based ecological monitoring through development of methods for documenting local observations (Kofinas, Brinkman). Local and traditional knowledge is acknowledged as a valuable resource in reducing uncertainty, engaging the public in the work of science, contributing to policy, and enriching overall understanding of social-ecological change [17, 93, 156]. In spite of greater recognition of local and traditional knowledge's value, improved methods of capturing local observations are needed. We will develop a smart-phone application that can be used by local residents to capture geo-referenced observations of environmental conditions and ecological change that expands on our existing on-line systems that post locals' observations in a manner that that is accessible to residents and allows for discussion among local observers and LTER researchers about the causes and implications of environmental change [231, 232]. The local observers network can be used to inform and validate LTER models (e.g., ALFRESCO), and provide insight into the societal implications of model output. We seek to build and implement a low-cost system that can be operational for the long-term, which will contribute to LTER research, and contribute directly to tasks 3 and 4 listed below. We will initiate the process with a select set of Interior Alaska communities and then expand it for the entire region.

Task SES3: Evaluate interactions among environmental change, harvest regulations, and hunter access to wildlife to assess how environmental change has influenced the association among wildlife distribution, harvest regulations, and hunter access to wildlife resources (Brinkman, Hollingsworth). Global-level changes in climate are having local-level impacts on the availability of wildlife resources at high latitudes [2, 89]. Increasingly, qualitative evidence suggests that climate-driven changes in the environment (shifting fire regime, erratic weather) have challenged hunters' ability to access traditional hunting areas during times that would optimize harvest opportunity [28, 45]. Current regulations that restrict harvest to narrow time periods may exacerbate this impact by restricting adaptation options (e.g., shifting timing of the hunt) [171]. Investigations systematically quantifying the mismatch among peak hunting conditions and harvest regulations are limited. Our objective is to explore the prevalence of an environmentally-driven mismatch in timing of regulated harvest and peak access to important wildlife resources. Our hypothesis is that if climate-driven changes in environmental conditions have shifted timing of peak access to wildlife resources, then rigid hunting seasons will restrict the sustainability of harvest opportunities. We will test our hypothesis by quantifying potential incompatibility through an analysis of temporally-specific differences in wildlife distribution, peak hunter access and harvest, harvest regulations, and related environmental change. We will use management areas with liberal hunting regulations as our control. Our approach will integrate data collected through community-based participatory research, field observation and estimates (LTER and agency collaborators), weather stations, and wildlife harvest reports. An anticipated outcome of this research is identification of individual (hunter) and institutional (agency) adaptation strategies that facilitate sustainable harvest of nutritional and culturally critical wildlife resources.

Task SES4: Assess the capacity of different communities to respond to environmental changes (Kofinas). The study of social-ecological systems has been approached in the past with two analytical frames. Resilience theory has taken a descriptive approach, focusing on traps that impede adaptation, and tipping points and potential regime shifts or state changes that create new feedbacks and underlying governing properties [87, 254]. Vulnerability analysis has focused on the potential harm of change to humans by examining exposure, sensitivity, and adaptive capacity of social systems [90, 244]. While each offers insight, there remain problems with construct validity and the generation of empirically testable hypotheses that can be analyzed across cases [18]. Here we integrate approaches to assess vulnerability, potential for adaptation, transformation, and social-ecological resilience in the face of environmental changes in a contrasting set of Interior Alaska communities, including urban, road-system, and off-road communities. Of particular interest are the past and potential performance of institutions at the local and regional levels that shape policy decisions, and local economic conditions, including subsistence, as a resource for adaptation. Our analysis will consider the capacity of existing and possible alternative institutions to be responsive to the livelihoods of residents. Sources of evidence and methods of analysis include review of past decisions of record (e.g., those of the Alaska Board of Game), interviews with opinion leaders, the actions of advocacy groups (e.g., NGOs, tribal governments), and local participation in the policy process at various levels (e.g., local advisory councils). Scenario runs of Village Subsistence ABM provide another method of comparing possible futures for different villages.

Section V. Integrating LTER science and resource management with regional environmental change through co-production

Historical records indicate that fire activity has been intensifying in interior Alaska over the past century [44] and current rates of burning now exceed those experienced in Alaska for the last millennium [144]. Continued climate warming will likely cause further increases in fire activity through the current century [7], raising serious concerns about how fires should be managed in the future and what will be the impacts of accelerating fire activity on human values and ecosystem services across the Alaskan landscape [54]. However, fire activity depends not only on climate and weather conditions, but also on the distribution of vegetation fuels across a landscape [153, 188, 189]. Previous LTER research has suggested that fire driven changes in successional patterns, such as those causing highly flammable spruce forests to be replaced by less flammable deciduous forests, may help mitigate the impacts of climate warming on fire behavior [132]. Such interactions could be enormously important in developing management strategies in response to accelerating fire activity in Alaska, but remain largely theoretical and have yet to be incorporated into the empirical models of fire behavior used in fire management. Here we propose a set of tasks aimed at improving the links between pressing fire management needs and LTER research on ecosystem succession and cross-scale landscape interactions.

Question 1: How will climate and disturbance interact to shape the composition and distribution of vegetation types in Alaska, and what are the implications for future fire behavior and fire management?

Task CP1: Document the impacts of alternate successional trajectories on the abundance and composition of fuels through succession for dominant vegetation types in interior Alaska (Johnstone, Mack, Rupp). We will quantify fuel composition and distribution across the different types and stages of forest succession within the RSN. Data from the RSN will be used to develop a crosswalk between standard LTER measurements of vegetation composition and estimates of 1-, 10-, and 100-hour fuels required by fire behavior models. Based on these calibrations, we will be able to translate many years of LTER vegetation observations into fuel estimates for a wide range of vegetation types. We will work with the fire management community in Alaska to develop a modeling framework that will allow our improved understanding of variations in fuel characteristics across successional trajectories to inform projections of future fire behavior under different climate and management scenarios. This could be through existing LTER models like ALFRESCO, or fire behavior models such as BorFIRE; the exact modeling framework we choose will need to be worked out as a collaborative dialogue between LTER scientists and Alaska fire managers.

Task CP2: Estimate the landscape consequences of different scenarios of changing fire regimes and fire management on patterns of carbon sinks and sources in interior Alaska (Johnstone, Mack, Rupp). BNZ LTER research has greatly enhanced our understanding of how net ecosystem carbon balance varies among vegetation types and in response to disturbance. In this task, we aim to explore how management choices, in conjunction with dynamic interactions of climate and disturbance, may alter patterns of carbon storage on the landscape and net forcing of ecosystem feedbacks to the atmosphere. We envision two phases of research to accomplish this task: 1) an initial simple spreadsheet model that can be used to explore scenarios of fire activity and vegetation change with managers, and 2) detailed investigation of the most plausible scenarios within the coupled modeling framework of ALFRESCO and DOS-DVM-TEM. Simple modeling exercises will allow managers and LTER scientists to quickly explore a wide range of possible scenarios and select those with the greatest interest to assess within a more complex and dynamic modeling framework.

We know comparatively little about the effects of human land use legacies on Alaska's boreal forest, whether from the early influences of Native Alaskan's [176, 179], logging, mining, and market hunting of the late 1800s [20, 255, 260], or how contemporary human disturbances are influencing ecosystem processes and the associated services on which communities depend [97]. The Alaska Department of Fish & Game (ADF&G) surveys moose populations and habitat use within Game Management Units of interior Alaska (ADF&G web data), and LTER collaborations with ADF&G are helping predictions concerning vegetation-moose interactions following fire and other changing disturbance regimes across the region [31, 43, 161]. However, a key management priority is to better understand how smaller-scale human disturbances, such as fire breaks, and timber/biofuels harvests affect successional trajectories and forage availability to moose, and how such activities could be integrated into an adaptive management plan that includes active habitat manipulations to influence distributions of moose in areas readily accessible by hunters [186]. Because of the strong association between hunter access and harvest success, it is important to assess how such disturbances change relationships among plant-herbivore interactions, moose densities, and harvest opportunities.

Question 2: How are moose and hunters responding to human disturbances near communities, and how can a better understanding of disturbance-vegetation-moose-human interactions inform management options to improve food security in interior Alaskan communities?

Task CP3: Quantify vegetation composition and change within fire break and timber/biofuel harvest areas, and assess use by both moose and hunters (Brinkman, Kielland, Ruess). We will establish long-term monitoring plots in existing fire break and harvest areas of different ages to evaluate how these disturbances affect forage availability, successional dynamics, and NPP. Vegetation dynamics and rates of browsing will be compared with similar data from nearby RSN plots to assess moose habitat preference and associated impacts on vegetation dynamics [161, 187]. These data will be combined with interview data with hunters to assess how impacts on access and hunting success change over time since disturbance [27].

Task CP4: Design and implement a landscape-level experiment to test management scenarios affecting forage availability, moose distribution, habitat use, and hunter behavior (Ruess, Brinkman, Kielland). We will assemble a research working group comprised of LTER scientists and agency personnel (ADF&G, Division of Forestry, AK Fire Service, DOT) to discuss data from Task CP3 and options for how multiple land-use practices can be coordinated to achieve a sustainable moose harvest and ensure food security to communities as landscapes and availability of subsistence resources continue to change. We envision an experimental design that includes multiple disturbances (fire breaks and timber/biofuel harvests) and undisturbed plots distributed across stands of different age since fire, with and without access, including corridors cleared to specifically modify access. Vegetation, wildlife, and human use variables mentioned above will be worked into the BNZ LTER monitoring program. Although previous BNZ LTER research has assessed wildlife-vegetation relationships, how human stakeholders affect or are affected by these relationships have been speculative and qualitative. Experimentally integrating the human dimension in the monitoring program will represent a novel effort that fosters linkages between research and management, and creates additional opportunities for science-agency co-production.

Summary: This proposal represents an integrated research framework to study the cross-scale controls over responses of the Alaskan boreal forest to changing climate-disturbance interactions, including the associated consequences for regional feedbacks to the climate system, and to identify the vulnerabilities and potential adaptations to social-ecological change with rural Alaskan communities and land management agencies. During our last funding cycle, we began studying how climate warming is altering the nature and interaction among disturbance regimes, notably fire frequency, size and severity, rate of permafrost thaw, surface hydrology, and changing trophic dynamics, and how these changes were leading to threshold shifts in ecosystems and landscape structure with regional and global consequences for climate feedbacks. We also initiated a program to study interior Alaska as a coupled social-ecological system, by exploring how economic, social, and ecological changes are affecting human-ecological interactions, cultural traditions, and the distribution, abundance, and access to ecosystem services by Alaskans. In this proposal, we extend this framework by focusing on how heterogeneity in vegetation, landscape structure, disturbance regimes, trophic dynamics, and cultural traditions across multiple temporal and spatial scales influence cross-scale linkages and feedbacks that control resilience and patterns of change. We are particularly interested in how changing climate-disturbance interactions are modifying physical, biological, and social-ecological fragmentation, connectivity, and feedbacks within and across local, landscape, and regional scales, and shifting connectivity with past ecosystems and disturbance regimes. Our research program addresses the dynamics of change through the integration of five components (Fig 11). (1) Studying **direct effects of climate change on ecosystems and disturbance regimes** by characterizing controls over the spatial heterogeneity of ecosystems and disturbance, and the sensitivities of these controls to regional climate, and by studying the spatial and temporal synchrony of multiple disturbances to assess which landscapes are most vulnerable to change; (2) Understanding patterns, mechanisms, and consequences for scale-dependent **climate-disturbance interactions** involving current and legacy influences of fire, permafrost and trophic dynamics as drivers of ecosystem and landscape change; (3) **linking landscape heterogeneity with regional and global climate feedbacks** by studying and modeling how intermediate-scale patterns and processes of upland and wetland ecosystems influence regional scale ecosystem dynamics and climate feedbacks; (4) Studying how climate variability and change are affecting **coupled social-ecological dynamics** by characterizing variability in changes to ecosystem services across a select group of interior Alaskan communities, and to collaborate with communities to find solutions that reduce vulnerability and improve adaptation to social-ecological change; (5) **Integrating LTER science and resource management with regional environmental change through co-production** by developing coordinated science with agencies to fill management knowledge gaps, assessing outcomes of policy decisions, and by communicating syntheses to policy makers in meaningful ways.

Our research program is based on both continuing and new projects and long-term experiments that inform retrospective and prospective modeling of regional ecological and social-ecological change. The research program is supported by a Regional Site Network, where we study and monitor population, community and ecosystem dynamics across multiple successional trajectories to understand how changing climate-disturbance interactions are both influencing and responding to heterogeneity and cross-scale dynamics within and among landscape types at the regional scale.

We expect synthesis activities will play a central role in the program. In addition to the modeling efforts mentioned above, we will promote integration and synthesis through monthly meetings focused on tasks within each section, and annual meetings focused on synthesizing findings within individual proposal sections. This approach has proven highly successful during the current funding cycle and resulted in a number of synthesis products. We will continue close collaborations with two important bridge institutions, the Alaska Fire Science Consortium (AFSC Fire ecologist Randi Jandt is also a BNZ LTER Affiliate Scientist, and Teresa Hollingsworth serves on the AFSC Advisory Board) and the Scenarios Network for Arctic and Alaska Planning (Director Scott Rupp is also Senior BNZ LTER Investigator) as we expand collaborations with agencies to co-design studies and experiments addressing fire and wildlife management gaps, and communicate findings to policy makers. During year 3, we plan to co-host a joint meeting with the ARC LTER focused on resilience and change in high latitude systems. Changes in climate-disturbance interactions are impacting these biomes in very different ways, but as woody plants, large herbivores, and disturbance regimes (fire, permafrost thaw, insects, pathogens, invasive plants) move northward, we are well poised to begin discussions on how to more closely link these two programs.

Although our research design is ambitious, we know from past experience that this breadth of activity is feasible. Our strategy is to establish an integrative framework for boreal research, involve a group of highly qualified researchers who work well together, and encourage them to link other funded research projects to the LTER framework. We look forward to continued participation in LTER cross-site synthesis activities, especially those dealing with changes in climate and disturbance regimes, non-steady-state dynamics, trophic cascades, and social-ecological dynamics.

Related Research Projects

Several of the research Tasks outlined above will be co-funded by the BNZ LTER and a number of outside research grants. Those grants and funding sources are listed in Table 2 within the Project Management Plan.

Education and Outreach Activities

The BNZ LTER has successfully engaged hundreds of youth in education and outreach programs concerning boreal forest ecology. However, the young people most likely to get involved in such projects are children whose parents or teachers already have a positive attitude toward science and scientists, while those whose parents or teachers have a neutral or even hostile attitude toward science and scientists, or for whom science is simply not a part of their lives, are very unlikely to participate in such programs. As a result, programs end up competing for the science-friendly audience, while a large group of young people never participate in any of them. The next phase of our education and outreach program, which we are calling *Preaching Outside the Choir*, will specifically target K-12 audiences that are unlikely to participate in any science outreach programs. We will initially focus on two different audiences, one urban and one rural.

Children in foster care: In Interior Alaska, 400-500 children are currently in out-of-home care, the majority in foster homes, and Alaska Native children are overrepresented in this group compared to the total population. Children in foster care face several obstacles to participating in science programs. Foster parents are often extremely busy people who are already transporting foster children to multiple appointments per week and may not have the time or resources to add an additional activity. Children may change homes and schools frequently, and decisions regarding their activities may be transferred between different foster parents or between foster and birth parents several times per year. Confidentiality requirements complicate participation in programs further. Science education is unlikely to be at the top of the priority list for social workers and others who are trying to keep these children safe. Yet children who have suffered abuse or neglect and are in unstable situations may feel particularly useless and may benefit greatly from being given an opportunity to contribute to the larger community. Developing skills, contributing “real” data that help answer scientific questions, and becoming part of a scientific community can help develop children’s resilience in the face of adversity, and can increase their interest in education in general. We will collaborate with the Office of Children's Services, the Alaska Center for Resource Families, and Facing Foster Care in Alaska to develop a program that is tailored specifically to this group and includes effective recruitment and retention programs. For example, a week-long summer camp with summer-long follow-up activities for middle- and high school foster care students could provide a safe environment for students to participate in scientific discovery while building connections with children facing similar circumstances. A module of an existing program like Project BrownDown [(198)] that is aimed at foster parents and teachers would provide foster parents with activities toward their required training programs and children with exposure to "real" data collection.

Children in rural communities: K-12 schools in Native villages throughout rural interior Alaska have limited access to high quality science education opportunities and interaction with professional scientists compared to schools along the road system and in Fairbanks. We propose to strengthen the feedbacks between our science and our SLTER program through two means. First, we hope to extend our SLTER program to additional remote villages by engaging students and teachers in citizen science projects that contribute usable data to BNZ research (eg. long-term ecological monitoring using GLOBE protocols, Project BrownDown research). Second, we will target participation by schools in communities where *Tasks SES 1-4* (above) are being conducted. We will use studies on subsistence foods and hunter access being conducted by BNZ in several communities as an opportunity to help the K-12 students learn about how landscape change affects their lives. By using a citizen science learning approach, we will empower students to contribute to the ecological research and facilitate local generation of knowledge on how the landscape is changing. The collaborative relationship between BNZ researchers and participating village schools will follow the model established in our successful Melibee Project citizen science effort [(22)], which includes in-person and online teacher training, ongoing communication between ecologists and participating schools through video-conferencing and email correspondence, and dissemination of research results that include the data collected by each school in the form of newsletters, presentations, and publications.

Arts and Humanities: BNZ has a strong history of leadership in arts, humanities, and ecological science (AHS) integration toward the goals of public outreach and education. In 2006, BNZ founded the program, *In a Time of Change (ITOC)*, which facilitates and produces AHS events and exhibits focused on social-ecological themes, including climate change, wildfire, and predator control. In alignment with BNZ's focus on wildfire in the boreal forest, we will develop several new ITOC projects focused on aspects and outcomes of ecological change in Interior Alaska, building upon the success of our previous 2012 ITOC visual arts project, *The Art of Fire* (Fig 23). We will continue using strategies that have proven successful in the past for achieving AHS collaboration, while incorporating new approaches for advancing meaningful AHS integration, including field workshops for competitively-selected artists, artist-in-residencies, multimedia exhibitions and performances, new media approaches (online exhibits, interactive apps, social media), improvisational theatre events, documentary and fictional filmmaking, and Alaska Native arts and storytelling. In addition to performing public outreach, we also foster interdisciplinary AHS collaboration that directly advances scientific research and contributes to fundamental intellectual merit of ecological research through the formation of AHS working groups focused on specific ecological themes, and through writing workshops promoting exchange of writing skills between professional nature and creative writers and scientists.

BNZ will also continue to take an active role in leading the advancement of AHS efforts across the LTER network (*Ecological Reflections*) [(73)], as well as in an extended network that includes non-LTER Field Stations and Marine Labs and sites of long-term ecological inquiry (known as *ArtSciConverge)*. Networking activities include organizing workshops and special conference sessions to exchange outcomes and strategies for AHS integration, developing conceptual models for meaningful AHS research, managing AHS data and other products, and assessing the impacts of AHS work. The overarching aims of these AHS networking activities are to revitalize and foster authentic relationships among AHS fields and combine expertise and ways of knowing of these diverse disciplines to create a more unified approach to solving the grand ecological and social challenges of the 21st century.

(10 most significant publications in bold)

1. Abbott BW & Jones JB (2015) Permafrost collapse alters soil carbon stocks, respiration, CH4, and N2O in upland tundra. *Global Change Biology* 21(12):4570-4587.
2. ACIA (2005) *Arctic Climate Impact Assessment* (Cambridge University Press, Cambridge) p 1042.
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Laboratory: University of Alaska Fairbanks: The Forest Soils Laboratory and the laboratories of all BNZ investigators are available to support the LTER program. These laboratories have capabilities of water, soil, and plant chemical analysis, stable isotope analyses, pollen analysis, dendrochronology, etc., as well as capabilities for training of students by long-term staff. The IAB Core Facility for Nucleic Acid Analysis is a full time staffed facility that maintains a suite of modern instrumentation for molecular benchwork, including nucleic acid extraction (clean hoods, mixer mills), nucleic acid and protein quantitation (NanoDrop, Qubit, BioAnalyzer, etc.), amplifiation (96 and 384 well end-point and qPCR), library preparation (size selection, sonication, etc.), and DNA sequencing (ABI 3130xL Sanger, Illumina MiSeq next gen, and Oxford Nanopore MinION). Additional auxiliary equipment include centrifuges (mini, micro, plate, ultra), balances, pH meters, incubators, ultrapure water production, vortexes, water baths, heat blocks, stir plates, electrophoresis stations, gel and blot documentation systems. There is also sample storage (-80C, –20C, +4C, RT) available. Support exists for analytical chemistry resources (GC-MS, FTIR, fume hoods), microscopy (light), and flow cytometry (BD FACS Aria). For more information, visit https://sites.google.com/a/alaska.edu/iab-corelab/.

Computer: In addition to the computer facilities used for data management and archival, which are described in the Data Management Plan, we have additional computer resources for spatial analysis and modeling. At the Scenarios Network for Alaska & Arctic Planning (SNAP), the PIs have significant computing resources to run numerical codes, analyze data and prepare presentations. These resources include more than 20 multi-core Apple and PC workstations for personal use by researchers and staff. Additionally, SNAP hosts a compute cluster of 15 compute nodes (480 cores) with a total of 3,840 Gigabytes of RAM. These servers were built using a SuperMicro chassis with custom internal hardware and Intel Xeon E5-2650 16-core CPUs. This cluster also makes use of an internal 10Gbit network, which connects the entire cluster together including more than 160 TBs of fast spinning disk storage. In addition, the International Arctic Research Center (IARC) has staff experienced in analyzing and archiving large data sets and in computer analyses including global and regional climate, oceanic circulation, sea ice and ecosystem modeling. IARC physical facilities include a machine room housing the IARC Data Archive, undergirded by 80 TB of disk storage and 240 TB of LTO-5 tape storage, and a 256 core private cloud platform for computational tasks. Finally, the PIs have access to significant supercomputer resources for running climate-scale and weather-scale models at Research Computing Systems (RCS) located at UAF. These supercomputers contain a variety of 4-core, 16-core, and GPU-enabled 12-core compute nodes with internal network bandwidth ranging from 10Gbit to 40Gbit interconnecting all nodes. RCS also manages a large-scale storage capacity for researchers of 360+ TB of fast spinning disk storage and 7.2 PB of magnetic tape storage.

Office: We provide temporary office and laboratory space for LTER affiliates and other scientists that collaborate with LTER researchers

Other: The BNZ LTER has concentrated research at two major field sites, Bonanza Creek Experimental Forest, and Caribou-Poker Creek Research Watersheds. At both sites there are long-term study plots, field experiments, and climate stations, as described in detail elsewhere http://www.lter.uaf.edu/. We recently completed a restructuring of the BNZ LTER monitoring program around a network of 106 long-term study sites scattered across the 3 Ecoregions of interior Alaska (~50,000 km^2 area), designated the Regional Site Network (RSN). Focusing on how Alaska's changing fire regime (and associated permafrost thaw) is altering successional pathways and transforming landscape structure and function, we selected stands of 3 age classes since the last fire; young stands (<15 yr), intermediate-age stands (40-60 yr), and mature stands (> 80 yr) stands. All stands were black spruce prior to being burned, but many of the young stands in particular, have lost permafrost and transitioned to hardwoods following the increase in high severity fires over the past 15 years. Variation among stands within age classes captures heterogeneity within and among burn scars in a number of interrelated factors, including landscape type and structure, burn severity, topography, site moisture, organic matter thickness, hardwood:conifer dominance, and herbivory. Vegetation composition and biomass, and tree insect/pathogen abundances have been inventoried for all stands, and a full soil characterization is underway which will allow us to assess fire and permafrost history, model effects of disturbance on changes in C & N stocks, and construct water budgets across the network. A core suite of sites will be monitored more intensively for soil climate, litterfall, decomposition rates, seed fall, vertebrate herbivory, seasonal tree growth (dendrometers), recruitment, understory composition, and pests and pathogens. In addition, the University of Alaska Herbarium houses the most comprehensive collection of Alaskan plants in the world, and there are LTER collections of soils and plants and University Museum collections of animal tissues.

Major Equipment: Laboratory equipment includes elemental autoanalyzers, C:N analyzers, gas chromatographs, mass spectrometers, total organic carbon analyzers, atomic absorption spectrometer, Europa GEOS 2002 Isotope Ratio Mass Spec, Thermal Elemental Iris DCP ICP, and 600 MHz Bruker NMR. Field equipment includes field transport (boats, snow machines, 4 wheelers, trucks), climate stations, eddy flux systems, and a suite of soil coring and plant ecophysiological field instruments.

Other Resources: We have secretarial services, accounting services, and a machine shop. A pool of field vehicles and computer maintenance and repair services are available on a cost-reimbursable basis.

Overview: The Bonanza Creek LTER Information Management System (BNZ-IMS) has strived to develop and maintain a comprehensive system to collect and manage project metadata and data resources in our pursuit to collect and disseminate quality ecological data to the public and research community. The majority of IMS activities are coordinated by the information manager, Jason Downing, with regular guidance from the BNZ site executive committee [Roger Ruess (PI), Jeremy Jones (Co-PI), Dave McGuire (Co-PI), Teresa Hollingsworth (Co-PI) and Michelle Mack (Co-PI)]. The BNZ site manager, Jamie Hollingsworth, also plays an active role in the oversite and development of the BNZ-IMS. To achieve success, the BNZ-IMS relies on the dedicated participation of the BNZ site management team to prioritize information management tasks and to ensure that the proper resources are available to complete operational projects. Operations are coordinated and collaborated with various BNZ Senior Personnel, graduate students, researchers, and other professionals from within the University of Alaska, other LTER sites, research institutions and state and federal agencies, NGOs, and Native organizations as we provide data management and guidance to our project participants.

The central feature of the BNZ-IMS is a relational database that contains critical information on research personnel, long-term monitoring plots and climate stations, sampling locations, publications, research projects, data processing, and archived project data. This database serves as the foundation for informational content to our web site as well as in the documentation and management of data products. There is an additional database that serves exclusively to house meteorological data from our network of climate monitoring stations. This network currently includes over 20 active field stations collecting approximately 15,000 measurement samples per day. The BNZ-IMS central database is running on a MySQL platform with over 100 related and indexed tables. The meteorological database is also running in MySQL and collects hourly measurements from our field locations. The MySQL database is one that we have used for many years (because it is an open source, robust and versatile database platform) and will continue to rely on for the core of our database needs. We also use some PostgreSQL and FileMaker software to facilitate some of our GIS interfaces or for field tablet data collection application development respectively.

The BNZ-IMS provides support for research project design and the implementation of key data management practices for our project participants. The timely submission, processing, and release of quality data are our top priorities. We provide a metadata spreadsheet for scientists and students to enter and organize their data and metadata for submission to the BNZ-IMS online data submission system. Researcher submissions are tracked by the IM to ensure the timely processing of data after submission. We provide training and consultation sessions for scientists and students on the development of data management plans and the design of research projects and data practices, and for data submission procedures for the BNZ-IMS and the LTER Network. These developments have improved the efficiency, quality, and quantity of data available through the BNZ LTER program. We have an explicit data policy that supports the open access and timely release of data in conjunction with the LTER Network Data Policy.

Once data have been uploaded to our secure server, submission materials are reviewed by IM personnel and uploaded into the database. After metadata are inserted into the database, they are available for review within our local web site as part of the BNZ data catalog. After the submitters have had a chance to review their catalog entries and grant approval, an Ecological Metadata Language (EML 2.1.0) metadata file is generated from the database to become part of the data package. This EML file is the standard metadata format used within the LTER Network Information System (NIS) as well as other ecological researchers and holds all the necessary metadata to locate and utilize the data. These metadata are then tested for compliance using the NIS Data Portal Tools. If the data package passes the compliance testing, it is uploaded into the LTER Data Portal; otherwise the errors are reviewed and either the data or metadata are updated as needed to comply with LTER standards. Packages are additionally retested, and eventually uploaded once they meet standards. The BNZ-IMS tracks data package status within the NIS and uses web services to link our data catalog packages to their LTER Data Portal progeny. With this system, it is simple to query a database to identify data products that need to be updated or uploaded.

Current Status: The BNZ LTER data catalog contains 502 separate data packages, i.e., the combination of data files and their associated metadata. Within these packages there are approximately 900 individual data tables and associated metadata files available for download. Of these 502 packages, we have identified 94 as our ‘core data’ files. ’Core data’ files are long-term records collected to help monitor trends and support the central research objectives of the LTER research program. For example, ‘core data’ include standard meteorological and ecological monitoring data that are used extensively in conjunction with various research projects and analyses. Core data also include several other data products that are collected either by the central BNZ Site Management team or by selected senior investigators who specialize in a particular discipline; such as hydrology, permafrost, population dynamics, and vegetation monitoring. Core data packages are updated regularly; manually collected data are updated yearly, while streaming climate data records are released after they have been processed and checked for quality. Annual updates of manually collected data are completed as soon as each data set has been collected and processed, depending on the data set type and measurement schedule. Climate data products are assured of their quality through two separate mechanisms. First, the sensor network management software that we use is able to apply a series of programmatic filters to the data streams that monitors the data values as they are being inserted into the database to ensure that the values fall with established and acceptable ranges. Secondly, technical staff visually reviews graphed data to identify and correct any erroneous sensor data caused by sensor damage or degradation. Core data collected for discipline-specific data packages are collected by identified senior scientists who are responsible for the quality assurances for those particular data packages prior to their inclusion in the BNZ-IMS.

The LTER Network Information System (NIS) was developed to promote advances in ecological science by providing critical information management and technology infrastructure to increase the availability and quality of data. To support this mission, personnel at the BNZ LTER are contributing to the operations and continued development of the NIS by actively participating in several working groups and development teams, participating in regular discussion groups, testing system tools as they are developed, and by contributing data to the NIS infrastructure. We are aware that the structure of the LTER Network data management system is currently being redesigned following the separation of the former LTER Network Office (LNO) into two separate management entities; one to handle communication and synthesis activities, and one to provide data management services. The newly formed LTER Network Communications Office (NCO) provides the first of those items and the LTER Informational Management Committee (IMC) has developed and submitted a proposal to NSF to provide the data management operations for the LTER Network over the next few years while longer term operational strategies are continually developed. BNZ IM personnel have participated in the development of the IMC proposal and will continue to stay involved with the operational management of the NIS as the LTER program moves forward. BNZ personnel are tracking this development and are eager to take advantage of new systems and services as they come online.

Over recent years, the BNZ information management team has made significant achievements towards increasing data availability by facilitating the insertion of data products into the NIS framework. This is done by ensuring that metadata collected from research personnel and incorporated into the BNZ metadata database conform to LTER best practices and contain all of the essential features for usability. We have focused considerable resources towards achieving this goal. Currently, 95% of our data packages have been uploaded into the LTER Network Data Catalog. The remaining data packages have been reviewed using metadata evaluation tools and are either in the process of being updated to meet network metadata standards or they are awaiting release adherent to the BNZ and LTER network data policies. There are a small number of special cases where a data package in our catalog is not appropriate for inclusion in the NIS and thus not submitted. We are continually working to add new data packages to our data catalog to ensure that all relevant data collected in collaboration with our research program are captured and preserved for use by the scientific community. This includes our implementation of improved tracking systems for expected data products and uncovering previously unidentified or so-called ‘dark data’ that needs to be released. ‘Dark data’ are data products that have not been adequately documented and submitted to a data repository and are therefore unavailable to the scientific community, such as historic data (including photographs) produced prior to the development of appropriate data warehouses, or graduate student data that failed to be submitted prior to student graduation.

As part of our annual information management review activities, the data packages and publications for each senior investigator are evaluated to make sure that all necessary materials have been submitted. These reviews are conducted by the IM via in-person meetings, video-teleconference tools, phone, and email communication to engage with the researcher to make sure expectations are being met and people are archiving data in a timely manner. We continually engage scientists and site leadership personnel to identify high priority data products and encourage scientists to upload their data in a timely manner. Annual training sessions that cover general data management, developing data management plans, discussions of procedures to share samples or data, and the process for submission of data resource to the BNZ-IMS are provided to researchers, staff, and students involved with our program. Additional guidance is available from the IM by request from any researcher or students that are obligated to provide their research data to the BNZ LTER program.

With the increased robustness of our climate station radio network and improved management software we are developing additional systems to feed data directory to other organizations in near-real-time. We have long operated in conjunction with the National Atmospheric Deposition Program (NADP) to collect samples and stream precipitation data directly to their database but we have recently added an additional stream to the National Weather Service (NWS) so that our main climate weather station data will be available through their online system. Researchers that collect data with established repositories for a specific discipline, such as GenBank, submit their data to those institutions so as to ensure data availability to researchers in the most appropriate format.

Data Access: Data collected as part of the BNZ LTER research program are made available through various methods to better serve our diverse audience of scientists, students, agency personnel, and the public. Our data products are grouped into several types, each of which has its own unique set of attributes. For example, the streaming climate monitoring stations provide "near-real-time" access to core climate data via a web interface (http://bnznet.iab.uaf.edu/vdv/index.html). This interface provides a visual representation of streaming climate measurements (air temperature, humidity, precipitation, soil moisture, soil temperature and solar radiation). Most of these remote stations are connected through radio networks and updated hourly. This interface provides direct access to the most recent stream of data, as well as all historical climate station data, in a user friendly graphical format. Data can be browsed via the graphing tool and then directly downloaded by the user or a scheduled job can be administered to deliver either aggregated or raw data products. Once these streaming data have been reviewed and assured for quality, they are migrated into our primary relational database where they can be used and managed for long-term archival and research analysis, and submitted to the LTER Network.

Additionally, users can also locate and acquire the 'Core' research data as well as individual project or student data through the BNZ LTER data catalog (http://www.lter.uaf.edu/data_b.cfm). This searchable interface allows users to browse, locate, and access data products that include our climate monitoring data, after additional quality control processing, as well as other investigator and student research data collected in connection with BNZ. This interface is integrated with our relational database to provide the most current information and allow for all relational connections among data products, research locations, publications, and personnel to be fully visualized. This catalog includes all of our data products; including those that are in development and those that are pending release, in addition to all the finalized data products.

Geospatial data products and services are continually developing and playing an increasingly important role in the application and analysis of ecological data. Our site manager, Jamie Hollingsworth, has played an active role at our site and within the network to aid in the development of spatial data tools and best practices. We are enriching our metadata scripts to include the necessary geospatial relevant metadata for the package to be identified and incorporated into the geospatial services of the NIS. With this enhancement, our spatial data projects will be more available to the research community. Maps, photo collections, and other visual data products are also made available through our web interface. These GIS data resources are being utilized by site management staff to provide mapping applications (via iPAD applications) to overlay research site location data for researchers to use in the establishment and documentation the spatial information for their data products.

IT Resources: The rapidly evolving landscape of informational technology tools and services necessitates that the BNZ-IMS infrastructure remain nimble in order to embrace or abandon choices as we continue with this long-term program. To that end, we at BNZ are currently in a transitional stage as we migrate away from outdated software and operational infrastructure in hopes of providing more efficient and effective services in the current informational ecosystem. This type of adaption is shared among LTER IM's as everyone utilizes more cloud computing and web services to complete our missions, and relies less on custom solutions.

Information technology resources of various types are used extensively to support the BNZ LTER program. To additionally support our IT needs, we use other resources and personnel available at the University of Alaska Fairbanks (UAF) including the Institute of Arctic Biology (IAB), the Office of Information Technology (OIT), the Research Computing Systems at the Geophysical Institute (RCS) (previously the Arctic Region Supercomputing Center (ARSC)) and the Scenarios Network for Alaska and Arctic Planning (SNAP). The current design architecture relies on a series of servers and workstations managed or administered by the site IM.

Under the current configuration, there is a primary production level server that houses our database and web services. This is a Linux server that hosts: 1) a MySQL Database Server, 2) an Apache web server using Adobe ColdFusion, and 3) a file server. The primary level server is administered through a cooperative agreement with SNAP, but all three of its key services will be transferred to new hosts as we continue with our evolution. The server and database are backed up routinely to backup systems at SNAP and to long term storage space with the RCS. Additional backups are located on the IM workstation and external hard drives that are stored off-site.

This primary level server will be retired from service as soon as all three of the current functions are transferred to their new hosts (anticipated completed July 2016). The database component has already been transition to being hosted by servers at RCS. They provide MySQL database servers for use by our project; we have been using their database services for over a year and are very pleased with our working relationship with the RCS. The RCS agreement provides for all regular maintenance and scheduled backups of the databases but we continue to make routine backups of these databases to the IM workstation and external drives that are kept off-site. The file service component of the current server will also be transitioned to a hosting through RCS. All of the files that we provide to our uses via our website or the NIS will be housed on the web servers run by RCS, who will be responsible for all the server maintenance and backups. The RCS services that are currently provided to the BNZ LTER project are done so at no direct cost to the program but there is the potential for future fees for such services. The final component to transition is the web server. We have decided to abandon our Adobe ColdFusion framework and are transitioning to a PHP-JavaScript configuration to host our web site and web services. The new design uses a more common and flexible web programing language with extensive code libraries and resources. The BNZ website will migrate into the greater IAB web infrastructure so as to be maintained and developed in conjunction with other IAB web resources, this way sharing web server and backup hardware within our institution. This will be done with leveraged IAB communications and programming staff resources to improve the appeal of our website and the functionality of the website to assist our users in their activities and provide appealing informational content to researchers and the public.

Another server hosts our sensor network software services: primarily LoggerNet by Campbell Scientific and Vista Data Vision (VDV) by Vista Engineering. This is a Windows server that is administered by BNZ LTER IM. The LoggerNet software configures and enables communication and downloading of raw data files to our secure server from remote field locations. Once on the server, Vista Data Vision provides a comprehensive management interface to ingest harvested data files into a relational database and provides extensive web based tools to monitor, review, and display data collected from our instrumented research sites. This software is now running version VDV2015 and recent upgrades have made it easier to manage and monitor sensor network resources, but also to have climate data feed into other conglomerate data files and engines. This server is also backed up on a routine basis to external hard drives and to long term storage space with the RCS. These backups are included on the external drives that are stored off-site. This server will remain configured and administered as it is now to accommodate our sensor network and management activities.

Finally, a third production level server hosts our spatial data and mapping services. This is a Windows Server that is managed by the UAF Office of Information Technology and hosts ARC GIS software and spatial databases. This server is used heavily by the core research field staff to manage activities across the Regional Site Network and other intensively monitored field sites. The BNZ Site Manager (Jamie Hollingsworth) has played the key role in developing GIS products and services for these field sites. He has also contributed to development activities for the NIS so as to include functionality specific to geospatial data so these resources can be released in formats and by means that better enable users of geospatial data collected as part of our and other LTER programs.

We also manage and facilitate communication and information sharing within our group and the LTER network by (1) hosting current information and announcements on our website, (2) using email lists, and (3) through the use of social media. Email communication methods have worked effectively to facilitate discussion and information exchange, but social media are emerging as valuable tools to further these discussions. In the last year, we have released BNZ LTER Facebook and Twitter accounts to stay current with these communication methods and we are exploring how these new services can help to support our mission.

IM Resources: Information management at BNZ LTER supports and facilitates research by providing resources (data and tools) to scientists and to the public. The BNZ LTER PI and site executive committee meet regularly with the IM and site manager to stay involved with setting goals and priorities for information management at BNZ LTER. This level of involvement in the guidance and direction of IM is critical to keep pace with developing standards and technology. As these standards and technologies continue to develop, we will monitor and evaluate emerging resources to evaluate how best we can serve our constituents. We keep informed of network developments to standardize formats and to manage and deliver data resources at LTER sites. The BNZ IM has been involved with various network working groups, workshops and training activities; Jason Downing served on the LTER Information Management Executive Committee from 2011-2015 and was recently elected to serve a term on the LTER Network Information System Advisory Committee (NISAC) starting in 2016. Current projects to design standardized information management architectures show significant promise, and we are currently monitoring and evaluating the progress to ascertain if the adoption of these systems could be beneficial for our site.

We are currently in the process of transitioning some of the IM tasks, mainly website design and implementation, to an organizational system where these tasks are completed in conjunction with staff from our host research institution, the UAF Institute of Arctic Biology. This managerial change will help us to better provide web services for our constituents as well as to allow our program to leverage some physical computer resources and technical expertise. This re-organization has included the involvement of a skilled web development programmer, Ed Debevec and an outstanding communications specialist, Marie Thoms, into projects, such as our website, where their knowledge and abilities are required to complete information management tasks or projects.

The BNZ-IMS, primarily accessed through our web site, is able to offer a host of data products, tools, resources and information to interested parties. Of primary focus are our data products which include tabular data and spatial data resources. The BNZ system is structured to manage and provide all critical metadata associated with each of these products so they can be fully used by scientists and the public. We also have an extensive publications archive that can be easily searched and downloaded, and publications are linked to associated data products. Additionally, we provide an archive of imagery, pictures, and maps associated with our data products and research activities. Another key component to our information management system handles the task of recording and managing personnel and research location information that can be queried and displayed to those interested. The IM team at BNZ is also committed to fostering and enabling wise and prudent information management by our scientists, students, and affiliates through providing consultation and information on available resources.

Project Management Plan

Leadership structure: NSF and the USDA Forest Service (USFS), through the Pacific Northwest Research Station, jointly fund the BNZ LTER project. The NSF and USFS components of the LTER program are integrated into a single program, so we describe the management as it actually functions, rather than distinguishing between the NSF and USFS components. Our Leadership Team consists of the PI (Ruess) and co-PIs Hollingsworth, Jones, Mack, and McGuire. Hollingsworth is a Research Scientist at the USFS Boreal Ecology Cooperative Research Unit (http://www.becru.uaf.edu/), and serves as the BNZ LTER liaison on all USFS official matters. BNZ LTER management decisions are made at several levels: (1) Ruess serves as the PI and is ultimately responsible to NSF for the overall implementation of the research program. (2) In practice, the five-person Leadership Team makes decisions jointly concerning the design and implementation of the research program. Each person has responsibility for overseeing specific aspects of the program: Ruess, overall integration (within-site and with LNO) and site management; T. Hollingsworth, data management, Forest Service communication; Jones, data management & permafrost/hydrology; Mack, vegetation/fire disturbance; McGuire, modeling. (3) The LTER Executive Committee (leadership team plus Brinkman, Site Manager, Data Manager, and student representative) provides feedback on issues with the research and monitoring programs, new opportunities, budgetary decisions, etc. In practice, these meetings are open to all LTER personnel, and there is broad participation by the BNZ LTER community. (4) Several individuals are responsible for coordination and integration within each research Section: (I) Climate sensitivity (T. Hollingsworth, Turetsky, Verbyla, Ruess), (II) Climate-disturbance interactions (Mack, Johnstone, Kielland, Jones, Schuur, Turetsky), (III) Climate feedbacks (McGuire, Eukirchen, Genet, Rupp), (IV) Social-ecological dynamics (Kofinas, Brinkman), (V) Co-production (Kielland, Brinkman, Johnstone, Ruess). (5) There is a team of senior personnel responsible for implementing each Task (see below) and for ensuring that the research is addressing hypotheses and overall project goals. (6) Each investigator is allocated a budget and is responsible for designing and implementing her/his portion of the research program (see Budget Justification).

Program integration and communication: The Leadership Team meets monthly to address practical issues and to plan and coordinate research and synthesis activities, and at our Research Symposium that is organized annually around one of the main proposal sections. Field research occurs year-round, but is most intensive during the growing season, when all PIs and grad students are collaborating through coordinated activities at shared research sites across the RSN and other long-term sites.

Budgeting and accountability: Approximately 47% of total direct costs are expenditures for Core Research needs. We define core research as the long-term observations, experiments, site maintenance, and data management that are critical for the overall program objectives. This includes (1) salaries for the Site Manager, Data Manager, and summer student hires, and (2) all necessary infrastructure for the monitoring and maintenance of sites within the Bonanza Creek Experimental Forest (BCEF), Caribou Poker Creek Research Watersheds (CPCRW), and RSN. The Site Manager (1) supervises technicians and summer student hires in the collection and archival of long-term data sets (e.g., climate, vegetation, NPP, hydrology, population dynamics, etc.), (2) supervises the maintenance of the research sites, experiments, and facilities, and (3) facilitates the research of on-site and visiting scientists pursuing LTER-related research. An additional technician supported by the USFS maintains the climate stations, works on the long-term vegetation plots, and processes samples and long-term data. Monitoring at CPCRW includes maintenance of hydrologic instrumentation and associated climate stations. Both technicians are involved in data reduction and archival. The Data Manager is responsible for data archival and management, as described in the Data Management Plan. The Data Manager works with the PIs to design data collection strategies, archives the data, facilitates its use by the scientific community, and interacts with the data management group of the LTER network. Each PI is responsible for her/his own budget and implementation of research as outlined in the proposal. Every two years each investigator must submit a progress report that includes major findings, publications, online (archived) datasets, and a mini-proposal that describes research plans for the next two years. These reports and mini-proposals serve as a basis for evaluation and budget reallocation by the leadership team. If necessary, more frequent budget reallocations will occur at the time of the annual progress report to NSF, as we have done in the past. Senior Personnel are expected to obtain outside funding to complement their BNZ LTER-funded research (~$5/NSF LTER). In addition to budgets for each research project, we maintain separate budgets for core research, data management, and general project costs. Core research includes monitoring of climate, hydrology, vegetation, and other essential long-term site measurements. General project costs include national travel, and some infrastructure costs.

Site security and site management: In the past, the BNZ research program has been concentrated in two intensive research areas: BCEF is located within the Tanana Valley State Forest and is leased to the USFS (renewable in 2018). CPCRW includes lands under the jurisdiction of UAF and the Alaska Department of Natural Resources (DNR). The LTER manages BCEF and CPCRW for the purpose of conducting research. We have close working relationship with Alaska Department of Natural Resources, DNR, Mining and Water to protect the long term availability of these areas for research. Recently, we established a new regional network of 94 long-term study sites scattered across 3 of the ecoregions of interior Alaska (~50,000 km^2) to study ecosystem responses to fire in black spruce forests. This represents a significant expansion of scale, from site-based to regionally-based, and complexity, from replicate stands within BCEF and CPCRW, to explicit recognition of heterogeneity across multiple spatial and temporal scales. The BNZ Site Manager (Jamie Hollingsworth) is responsible for managing LTER research at all these research sites, including permitting, transportation, and the planning and implementation of the core research program. Supplements to the BNZ LTER over the last funding cycle have enabled significant improvements in site management, and include expanding our sensor network with radio communications for our 10 plus microclimate stations, improved coordination of field work (ATVs and snow machines), improved boat communication and safety, and assessment of statistical power and required sample sizes for long-term vegetation measurements. These efforts have substantially improved the quality, continuity, efficiency, and safety of data collection, releasing time to undertake new activities.

The CPCRW is the core site for the taiga domain of NEON, which will provide the infrastructure to measure larger scale measurement of CO_2, CH_4 and water vapor fluxes, and energy exchanges. Additionally, a relocatable tower for the taiga domain will be installed near our Healy (Eight Mile Lake) watershed site to examine the effects of permafrost thaw on ecosystem C and energy exchanges. CPCRW will also be host to a NEON aquatic array, which will provide the infrastructure to examine stream hydrology, and DOC and nutrient fluxes at a higher temporal resolution than is currently possible, and will allow expansion of our watershed solute export studies to higher-order streams.

Engagement of new investigators, non-LTER scientists, and Alaskan communities: We include 6 new investigators to our research team in this proposal to replace 4 investigators no longer involved with the program (3 of whom have retired from active research), and to meet the needs of our focus on cross-scale dynamics, climate feedbacks and human dimensions. New investigators include T. Brinkman (human dimensions), P. Doak (insect population biology), H. Genet (modeling), S. Goetz (remote sensing), T. Harms (watershed biogeochemistry), and FS Hu (paleoecology). Mary Beth Leigh (UAF) recently joined the BNZ LTER as our liaison to the Fairbanks arts community, and has organized our *In the Time of Change* program. We have been modestly successful in increasing diversity at our site, going from one woman and no minorities 15 years ago to 12 women (48%) and two minorities among the PIs and senior personnel in our current proposal. Our 78 graduate students in the last funding cycling included 43 who were women or minorities, including Native Alaskans. Our major effort to enhance diversity is through recruitment of minority graduate students, particularly Alaska Natives. Minority recruitment has been a strong emphasis of the IGERT program in Resilience and Adaptation, and many of these students become involved in BNZ LTER research. A key way in which we engage non-LTER investigators in our LTER research is through our Affiliate LTER investigator program. The BNZ LTER Affiliates are encouraged to participate in our annual symposium, have the same access to LTER data, field sites, and facilities as do LTER Senior Personnel, and are encouraged to archive their data in the LTER database. For example, Terry Chapin is an affiliate LTER investigator, and continues to work closely with us, focusing on rural community sustainability and resilience. We attempt to provide transportation costs to the LTER symposium and assist with field logistics whenever possible. Many affiliates have written proposals with LTER investigators as a result of this collaboration. In addition, the BNZ LTER facilitates research by numerous national and international groups conducting both short- and long-term projects and experiments at our permanent research sites. Finally, we have active research partnerships with state (AK Dept of Fish and Game, BLM AK Fire Service, Division of Forestry, State and Private Forestry, AK Fire Science Consortium, AK Interagency Coordination Center,) and federal (NPS, USFWS, USFS, USGS) agencies, NGOs (Nature Conservancy, Wildlife Conservation Society, Sitka Conservation Society), and Alaska Native Organizations (Tanana Chiefs Conference, Council of Athabascan Tribal Governments, and various Village Corporations).

Table 1. Responsibilities of senior personnel for research tasks within Sections: C = Direct Effects of Climate; D = Climate-Disturbance Interactions; CF = Climate Feedbacks; SES = Social-Ecological Dynamics, CP = Co-Production.

	Primary	**Secondary**		**Primary**	**Secondary**
Brinkman	SES1,3, CP3	SES2,4, CP4	**Mack**	D3	C2, D1, D5, CP1,2, CF3
Doak	D9		**McGuire**		CF1-5
Euskirchen	CF4	CF2	**Mulder**	SLTER	C1
Genet	CF5	D2, D3, CF1,3	**Romanovsky**		C4, CF1-2, 4-5
Goetz		C2	**Ruess**	D7, CP4	C2, D1,2, D8, CP3,4
Harms		D3,4	**Rupp**	CF1,2	D7, CF3-4, CP1,2
Hollingsworth	C1, C3	D1, D3, SES1,3	**Schuur**	D6	C4, D3, D5
Hu	CF3		**Sparrow**	SLTER	
Jones	D4		**Taylor**		D1, D3
Johnstone	C2, D1, CP1,2	D3	**Turetsky**	C4, D5	C3, D3, D6, CF1-5
Kielland	D2, D10	D8, CP3,4	**Verbyla**		C1,C3
Kofinas	SES2,4		**Wagner**	D8	D7, D9
Leigh	ITOC				

Table 2. List of outside grants co-funding BNZ LTER Tasks that we regard as essential for the completion of work outlined in this proposal.

PI	Co-Funding Grant	BNZ Task
Brinkman, w/ Hollingsworth, Verbyla, & Brown	Biophysical characteristics and mechanisms of environmental disturbances influencing human access to ecosystem services in boreal Alaska (NASA-TE, 2015-2018)	SES1-3
Brinkman, w/ Chapin, Little	Adaptive coupling of human-environmental linkages in response to globally driven changes in subsistence in rural Alaska (NSF-CNH, 2015-2019)	SES1-3
Goetz, w/ Mack	Mapping and modeling attributes of an arctic-boreal biome shift: Resource management implications within the ABoVE domain. (NASA-TE, 2015-2018)	C2
Mack, w/ Taylor, Genet, & McGuire	Collaborative Research: The roles of plant roots, mycorrhizal fungi and uptake of deep nitrogen in the permafrost carbon feedback to warming climate (NSF-PLR 2015-2018).	D3
Mack, w/ Schuur, Johnstone, & Goetz	Increasing fire severity and the loss of legacy carbon from forest and tundra ecosystems of Northwestern North America. (NASA-TE, 2015-2019)	D3

BNZ DATA SETS IN THE LTER NETWORK INFORMATION SYSTEM (NIS)

Bonanza Creek Experimental Forest: Hourly Temperature (sample, min, max) at 50 cm and 150 cm from 1988 to Present

Bonanza Creek Experimental Forest: Hourly Wind Speed and Wind Direction at 3m and 10 m from 1988 to Present

Bonanza Creek Experimental Forest: Hourly Soil Temperature at varying depths from 1988 to Present

Bonanza Creek Experimental Forest: Hourly Precipitation data, 1988 to Present

Bonanza Creek Experimental Forest: Hourly Soil Moisture at varying depths from 2002 to Present

MODIS Leaf Area Index estimates for Alaska: 2002

Active layer depths: Bonanza Creek Fireline (1984 - Present)

Active layer depths: Wickersham Fireline Sites (1972 - Present)

Analysis of vegetation distribution in interior Alaska and sensitivity to climate change using a logistic regression approach

Bonanza Creek Experimental Forest: Active layer depths at core floodplain sites

Artificial Communities Experiment: Seedling growth

Yearly Seedfall Summary at Bonanza Creek LTER Control Plots (1985 - Present)

Tree stand structure summary at Bonanza Creek Experimental Forest LTER sites

Tree regeneration after fire: Yukon Lodgepole Pine Surveys, mineral soil analysis

Tree regeneration after fire: Yukon Lodgepole Pine Surveys, organic soil analysis

Tree regeneration after fire: Yukon Lodgepole Pine Survey, pre fire analysis

Tree regeneration after fire: Yukon Lodgepole Pine Surveys, seedlings analysis

Tree regeneration after fire: Yukon Lodgepole Pine Surveys, tree age analysis

Artificial Communities Experiment: Net Nitrogen Mineralization and Nitrification Potentials

Abundance of stream macroinvertebrates and benthic organic material in CPCRW

Biomass of stream macroinvertebrates and benthic organic material in CPCRW

Biogeochemistry of Permafrosted/NonPermafrosted Watersheds in CPCRW: Summer 1995

Biomass, %N, and %C data for the BBC collapse scar for 2003 and 2004

Black spruce allometric measurements: 2000 - 2001

Spruce Seedling Data Bonanza Creek Experimental Forest Floodplain Inside and Outside of the Moose Exclosures

Bonanza Creek Experimental Forest Beetle Population Counts

Tree regeneration after fire: Wickersham Dome long-term vegetation study, birch height data

Tree regeneration after fire: Wickersham Dome long-term vegetation study, bl. spruce cone analysis

Tree regeneration after fire: Wickersham Dome long-term vegetation study, bl. spruce height data

Chugach National Forest Beetle Population Counts

Tree regeneration after fire: Wickersham Dome long-term vegetation study, aspen height data

Bonanza Creek Experimental Forest Beetles Per Trap 1975-2012 - Werner

Tree regeneration after fire: Wickersham Dome long-term vegetation study, shrub height data

Bonanza Creek Experimental Forest Defoliating Insect Population Levels Per Leaf 1975-2012 - Werner

Hectares of Alaskan Forested Ecosystems Infested by Phytophagous and Phloeophagus Insects, 1955-2008

Tree regeneration after fire: Effects of burn severity, CPCRW soil analysis

Tree regeneration after fire: Effects of burn severity, Delta soil analysis

Tree regeneration after fire: Effects of burn severity, CPCRW vegetative cover analysis

Tree regeneration after fire: Effects of burn severity, Delta vegetative cover analysis

Tree regeneration after fire: Effects of burn severity, seedling germination analysis

Tree regeneration after fire: Effects of burn severity, germinated seedlings analysis

Tree regeneration after fire: Effects of burn severity, transplanted seedlings analysis

AVHRR/Landsat TM Classified images at 1km and 25km grain size centered on Bonanza Creek LTER

Acetylene reduction and 15N2 uptake rates for Alnus tenuifolia and Alnus crispa in six different successional habitats

del 15N Values for Tanana River Floodplain Soils and Xylem Sap Samples

Soil DOC and moisture measurements along climate and black spruce productivity gradients in interior Alaska

Soil respiration measurements along climate and black spruce productivity gradients in interior Alaska

Densities of snowshoe hares at Bonanza Creek Experimental Forest

Snowshoe hare physical data in Bonanza Creek Experimental Forest: 1999-Present

Snowshoe hare pellet count data in Bonanza Creek Experimental Forest

Fine root and coarse root biomass in Bonanza Creek Experimental Forest: 1990-1991

Fine root respiration on the floodplain in Bonanza Creek Experimental Forest

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Forest floor chemistry, BCEF LTER sites, summer 1989 samples

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Height of Dominant Woody Plants Inside and Outside Exclosures Located in FP1

Initial Tree Diameter data taken in various studies, 1968-1972

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Litter Trap Results at the Tanana River Exclosures: 2001 - Present

Litterbag decomposition study, BCEF LTER sites, 1989-1997

Litterfall and Hare Pellet Summary at Bonanza Creek LTER Control Plots (1985 - Present)

Litterfall collected from LTTG Sites (1 meter litter trays): 1967 - Present

Litterfall Weights From LTER Study Site Treatment Plots: 1990 - Present

LTER treatment plot circumference growth: 1989 - Present

Height and DBH measurements of Lodgepole Pine Plantations in Alaska: 1984 - 2004

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Organic layer thickness: Wickersham fire sites (1971 - 2004)

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Age data from Deuce and Dune Lakes, Interior Alaska

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Standardized ring-width chronologies for white and black spruce at three sites in the southern Brooks Range, Alaska

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Tree regeneration after fire: Delta 1994 burn surveys, data to develop allometric equations re. seedling height or diameter to dry biomass

Tree regeneration after fire: Delta 1994 burn surveys, live aspen seedling diameters

Tree regeneration after fire: Delta 1994 burn surveys, pre-fire stem counts and basal areas, for species other than black spruce

Tree regeneration after fire: Delta 1994 burn surveys, pre-fire stem counts and basal areas, for black spruce

Tree regeneration after fire: Delta 1994 burn surveys, thickness of different soil layers

Tree regeneration after fire: Delta 1994 burn surveys, Salix live seedling diameters

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Tree regeneration after fire: Aspen removal experiment, Counts of seedling germination

Tree regeneration after fire: Aspen removal experiment, aboveground biomass of seedlings from sown seed

Tree regeneration after fire: Aspen removal experiment, biomass of 2002 growth of transplanted seedlings

Tree regeneration after fire: Aspen removal experiment, soil moisture analysis 2002

Average Tree Growth (DBH,Circumfrance,and BasalArea) at LTTG Sites, 1969-Present: Yearly

Tree regeneration after fire: Aspen removal experiment, organic layer depth measurements 2001, 2002

Tree regeneration after fire: Aspen removal experiment, soil moisture and pH 2001

Tree regeneration after fire: Aspen removal experiment, vegetation cover 2000 - 2002

Nel-Rep plots: Spruce and alder heights and diameters 1990-1997

Tanana River Floodplain Dissolved Organic Nitrogen (T30 DON) Budget

Tanana River Floodplain Dissolved Organic Nitrogen (DON) Budget, GPS coordinates for Tanana River Floodplain study plots

Tanana River Floodplain Dissolved Organic Nitrogen (T0 DON) Budget

Tanana River Floodplain Dissolved Organic Nitrogen (DON) Budget, extracted soil protein content

Raw D and 18O isotope data for a core from the center and moat of the BBC collapse scar: Bonanza Creek Experimental Forest Flood Plains

Growing Season D and 18O isotope data for a core from the center and moat of the BBC collapse scar: Bonanza Creek Experimental Forest Flood Plains

GIS file of permafrost distribution in Caribou-Poker Creeks Research Watershed

Net primary production, heterotrophic respiration, and net ecosystem production out from TEM outputs: 1899 - 2100

Net primary production, heterotrophic respiration, and net ecosystem production out from TEM outputs compared with Tower data: 1899 - 2100

Net ecosystem production (NEP) raw data for the coupled and uncoupled simulation for all North American black spruce grid cells (n=1758)

Bonanza Creek LTER Study Sites, Roads, and other Locations: GIS/Spatial Data

Height and diameter measurement of spruce in response to harvest: 1993 - 2002

GIS point locations for Forest Soils Laboratory, SALRM research sites: 1967 - 2000

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Soil physical and chemical properties based on genetic horizon from 4 replicate pits placed around the replicate LTER control plots sampled in 1988 and 1989.

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Braun-Blanquet sorted vegetation tables for 150 extensive mature black spruce sites in interior Alaska

Point-center quarter method black spruce heights, diameter, and location for 150 mature black spruce sites in interior Alaska

Tree core and ring data for 150 mature black spruce sites in interior Alaska

Active layer depths: 150 mature black spruce sites in interior Alaska (2000-2003)

Caribou-Poker Creeks Research Watershed: Daily Flow Rates for C2, C3, C4

Effects of mammalian browsing on fine root processes and production in the floodplains of BCEF

Riparian clearing in CPCRW: Macroinvertebrate and CPOM data; 1982 - 1986

In situ Denitrification Rates in the Riparian Zone of Caribou-Poker Creeks Research Watershed, Alaska, 2002 - 2004

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Soil Water (Lysimeter) Chemistry for Mature Balsam Poplar and White Spruce for BCEF

Stream water chemistry of CPCRW, 2002-2010

Bonanza Creek Experimental Forest: Barometric Pressure at LTER1, 1995 - Present

BNZ LTER: Hourly photosynthetically active radiation (PAR), 1988 - Present

National Atmospheric Deposition Program (NADP): Seasonal Wet Depositions Totals (kg/ha), 1992 - Present

National Atmospheric Deposition Program (NADP): Concentration Data, 1992 - Present

Air Temperature, Soil Temperature, Precipitation, Snow Depth at Long Term Tree Growth Sites; 1968-Present : Weekly

Caribou-Poker Creeks Research Watershed: Water and streambed temperature, 1994

Bonanza Creek Experimental Forest: Hourly Snow depth data, 1988 to Present

Air Temperature for 4 LTTG sites, digitized from thermograph weather charts: Hourly Data; 1968-1989

Caribou-Poker Creeks Research Watershed: Hourly Air Temperature (mean, min, max) from 1995 to Present

Caribou-Poker Creeks Research Watershed: Hourly Wind Speed and Direction from 1988 to Present

Caribou-Poker Creeks Research Watershed: Hourly Precipitation data, 1998 to Present

Long Term Tree Growth Sites: Hourly Temperature and Hourly Relative Humidity at 150 cm from 1988 to Present

Ground Water Depth Readings at BCEF/LTER Floodplain Sites, 1991-Present: Weekly

Ground Water Depth Readings at BCEF/LTER Floodplain Sites, 1991-Present: Hourly

Bonanza Creek Experimental Forest Precipitation (Water Buckets/Rain Gauges) at BCEF LTER sites: Weekly

Caribou-Poker Creeks Research Watershed: Hourly Precipitation data from weighing buckets, 1992 to 1995

Vegetation Plots of the Bonanza Creek LTER Control Plots: Species Percent Cover (1975 - 2009)

Vegetation Plots of the Bonanza Creek LTER Control Plots: Species Count (1975 - 2004)

Bonanza Creek Experimental Forest: Evaporation measurements from core sites: hourly (1988 - Present)

Bonanza Creek Experimental Forest: Snow Pillow measurements: hourly (1988 - Present)

Caribou-Poker Creeks Research Watershed: Barometric Pressure, 2000 - Present

Bonanza Creek Experimental Forest: Dew Point measurements: hourly (1988 - Present)

BNZ LTER: PYR measurements: hourly (1988 - Present)

Bonanza Creek Experimental Forest: Vapor Pressure measurements: hourly (1988 - Present)

Bonanza Creek Experimental Forest: UV measurements: hourly (1988 - Present)

Bonanza Creek Experimental Forest: Precipitation Weighing Bucket Measurements: hourly (1988 - Present)

Average D and 18O isotope data for a core from the center and moat of the BBC collapse scar: Bonanza Creek Experimental Forest Flood Plains

Ground cover and biomass projection photos for the BBC collapse scar

CO2, CH4, and H2O flux data and associated environmental variables for the BBC collapse scar for 2004

Meteorological data for the BBC collapse scar for 2003 and 2004

Soil data for cores from a transect from the center of the BBC collapse scar into the surrounding burn

Tree ring width data for trees adjacent to the BBC collapse scar

Tree band growth data taken at BCEF sites (1989 -Present)

Active Layer Depth Data for the BBC collapse scar for 2003 and 2004

Soil Respiration in Bonanza Creek Experimental Forest from Upland and Floodplain sites 1990-1992

Soil Respiration in Bonanza Creek Experimental Forest Floodplain Black Spruce Sites

Weekly Soil Solution Nutrient Concentrations in Bonanza Creek Experimental Forest for the summers of 1985-1988

Soil temperature in Black Spruce Carbon cycling study along a temperature gradient in interior Alaska

White Spruce Seedling Counts at Bonanza Creek Experimental Forest Vegetation Plots (4-sq meters)

Tree Growth data taken at LTTG sites, 1969-Present: Reported Yearly

Soil Moisture taken with a neutron probe 1969-1974 from 11 sites: Weekly

Aspect raster layer for interior Alaska

Digital Elevation Model (DEM) raster layer for interior Alaska

Palmer Drought Severity Index (PDSI) for Fairbanks, AK 1949-2006

Tanana River Yearly Ice Break Up Observed at Nenana, AK (1917 - Present)

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Vegetation cover: Wickersham fire sites (at the Viereck thaw probe locations), 1977-2004

Tree heights and diameters: Wickersham fire sites (at the Viereck thaw probe locations), 1995 and 2004

Caribou-Poker Creeks Research Watershed Radiation Measurements: Net Radiation, Up and Down Shortwave/Longwave Radiation

Black spruce needle nitrogen concentration from 1998

Black spruce needle nitrogen concentration from 5 stands in 1999

Aboveground component weights (weight and dry) for the major tree species found in interior Alaska

Organic layer data from burned black spruce stands for the effects of variations in post-fire organic layer thickness studies in the Delta Junction region, 1995-2003

Mineral soil moisture and temperature data from unburned stands used in the effects of variations in post-fire organic layer thickness studies in the Delta Junction region, 1995-2003

Data to estimate stand density and average basal diameter from unburned black spruce stands used in the effects of variations in post-fire organic layer thickness studies in the Delta Junction region, 1995-2003

Organic layer data from unburned black spruce stands used in the effects of variations in post-fire organic layer thickness studies in the Delta Junction region, 1995-2003

Bulk density and percent carbon from surface organic layers in unburned black spruce stands used in the effects of variations in post-fire organic layer thickness studies in the Delta Junction region, 1995-2003

Mineral soil moisture and temperature data from burned stands used in the effects of variations in post-fire organic layer thickness studies in the Delta Junction region, 1995-2003

Profiles of 0-50 cm soil CO_2 and N_2O concentrations collected in the CPCRW from 1998-2002

Soil Respiration in burned and unburned areas in and around watershed C4 within the Caribou-Poker Creeks Research Watershed from 1998-2004

Active layer depths: Boundary Fire Fireline (2004 - Present)

Active layer depths: Survey Line Fire (2004 - Present)

Bonanza Creek Experimental Forest: Hourly Relative Humidity (mean, min, max) at 50 cm and 150 cm from 1988 to Present

Greenup values for interior Alaska 1976 - Present

Caribou-Poker Creeks Research Watershed Hourly Relative Humidity (mean, min, max) at varying heights from 1988 to Present

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Soil Moisture (TDR) Measurements at LTER Moisture Exclusion Treatment Plots: 1994-Present (weekly)

Soil Moisture (Tensiometer) Measurements at LTER Floodplain Moisture Exclusion Treatment Plots: 1991-2003 (weekly)

Soil Temperature Measurements at LTER Floodplain Successional Sites (FP1A,FP2A,FP4A): 1985-present (hourly)

Soil Moisture Tension Measurements at LTER Floodplain Successional Sites (FP1A,FP2A,FP4A): 1985-2003 (hourly)

Soil Moisture (TDR) Measurements at FP2A: 1993-1995

Soil Moisture (TDR), Temperature, and Precipitation Measurements at UP2A Moisture Exclusion Treatment Plots: 1996-2000

Soil Moisture (TDR), Temperature, and Precipitation Measurements at FP3A Moisture Exclusion Treatment Plots: 2002-Present

Tree inventory data taken at BCEF sites (1989-Present)

Soil nitrogen and carbon from organic and mineral soil of 32 mature black spruce sites across interior Alaska (Sampled 2001)

APEX fen control plot soil temperatures, 2005-Present

APEX fen Raised plot soil temperatures, 2005-Present

APEX fen Lowered plot soil temperatures, 2005-Present

Alaskan Peatland Experiment (APEX): Static chamber methane fluxes from fen sites, 2005-2011

Water table level data from APEX Fen plots, 2005-2006

Photosynthetically active radiation (PAR) data from APEX Fen, 2005 - 2006

Bonanza Creek moisture gradient physical data at BZBS: hourly temperature, moisture and photosynthetically active radiation.

Bonanza Creek moisture gradient physical data at BZWB: hourly temperature, moisture and photosynthetically active radiation.

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Bonanza Creek moisture gradient soil core data: 2004.

Bonanza Creek moisture gradient soil core data: 2005.

BNZ Soil Temperature Data for submission to EcoTrends

BNZ Stream Flow Data for submission to EcoTrends

Effects of stem canker disease on N fixation inputs by Alnus tenuifolia to early-successional floodplains in interior and south-central Alaska. I. Nitrogen fixation rates, leaf chemistry and soil chemistry.

Environmental and stand data for sites located in the 2004 burns off the Steese, Taylor, and Dalton Highways, collected in 2005-2007

Pre-fire and Post-re species abundance (Braun-Blaunquet abundance methods) for 14 sites from 2001-2006.

Artificial Communities Seedling Growth: Bonanza Creek Experimental Forest (planted in 1989; measured in 1992, 1995, and 2002).

Alaska Statewide annual maximum Normalized Difference Vegetation Index (NDVI) values from 1982-2003 at 8km pixel size

Pond Area Estimates: Nine Study Regions in Alaska for 3 time periods (1950s, 1978-1982, 1999-2001) using remotely sensed images

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Energy feedbacks of northern high-latitude ecosystems to the climate system due to reduced snow cover during 20th century warming-I

Energy feedbacks of northern high-latitude ecosystems to the climate system due to reduced snow cover during 20th century warming-II

Energy feedbacks of northern high-latitude ecosystems to the climate system due to reduced snow cover during 20th century warming-III

Energy feedbacks of northern high-latitude ecosystems to the climate system due to reduced snow cover during 20th century warming-IV

Energy feedbacks of northern high-latitude ecosystems to the climate system due to reduced snow cover during 20th century warming-V

Human influences on wildfire in Alaska from 1988 through 2005-Shapefile Outline for Interior Alaska

Firescars with distance from major rivers in Interior Alaska (1988-1993)

Firescars with distance from major rivers in Interior Alaska (1994-1999)

Firescars with distance from major rivers in Interior Alaska (2000-2005)

Firescars with distance from highways in Interior Alaska (1988-1993)

Firescars with distance from highways in Interior Alaska (1994-1999)

Firescars with distance from highways in Interior Alaska (2000-2005)

Firescars with distance from towns in Interior Alaska (1988-1993)

Firescars with distance from towns in Interior Alaska (1994-1999)

Firescars with distance from towns in Interior Alaska (2000-2005)

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Summary of environmental and stand characteristics of thinleaf alder sites along the Tanana River floodplains from 2006-2007.

Stem diameter of trees and shrubs in thinleaf alder sites along the Tanana River floodplains and severity of stem canker infection of alder in 2006.

Age, size, and disease severity of thinleaf alder stems along the Tanana River floodplains, collected in 2006 and 2007.

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Standardized ring-width chronologies of thinleaf alder growth along the Tanana River floodplains spanning 1968-2006.

Nitrogen cycling at treeline. I. Study Sites and Vegetation

Nitrogen cycling at treeline. II. Percent Soil Carbon and Nitrogen

Nitrogen cycling at treeline. III. Total Soil Carbon and Nitrogen Content

Nitrogen cycling at treeline. IV. Soil Profile Descriptions

Nitrogen cycling at treeline V. Insitu Nitrogen mineralization

Nitrogen cycling at treeline VI. Common Litter Decomposition

Nitrogen cycling at treeline VII. Laboratory Decomposition

The role of fire in the carbon dynamics of the boreal forest I. - Response of area burned to changing climate in western boreal North America using a Multivariate Adaptive Regression Splines (MARS) approach (2003-2100).

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Bonanza Creek Experimental Forest: Weekly TDR measurements at core upland and floodplain sites.

Caribou-Poker Creeks Research Watershed: Hourly Precipitation Weighing Bucket Measurements

Caribou-Poker Creeks Research Watershed: Hourly Snow Depth Measurements

Caribou-Poker Creeks Research Watershed: Hourly Snow Pillow Measurements

Caribou-Poker Creeks Research Watershed: Dew Point Measurements: Hourly Data

Caribou-Poker Creeks Research Watershed: Vapor Pressure Measurements: Hourly Data

Caribou-Poker Creeks Research Watershed: Hourly Soil Temperature at varying depths from 1988 to Present

Black spruce seed counts from seed rain traps in the 2004 burns off the Steese, Taylor, and Dalton Highways, collected in 2005-2007.

Black spruce seed viability from seed rain traps in the 2004 burns off the Steese, Taylor, and Dalton Highways, collected in 2005-2007.

Caribou-Poker Creeks Research Watershed: Hourly Soil Moisture at varying depths from 2000 to Present

Changes in vegetation in northern Alaska under scenarios of climate change, 2003-2100: I - Trends in air temperature, precipitation, and cloudiness

Changes in vegetation in northern Alaska under scenarios of climate change, 2003-2100: II - Change in net primary production (NPP)

Changes in vegetation in northern Alaska under scenarios of climate change, 2003-2100: III - Decadal net primary productivity (NPP) and heterotrophic respiration

Changes in vegetation in northern Alaska under scenarios of climate change, 2003-2100: IV - Relationship between selected carbon pools and fluxes

Changes in vegetation in northern Alaska under scenarios of climate change, 2003-2100: V - Change in summer albedo by climate scenario

Post-fire recovery in the 2004 burns of interior Alaska: Densities of tree seedlings measured in 2008 by Joint Fire Science Program

Eight Mile Lake Research Watershed, Thaw Gradient: Growing season soil profile CO2 production at 10, 20, 30, and 40 cm, 2005-2007.

White Spruce NPP: Tree density and basal area by diameter sizeclass in upland and floodplain mid- and late-successional stands: 1989-2008

White Spruce NPP: average NPP per tree by age cohort for 4 time periods between 1993 and 2008

White Spruce NPP: average NPP per tree by diameter sizeclass for 4 time periods between 1993 and 2008

White Spruce NPP per tree and per ha averaged across a 15 year period (1993 to 2008)

White Spruce NPP per tree calculated from dendrometer bands annually from 1994 to 2008

White spruce tree diameter vs age in mid-successional and late-successional long-term Bonanza Creek LTER inventory plots

Core Meteorological Measurements for the APEX Alpha Fen Bonanza Creek Experimental Forest: 2007-Present

Log Decomposition Dynamics in Interior Alaska 1 - Site Data

Log Decomposition Dynamics in Interior Alaska 2a - Log Data

Log Decomposition Dynamics in Interior Alaska 2b - Log Sampling Schedule

Log Decomposition Dynamics in Interior Alaska 3 - Disk Data

Log Decomposition Dynamics in Interior Alaska 4 - Nutrient Data

Log Decomposition Dynamics in Interior Alaska 5a - Preliminary Results (treatment down) - Absolute

Log Decomposition Dynamics in Interior Alaska 5b - Preliminary Results (treatment down) - Retained

Aspen NPP: Tree density and basal area by diameter sizeclass in upland mid- and late-successional stands: 1989-2008

Aspen NPP: average NPP per tree by diameter sizeclass for 4 time periods between 1993 and 2008

Aspen NPP per tree calculated from dendrometer bands annually from 1994 to 2008

Aspen tree diameter vs age in mid-successional long-term Bonanza Creek LTER inventory plots

Birch NPP: Tree density and basal area by diameter sizeclass in upland and floodplain mid- and late-successional stands: 1989-2008

Birch NPP: average NPP per tree by diameter sizeclass for 4 time periods between 1993 and 2008

Alaska paper birch NPP per tree calculated from dendrometer bands annually from 1994 to 2008

Alaskan paper birch tree diameter vs age in mid-successional and late-successional long-term Bonanza Creek LTER inventory plots

Balsam Poplar NPP: Tree density and basal area by diameter sizeclass in upland and floodplain mid- and late-successional stands: 1989-2008

Balsam Poplar NPP: average NPP per tree by diameter sizeclass for 4 time periods between 1993 and 2008

Balsam poplar NPP per tree calculated from dendrometer bands annually from 1994 to 2008

Balsam poplar tree diameter vs age in mid-successional and late-successional long-term Bonanza Creek LTER inventory plots

Eight Mile Lake Research Watershed, Thaw Gradient: Growing season CO2 fluxes and several ecosystem measurements, growing season 2006-2007.

Air Temperature and Relative Humidity at Long Term Tree Growth Sites; 1989-Present: Hourly

Soil Temperature measurements at Long Term Tree Growth Sites; 1989-Present: Hourly

Air Temperature and Relative Humidity at Long Term Tree Growth Sites; 2001-Present: Hourly

Caribou Poker Creek Research Watershed GIS Data: Steam Lines

Caribou Poker Creek Research Watershed GIS Data: Spot 5 Imagery

Caribou Poker Creek Research Watershed GIS Data: Permafrost

Caribou Poker Creek Research Watershed GIS Data: Digital Elevation Model (DEM)

Caribou Poker Creek Research Watershed GIS Data: Research Area Boundary (NAD83)

Bonanza Creek LTER GIS Data: Core Research Plot Locations

Bonanza Creek Experimental Forest GIS Data: Stream Lines

Bonanza Creek Experimental Forest GIS Data: Spot 5 Imagery

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Bonanza Creek LTER GIS Data: Roads and Trails within 100km of Fairbanks

Spatial patterns of understory vegetation and soil in an Alaskan upland boreal forest fire chronosequence. Three sites located in Delta Junction Alaska. Soil sampled during summer 2007

The effects of nitrogen and warming on inorganic nitrogen pool and production rates in arctic and boreal ecosystems: inorganic nitrogen transformation during a 3-month laboratory incubation

The effects of nitrogen and warming on soil respiration in arctic and boreal ecosystems: microbial respiration during a 924-day laboratory incubation

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APEX beta NW site: hourly soil temperature, soil moisture, air temperature and RH, photosynthetically active radiation (PAR), and rain.

APEX beta SE site: hourly soil temperature, soil moisture and net radiation.

APEX beta SW site: hourly soil temperature, and soil moisture.

APEX gamma black spruce site: hourly soil temperature, soil moisture, air temperature and RH and photosynthetically active radiation (PAR).

Cooperative Alaska Forest Inventory

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Hess Creek: soil temperatures at different depths from 2007-2009

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Soil N pools and process rates for catenas at Caribou-Poker Research Watersheds and the Kuparuk River

Kuskokwim River Floodplain: White Spruce (Picea glauca) annual tree-ring width measurements (mm) at breast height from tree-core samples taken above Red Devil on the Kuskokwim River in July, 2007.

Soil Moisture (VWC) at LTER Moisture Manipulation Treatments

Soil Temperature at LTER Moisture Manipulation Treatments

Locations and Time of Alaska Lightning Strikes 1986-2010

Statewide 2-km raster of year since last wildfire

Statewide 2-km raster of number of fires within each 2-km pixel since 1942

Surface and hyporheic water chemistry of the Tanana River

Alaskan Peatland Experiment: Community structure and productivity data for 2007-2010 I - Species List

Alaskan Peatland Experiment: Community structure and productivity data for 2007-2010 II - Species Abundance

Alaskan Peatland Experiment: Community structure and productivity data for 2007-2010 III - Understory Biomass

Alaskan Peatland Experiment: Community structure and productivity data for 2007-2010 IV - Understory Vascular ANPP

Alaskan Peatland Experiment: Community structure and productivity data for 2007-2010 V - Moss NPP

Alaskan Peatland Experiment: Community structure and productivity data for 2007-2010 VI - Tree Biomass and NPP

Alaskan Peatland Experiment: Community structure and productivity data for 2007-2010 VII - BGNPP

Alaskan Peatland Experiment: Community structure and productivity data for 2007-2010 VIII - VGA

Alaskan Peatland Experiment: Community structure and productivity data for 2007-2010 IX - Stem Density

Alaskan Peatland Experiment: Community structure and productivity data for 2007-2010 X - Leaf Area

Eight Mile Lake Research Watershed, Carbon in Permafrost Experimental Heating Research (CiPEHR): Half-hourly soil moisture and temperature data, 2008-2013.

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Impacts of wildfire on stream water chemistry in the Caribou-Poker Creeks Research Watershed during the summers of 2002-2007

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Site, environmental and stand data across an age since fire range of 6-338 years for 30 sites in northern Yukon and central Alaska

Samples of individual trees (cones, age) within sites across an age since fire range of 6-338 years for 30 sites in northern Yukon and central Alaska

Alaska Peatland Experiment: Biweekly flux data and environmental measurements (soil temperature, soil moisture, seasonal thaw depth, water table depth)

Alaska Peatland Experiment: 2009 All sites Root Biomass data taken during peak biomass (late July)

Alaska Peatland Experiment: 2010 Alpha Root Biomass data taken during peak biomass (late July)

Alaska Peatland Experiment: 2011 Gradient Root Biomass data taken during peak biomass (late July)

Alaska Peatland Experiment: 2011 Beta Root Biomass data taken during peak biomass (late July)

Alaska Peatland Experiment: 2010-2011 Root Respiration Experiment Root Fluxes

Alaska Peatland Experiment: 2010-2011 Root Respiration Experiment Aboveground biomass

Alaska Peatland Experiment: 2010-2011 Root Respiration Experiment Ecosystem Respiration Fluxes

Alaska Peatland Experiment: 2010-2011 Root Respiration Experiment Percent Cover

Alaska Peatland Experiment: 2010-2011 Root Respiration Experiment Soil Descriptions

Alaska Peatland Experiment: 2010-2011 Root Respiration Experiment Vascular Green Area

Eight Mile Lake Research Watershed, Carbon in Permafrost Experimental Heating and Drying Research (DryPEHR): Growing season, chamber-based, CO2 flux data, 2011.

Eight Mile Lake Research Watershed, Carbon in Permafrost Experimental Heating and Drying Research (DryPEHR): Weekly thaw depth data, 2011.

Eight Mile Lake Research Watershed, Carbon in Permafrost Experimental Heating Research (CiPEHR): Seasonal water table depth data, 2011.

Eight Mile Lake Research Watershed, Carbon in Permafrost Experimental Heating and Drying Research (DryPEHR): Seasonal water table depth data, 2011.

Eight Mile Lake Research Watershed, Carbon in Permafrost Experimental Heating Research (CiPEHR): Foliar CN at peak biomass, 2009-2011.

Eight Mile Lake Research Watershed, Carbon in Permafrost Experimental Heating Research (CiPEHR): CN from senescent leaves, 2009-2010.

Eight Mile Lake Research Watershed, Carbon in Permafrost Experimental Heating Research (CiPEHR): Aboveground plant biomass, 2009-2013.

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Black spruce soil delta15N values from 31 sites centered around Fairbanks, AK collected in 2007.

Bonanza Creek Experimental Forest Beetles Per Trap Beginning in 1975 - Kruse

Bonanza Creek Experimental Forest Defoliating Insect Population Levels Per Leaf Beginning in 1975 - Kruse

Eight Mile Lake Research Watershed, Carbon in Permafrost Experimental Heating Research (CiPEHR): Annual and growing season decomposition of a common substrate, 2008-2013.

Eight Mile Lake Research Watershed, Ecosystem carbon balance along a permafrost thaw gradient: Annual decomposition of a common substrate, 2004-2012.

Survey of aspen leaf mining and leaf defenses, including foliar phenolic glycosides and extrafloral nectaries

Stream water dissolved organic matter

Known-fate survival information for radio-tagged snowshoe hares captured in Bonanza Creek Experimental Forest from June 2008 to November 2012

Eight Mile Lake Research Watershed, Thaw Gradient, The radiocarbon value of ecosystem respiration, 2004-2012 I: Reco.

Eight Mile Lake Research Watershed, Carbon in Permafrost Experimental Heating Research (CiPEHR): The radiocarbon value of ecosystem respiration, 2009-2012 I: Reco.

Eight Mile Lake Research Watershed, Thaw Gradient, The radiocarbon value of ecosystem respiration, 2004-2012 II: Rplant.

Eight Mile Lake Research Watershed, Thaw Gradient, The radiocarbon value of ecosystem respiration, 2004-2012 III: Atm.

MODIS annual maximum NDVI for Tanana-Yukon Uplands Ecoregion from 2000-2012.

Eight Mile Lake Research Watershed, Thaw Gradient: half-hourly soil temperature 2004-2010.

Eight Mile Lake Research Watershed, Thaw Gradient: Active Layer thickness

Eight Mile Lake Research Watershed, Thaw Gradient: Seasonal thaw depth

Soil Microbial and N cycling data along a wetland plant community gradient

Del 13C-CO2 of in situ soil respiration post tracer addition

Biomass %N, %C, natural abundance 15N and 13C isotopic signatures for common and rare under- and overstory plants in long unburned and burned (1999) boreal forest stands, Caribou-Poker Creek and Delta Junction

Koyukuk Flats: soil temperatures at different depths from 2008-2009

Surface carbon, water and energy fluxes measured by eddy covariance at 3 sites within the Alaska Peatlands Experiment and Bonanza Creek Experimental Forest

Long term consequences of aspen leaf miner outbreak for plant performance

Consequences of aspen leaf miner outbreak for plant performance

Induction of aspen chemical defense by leaf mining, tested experimentally in 2006

Induction of aspen chemical defense by leaf mining, tested experimentally in 2007.

Nitrogen fixation, nodule respiration, and nodule Frankia identity in alder growing in control, N-fertilized, and P-fertilized stands.

Shrub, Seedling and Sapling Density at Bonanza Creek LTER Research Sites (1975-Present)

Point Bar Vegetation Survey of Bonanza Creek LTER Research Plots (2007-Present)

Soil C, N, P, and Frankia nifD-K RFLP genotypes distribution from Alnus tenuifolia nodules in early and late succession 2005

Nitrogen and Phosphorus resorption of thin-leaf alder growing in control, N-fertilized, and P-fertilized plots across a floodplain successional gradient.

Eight Mile Lake Research Watershed, Thaw Gradient Extended sites: Physical properties of soil (temperature, moisture and thaw depth).

Eight Mile Lake Research Watershed, Thaw Gradient Extended sites: Thaw depths.

Eight Mile Lake Research Watershed, Thaw Gradient Extended sites: Vegetation cover and abundance.

Eight Mile Lake Research Watershed, Thaw Gradient Extended sites: Physical data from land cover classes from an upland watershed undergoing permafrost thaw.

Eight Mile Lake Research Watershed, Thaw Gradient Extended sites: Vegetation data from land cover classes from an upland watershed undergoing permafrost thaw.

Organic layer thickness measurements from burned and unburned black spruce forests in Alaska collected between 1994 and 2012

Coarse Woody Debris (CWD) biomass across a compositional gradient of intermediate-aged and mature forest stands within Interior Alaska collected 2008-2011.

Fine Woody Debris (FWD) biomass across a compositional gradient of intermediate-aged and mature forest stands within Interior Alaska collected 2008-2011.

Foliage chemistry across a compositional gradient of intermediate-aged and mature forest stands within Interior Alaska collected 2008-2011.

Snag size and composition across a compositional gradient of intermediate-aged and mature forest stands within Interior Alaska collected 2008-2011.

Size and composition of all live and dead trees and large shrubs across a compositional gradient of intermediate-aged and mature forest stands within Interior Alaska collected 2008-2011.

Twig chemistry across a compositional gradient of intermediate-aged and mature forest stands within Interior Alaska collected 2008-2011.

Yukon River Basin Fire and Permafrost Study: Site description and summary of environmental data (2009-2012)

Yukon River Basin Fire and Permafrost Study: Soil physical and chemical characteristics by soil layer and year (2009-2012)

Yukon River Basin Fire and Permafrost Study: Elevation of soil surface and permafrost table along transects with different fire disturbance regimes (2009-2012)

Yukon River Basin Fire and Permafrost Study: Plant species cover in burned and unburned evergreen stands (2012)

Yukon River Basin Fire and Permafrost Study: Air temperature and soil temperature at 5 cm and 100 cm depths in burned and unburned stands (2009-2012)

Eight Mile Lake Research Watershed, Carbon in Permafrost Experimental Heating Research (CiPEHR) Extended sites: winter ecosystem respiration chamber measurements using snow removal method. Oct-Nov 2009, Oct-Dec 2011, Oct-Nov; March-April 2012, Feb-May 2013.

Eight Mile Lake Research Watershed, Carbon in Permafrost Experimental Heating Research (CiPEHR): Seasonal water table depth data, 2012-2013.

Far northeastern Siberia boreal forest data: Thaw depth within experimental burn plots

Far northeastern Siberia boreal forest data: Canopy cover across a larch forest density gradient

Far northeastern Siberia boreal forest data: Coarse woody debris abundance across a larch forest density gradient

Far northeastern Siberia boreal forest data: Mean soil temperature within experimental burn plots

Far northeastern Siberia boreal forest data: Larch recruitment within experimental burn plots

Far northeastern Siberia boreal forest data: Soil horizon and thaw depths across a larch forest density gradient

Far northeastern Siberia boreal forest data: Larch tree snag (dead tree) size distribution across a density gradient

Far northeastern Siberia boreal forest data: Larch tree size distribution across a density gradient

Far northeastern Siberia boreal forest data: Fine woody debris abundance across a larch forest density gradient

Eight Mile Lake Research Watershed, Thaw Gradient: Seasonal water table depth.

Observational study of post-fire mycorrhizal communities associated with resprouting Betula nana shrubs across a fire-severity gradient in the Anaktuvuk River Fire burn scar, 2009

ARISA fungal community profiles for each resprouting Betula nana shrub sampled in an observational study of post-fire mycorrhizal communities across a fire-severity gradient in the Anaktuvuk River Fire burn scar, 2010

Eight Mile Lake Research Watershed, Carbon in Permafrost Experimental Heating Research (CiPEHR): Winter ecosystem respiration measurements using soda lime, 2010-2015.

Eight Mile Lake Research Watershed, Carbon in Permafrost Experimental Heating Research (CiPEHR): Phenology of Dominant Plant Species I - Bud burst and Senescence

Eight Mile Lake Research Watershed, Carbon in Permafrost Experimental Heating and Drying Research (DryPEHR): DryPEHR Project Phenology of Dominant Plant Species I - Bud burst and Senescence

Eight Mile Lake Research Watershed, Carbon in Permafrost Experimental Heating Research (CiPEHR): Fall ecosystem respiration chamber measurements, 2009; 2011-2013.

Eight Mile Lake Research Watershed, Carbon in Permafrost Experimental Heating and Drying Research (DryPEHR): Fall ecosystem respiration chamber measurements, 2011,2013.

Eight Mile Lake Research Watershed, Carbon in Permafrost Experimental Heating Research (CiPEHR): Winter ecosystem respiration chamber measurements using on-plot method, Oct 2012-May 2013.

Eight Mile Lake Research Watershed, Carbon in Permafrost Experimental Heating and Drying Research (DryPEHR): Winter ecosystem respiration chamber measurements using on-plot method, Oct 2012-May 2013.

Eight Mile Lake Research Watershed, Carbon in Permafrost Experimental Heating and Drying Research (DryPEHR): Half-hourly soil moisture and temperature data, 2010-2013.

Monitoring permafrost thaw in Denali National Park and Preserve: year one of data collection 2013

Relationship of Community Characteristics to Harvest Reporting: Comparative study of household surveys and harvest tickets in Alaska

Development of Illumina oligos for fungal ITS sequencing

Eight Mile Lake Research Watershed, Carbon in Permafrost Experimental Heating Research (CiPEHR): Phenology of Dominant Plant Species II - Berry Production.

Eight Mile Lake Research Watershed, Carbon in Permafrost Experimental Heating Research (CiPEHR): Phenology of Dominant Plant Species III - Flowering Date.

Eight Mile Lake Research Watershed, Carbon in Permafrost Experimental Heating and Drying Research (DryPEHR): Phenology of Dominant Plant Species II - Berry Production.

Eight Mile Lake Research Watershed, Carbon in Permafrost Experimental Heating and Drying Research (DryPEHR): Phenology of Dominant Plant Species III - Flowering Date.

Stream TASCC nutrient additions conducted in headwater streams of the Caribou-Poker Creeks Research Watershed (CPCRW) and along the Steese Highway during the summer of 2013.

Environmental and stand data for 88 sites located in the 2004 burns off the Steese, Taylor, and Dalton Highways, and for the 2005 burn near Eagle Plains, Yukon.

Tree ring widths from 1974-2003 for approximately 10 trees/site for 82 sites located in the 2004 burns off the Steese, Taylor, and Dalton Highways, and for the 2005 burn near Eagle Plains, Yukon.

Total tree ring widths, earlywood ring widths, latewood ring widths, and stable carbon isotope composition of tree rings from 1979-2003 for 18 trees (3 trees/site for 6 sites) located in the 2004 burn along the Steese Highway.

Algae alleviate carbon limitation of heterotrophic bacteria in a boreal peatland

Effects of permafrost thaw on nitrogen availability and plant-soil interactions in a boreal Alaskan lowland: I - Percent Cover Data 2013

Effects of permafrost thaw on nitrogen availability and plant-soil interactions in a boreal Alaskan lowland: II - Nitrogen Data 2013

Effects of permafrost thaw on nitrogen availability and plant-soil interactions in a boreal Alaskan lowland: III - Root Abundance 2013

Effects of permafrost thaw on nitrogen availability and plant-soil interactions in a boreal Alaskan lowland: IV - Plant vs Nitrogen Data 2013

Effects of permafrost thaw on nitrogen availability and plant-soil interactions in a boreal Alaskan lowland: V - Isotope Data 2013

Effects of permafrost thaw on nitrogen availability and plant-soil interactions in a boreal Alaskan lowland: VI - Soil Nitrogen Pools

Canopy cover in mature black spruce forest, mature mixed forest, and early successional forest in Bonanza Creek Experimental Forest.

Fates and morphometrics of snowshoe hares collared in Bonanza Creek Experimental Forest from 2008 to present

Horizontal cover in mature black spruce forest, mature mixed forest, and early successional forest in Bonanza Creek Experimental Forest.

Structural cover at snowshoe hare predation sites in Bonanza Creek Experimental Forest from 2008 to 2012.

Vegetation composition for 84 sites in the Regional Site Network, compilation from previous surveys.

Active Layer Depth or Permafrost Presence for the Regional Site Network.

Organic Horizon Depth in the Regional Site Network.