Establishment of a permanent sample plot network to enhance our understanding of forest and permafrost dynamics following a severe fire year – a report on 2015 activities

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1. Summary of Deliverables:

- A network of 214 permanent sample plots distributed across both the Taiga Plains and Taiga Shield across a 400km latitudinal gradient (Fig 1; Table 1), facilitating monitoring of the recovery of NWT ecosystems following the largest fire year on record.
- Spatially distributed information about fire severity as a function of biotic, abiotic, and fire weather variables allowing for improved understanding of drivers of severe burning, which will improve predictive tools of vegetation/habitat recovery post-fire.
- Characterization of carbon stocks in NWT soils and how this is impacted by severe fire years.
- Time zero measurements for ongoing chronosequence sampling to understand the recovery of caribou habitat following fire.
- Outreach and engagement activities surrounding the role of fire in boreal forests in communities throughout the summer and ongoing

2. Background: The fire season of 2014 saw 3.4 million ha of forested lands impacted by wildfires in the Northwest Territories (NWT), which made this the largest fire season in the NWT's history. The fires were concentrated in the region around Great Slave Lake and thus affected the majority of NWT residents. The 2014 fire season was long and intense and the impacts of this event will have long-lasting but uncertain impacts for the communities and ecosystems of this region. Climate change is predicted to increase the frequency of these extreme fire years and as such, governments and communities must build the knowledge and capacity to adapt to these changing conditions. Presently predictions about the behavior of fires and their impacts on the affected ecosystems are based upon our understanding of more southerly boreal forests; there is thus a pressing need to improve our understanding of the response of high latitude boreal ecosystems to fire. The 2014 fires presented a unique opportunity to address important knowledge gaps across a diverse range of ecological conditions and levels of burn severity in the southern NWT. During the summer of 2015, a diverse team of researchers (outlined below) came together to establish a network of permanent sampling plots in fire scars from 2014. These plots are unique in that they provide a co-located set of measures of fire severity (canopy and soil), permafrost conditions, pre-fire stand age and structure, detailed characterization of post-fire soil conditions (residual organic matter, soil carbon content and loss, bulk density, and nutrient status), and post-fire vegetation recovery, which will provide novel insights into the impacts of the 2014 fires.

3. Research objectives:

1) Quantify fire severity across the wide range of burning conditions from the 2014 fires and link this with pre-fire site conditions. We expected that there would be highly variable consumption of fuels based on the long fire season with later season fires leading to large consumption of aboveground fuels and organic soils.
2) Determine the role of fire severity in dictating post-fire forest successional trajectories. We expect that severe fire and/or short fire return interval will:
    a. remove the organic layer exposing mineral soils and facilitate deciduous regeneration
    b. reduce or eliminate seed/cone banks thereby slowing recovery of trees
    c. damage belowground structures that facilitate resprouting thereby slowing rates of regeneration
3) Assess carbon combustion that occurred during the 2014 fires and determine to what extent severe fire years are releasing legacy carbon (carbon age > stand age). We expect that soil moisture conditions will dictate the loss of legacy carbon from the system.
4) Measure the immediate and ongoing changes in permafrost conditions and how/whether permafrost systems respond differently to fire (fire severity, successional trajectories, loss of carbon). We expect that sites with warmer permafrost pre-fire will experience complete permafrost degradation

due to the loss of "ecosystem protection". We also expect that these changes in permafrost conditions have the potential to alter forest successional pathways.

4. 2015 Research Team:

Principal investigators: Jennifer Baltzer (Wilfrid Laurier University), Jill Johnstone (University of Saskatchewan), Merritt Turetsky (University of Guelph), Michelle Mack (Northern Arizona University), Antoni Lewkowicz (University of Ottawa), Steve Cumming (Université Laval)

GNWT: Tyler Rhea (CBI measurements)

Postdoctoral Fellows: Nicola Day (Laurier), Xanthe Walker (Northern Arizona University)

Students: Jean Holloway (Ottawa), Kirsten Reid (Laurier), Alison White (Laurier), Mara McHaffie (Guelph), Talia Plaskett (Guelph), Quinn Decent (Guelph)

5. Field methods: Between June and August of 2015, we sampled 214 plots in seven separate 2014 burn scars across the Taiga plains and the Taiga shield (Fig. 1). Within each burn, geospatial data was used to define a domain of inference for sampling. Within that domain, we randomly sampled the landscape with a view to enabling later up-scaling of field-based measures for the purpose of parameterizing models of land cover change associated with fire in the NWT. Priority was to select fires accessible either by road or boat, with some necessary sampling by helicopter and floatplane (Fire ZF104). We constrained sampling to be within 1 km of highways or shorelines. Within each burn, a large number of random points were generated for available strata in each burn. These strata included: a) date of burn (based on MODIS-derived fire progression maps), b) pre-fire vegetation (based on Canadian Land Cover Classification [LLC05] information or, where possible leading species information from Forest Resource Inventory [FRI] data), and c) fire history (stratifying across fire history ensured that we captured a range of fire return intervals). We assessed soil moisture at each random point using the method outlined by Johnstone et al. (2008; Fig. 2). We then found at least one, but usually two, other points that were of a different moisture category and within 100-500 m from the random point. See Table 1 for information pertaining to number of plots within each strata and burn.

Each sampling plot consisted of two 30 m parallel transects that were 2 m apart and ran south to north (Fig. 3). Transects were permanently marked by placing wooden stakes and/or metal pegs at each end. At each plot we recorded latitude, longitude, and elevation with a GPS receiver using waypoint averaging, and slope and aspect with a clinometer and compass. Locations of all sampling locations are provided in the associated excel spreadsheet.

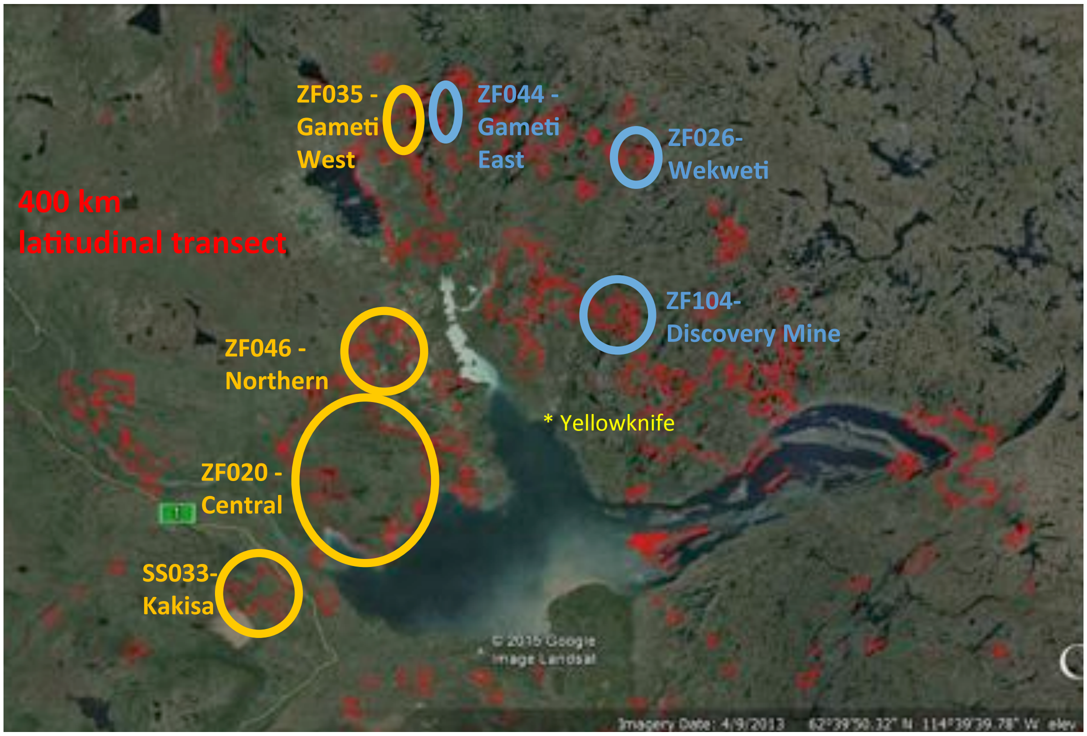

Figure 1. *Google earth image showing sampling locations spanning a 400 km latitudinal gradient. Taiga Plains and Taiga Shield fires are depicted with yellow and blue, respectively. Red outlines represent the perimeters of 2014 fires in the image area.*

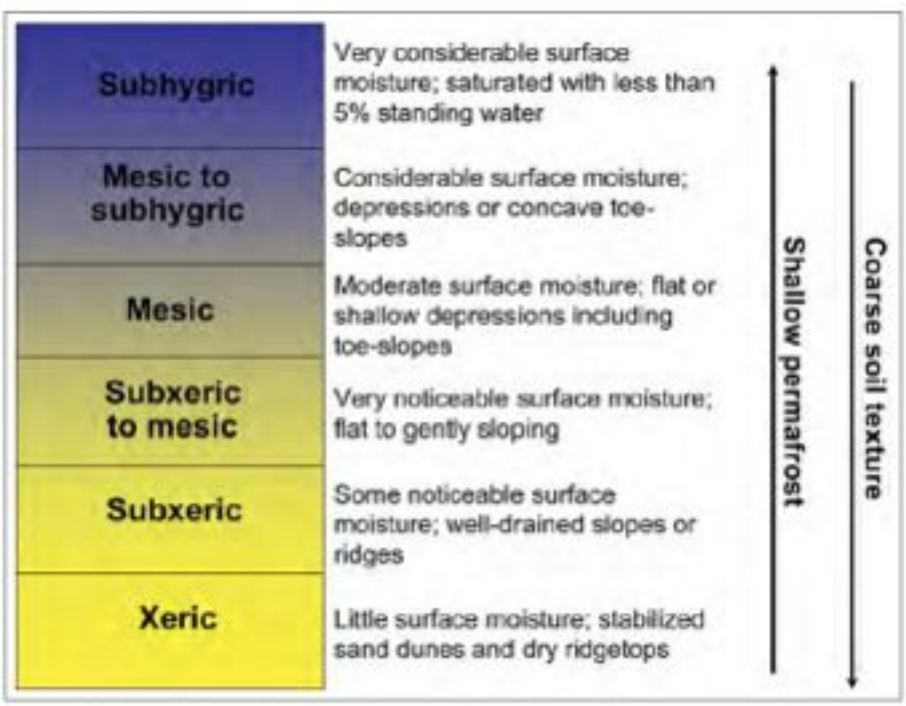

Figure 2. *Key to classification of site moisture used in 2015 sampling. At each sampling location, plots were set up across as much of this moisture gradient as we could capture within 500m. Reproduced with permission from Johnstone et al. (2008). For images of each category as sampled in 2015, please see Appendix.*

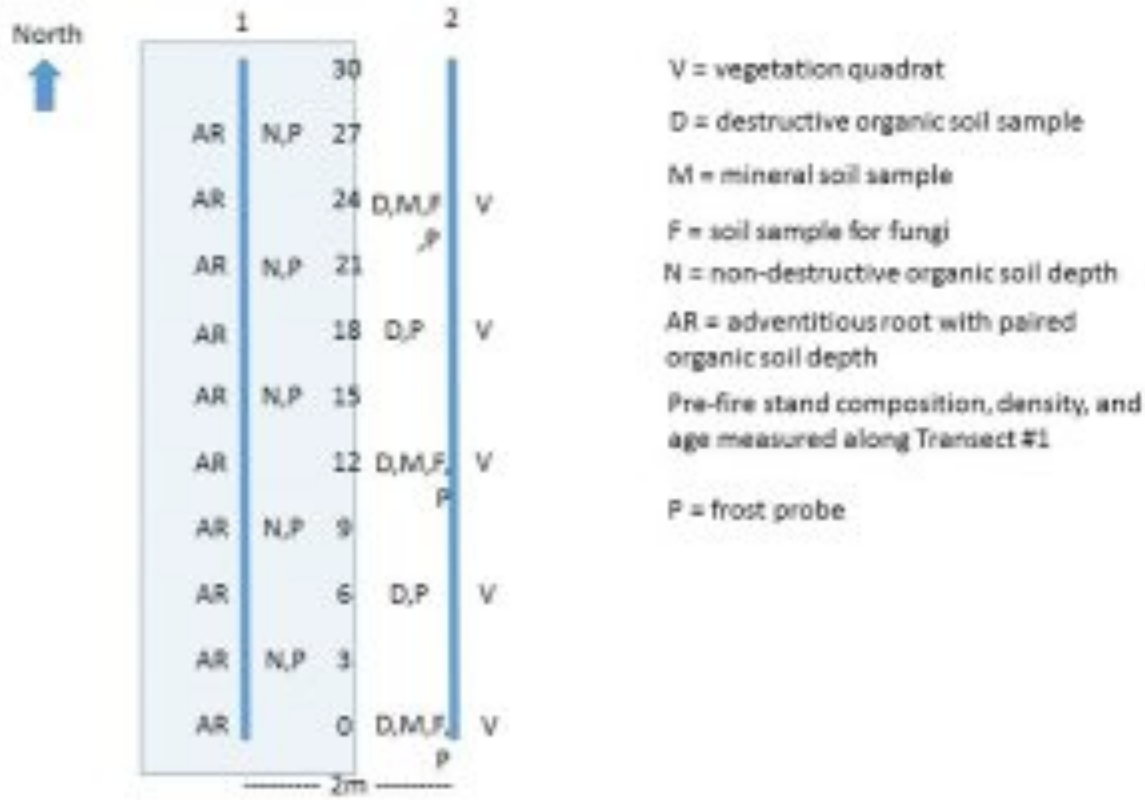

Figure 3. *Diagram of sampling transects that were established in 2015. Each plot consisted of two parallel transects. Transect 1 was used to characterize pre-fire stand structure and aboveground biomass consumption in a 2x30 m belt (blue shading). Along that transect, loss of organic soils was measured using the adventitious root (AR) method and non-destructive measures of residual organic layer thickness and maximum thaw depth were taken at six meter intervals. Along the second transect, paired soils (D, M, F), maximum that depth (P) and vegetation (V) data were collected as described in section. Soil profiles and destructive soil samples were collected for laboratory analysis. Methods are described in sections 5a – 5e.*

5a. Vegetation: Vegetation was assessed on the east side of the east transect. For this, a 1 m^2 quadrat was placed at five points along the transect (0, 6, 12, 18, 24 m; V symbol in Fig. 3; Fig. 4a,b). The quadrats were permanently marked by placing metal pegs in the southwest and northeast corner. Within each quadrat, we assessed covers to the nearest percent of organic matter, mineral soil, litter, charcoal, ash, water, scorched feathermoss, scorched lichen (divided into foliose, fruticose, and crustose), rock, woody debris, *Marchantia* (a common liverwort that colonises post-fire), *Ceratodon* (a common moss that colonises post-fire), and scat. We assessed plant regeneration by recording the presence of vascular plants, non-vascular plants, and lichens. We did not record percent covers of plants to avoid bias throughout the season, i.e. transects sampled later in the season were more likely to have higher plant biomass.

To assess regeneration of trees, we counted each tree seedling in each quadrat. This was done for both coniferous species (*Picea mariana*, *Picea glauca* and *Pinus banksiana*) and deciduous species (*Populus tremuloides* and *Betula* spp.). Each seedling was tagged by placing a marker immediately southwest of the seedling (Fig. 5a).

To investigate how plants regenerate post-fire in the NWT, the mode of regeneration for each vascular plant was assessed in the plot area. Each plant species was categorized according to one of four categories: regeneration from belowground, regeneration from aboveground, regeneration from seed, or survival intact. We endeavored to obtain this information for at least two individuals of each species per plot by excavating individuals and recording regeneration mode. Resprouting was the most common form of regeneration (Fig. 4c,d).

To assess seed rain and potential regeneration of trees, seed traps were laid at 25 black spruce-dominated plots in the road accessible Taiga Plains burn scars between 26 and 28 June. At each plot, traps were laid every 3 m between the two transects (10 traps/plot). Seed traps consisted of rectangular garden trays (52 cm x 22.5 cm x 7 cm) with a layer of Astroturf inside and secured in the ground with four nails (Fig. 5b). Contents of the traps were collected during 26 to 29 August and then reset to collect seed rain over the winter. These are to be collected in May 2016. Samples from 2015 are currently being sorted to obtain number and viability of all seeds present in the traps.

***Figure 4. Vegetation sampling methods**. A, B) 1 m^2 Vegetation quadrats; C,D) Shrubs resprouting after fire. Photo credits: N. Day (A-C); A. White (D).*

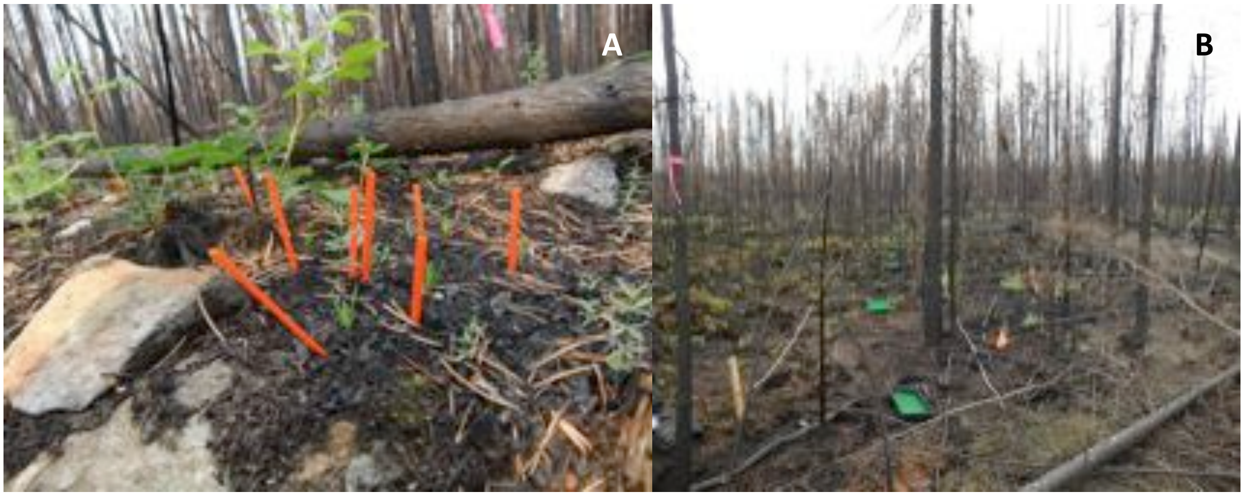

Figure 5. Vegetation sampling methods. *A) Pinaceae seedlings marked for monitoring; B) Seed traps in a sampled stand. Photo credits: N. Day.*

5b. Soil fungi: To assess soil fungal communities and heat-resistant fungi that may play important roles in plant regeneration, soil was collected from 79 burned transects at 0, 12, and 24 m. Soil was collected at two depths: 0-5 cm, and 5-10 cm. Samples were kept on ice and frozen within five days. Sampling equipment was disinfected between transects by wiping with Clorox wipes. Next generation sequencing (Illumina) will be used to determine presence and abundances of fungi in these soil samples and link this with regeneration potential.

To assess colonization by ectomycorrhizas on jack pine one year post fire, five seedlings were collected from the area around 12 transects where seedlings were abundant; six in ZF20 and six in ZF46. These seedlings were carefully dug out of the soil. Loose soil was shaken free of the seedling and then washed in tap water before being stored in 50% ethanol (Fig. 6B). Five more seedlings were collected from the transect area to assess rhizosphere fungi and culture ectomycorrhizas. For these, a core of soil was dug around the seedling and kept intact (Fig. 6A). These were stored on ice.

5c. Soil measurements: Soil measurements were made along both transects within each plot. Post-fire organic soil depth was measured every 3 m (10 points/plot; Fig. 7a, d). To assess soil C and N, we collected the full soil organic layer (SOL) profile at five points per plot, located beside the vegetation quadrats (Symbol D in Figure 3). An intact, approximately 5 cm x 10 cm, sample of the SOL was collected using a bread knife and pruners (Fig 7b,e). Dimensions of each SOL sample was recorded in the field for accurate measurements of bulk density of the soil. At three points per plot a mineral soil core (7 cm diameter) or grab sample of approximately the same diameter was collected below the SOL (Symbol M in Fig 3; Fig. 7d). Organic samples were immediately frozen until they could be processed in the laboratory at Northern Arizona University. Mineral soil samples were air-dried.

Fig. 6. Soil fungal sampling. *A) Jack pine seedling extracting in an intact core for transport to Laurier for ectomycorrhizal assessment using genomic methods; B) Jack pine seedling showing mycorrhizal colonization of its rooting system. These soil-free samples were preserved in ethanol for later quantitation of rates of colonization. Photo credits: N. Day.*

Figure 7. Soil sampling methods*. A) Excavation of a deep organic soil profile; B) Organic soil profile; C) Frost probing measurements; D) Shallow organic layer overlying mineral soil; E) Soil samples packaged for shipment. Photo credits: N. Day (A, B, D); X. Walker (E); J. Baltzer (C)*

In addition to the ten SOL depth measurements, we also measured SOL depth near the base of ten trees per plot (Symbol N in Fig. 3). The SOL depth was measured as close to the tree as possible. At the tree sampling points, we also measured the height from the top of the SOL to the highest adventitious root height (Symbol AR in Fig. 3) on 1-3 adventitious roots per tree. The adventitious root measurements allow for quantitation of loss of organic soil (i.e., carbon) from the site during fire as these small roots are produced as the moss layer grows upward (Boby et al. 2010).

5d. Stand measurements: In each plot, we measured the diameter at breast height (DBH; 1.3 m) for all trees ≥ 1.3 m in height and the basal diameter of trees < 1.3 m tall that were originally rooted within a 2 m x 30 m belt transect (shaded blue region in Fig. 3). Fallen trees that were killed by fire were included in this census. Trees that were dead at the time of fire, based on extreme charring, were also measured. Stem measurements were used to calculate tree density (number stems / m^2), basal area (m^2 per hectare), and above ground biomass (grams dry mass / hectare) of branches, leaves, and cones for each tree species encountered in the census. We also assessed tree consumption, where each tree was ranked from 0 to 3; 0=none, alive and no consumption; 1=low, only needles consumed, most small twigs and branches remaining; 2=moderate, with few needles and small twigs remaining but many branches; 3=high, most of the aboveground canopy except the central trunk and branch stubs consumed.

5e. Permafrost measurements: Depth of thaw was measured every 3 m (10 points/plot; Symbol P in Fig. 3) using a 1.2 m steel probe (Fig. 7c). These measurements were conducted as close to the end of the growing season as logistically possible to capture maximum thaw depth (from July 12 to Aug 26). All thaw depth measurement in the plains burn scars occurred in the last week of August. Thaw depth was not measured for two plots on the shield (ZF104).

In addition to these thaw depth measurements, detailed permafrost and energy balance information is being collected at a subset of the sampling locations. A total of 17 sites were set up in 2015, and a further three are planned for 2016. To track post-fire permafrost changes, we established climate and ground temperature monitoring stations coupled with direct current electrical resistivity tomography (ERT). Local climate is being monitored using shielded air temperature measurements every two hours at a height of 1.5 m above the ground surface using Onset HOBO 2-Channel Loggers (U23; Fig. 8). Ground temperatures are being monitored at every site using Onset HOBO 4-Channel External Data Loggers (U12-008) with thermistors installed at various depths in the active-layer and at select sites deeper into the ground following water jet drilling. Snow stakes mounted with iButton loggers were deployed to monitor snow accumulation at all sites, which is a critical component of the local energy balance. Early and late season ERT measurements were carried out at all sites along 160 m transects to establish the evolution of permafrost following the fires; these measurements will be repeated in 2016. This involves establishing arrays of 61 steel electrodes connected with cables. A current is sent between two electrodes while the resistivity of the material is measured. An ABEM terrameter LS was used and electrodes were set up in a Wenner array using a 2 m spacing, which penetrates the ground to a maximum depth of 25 m.

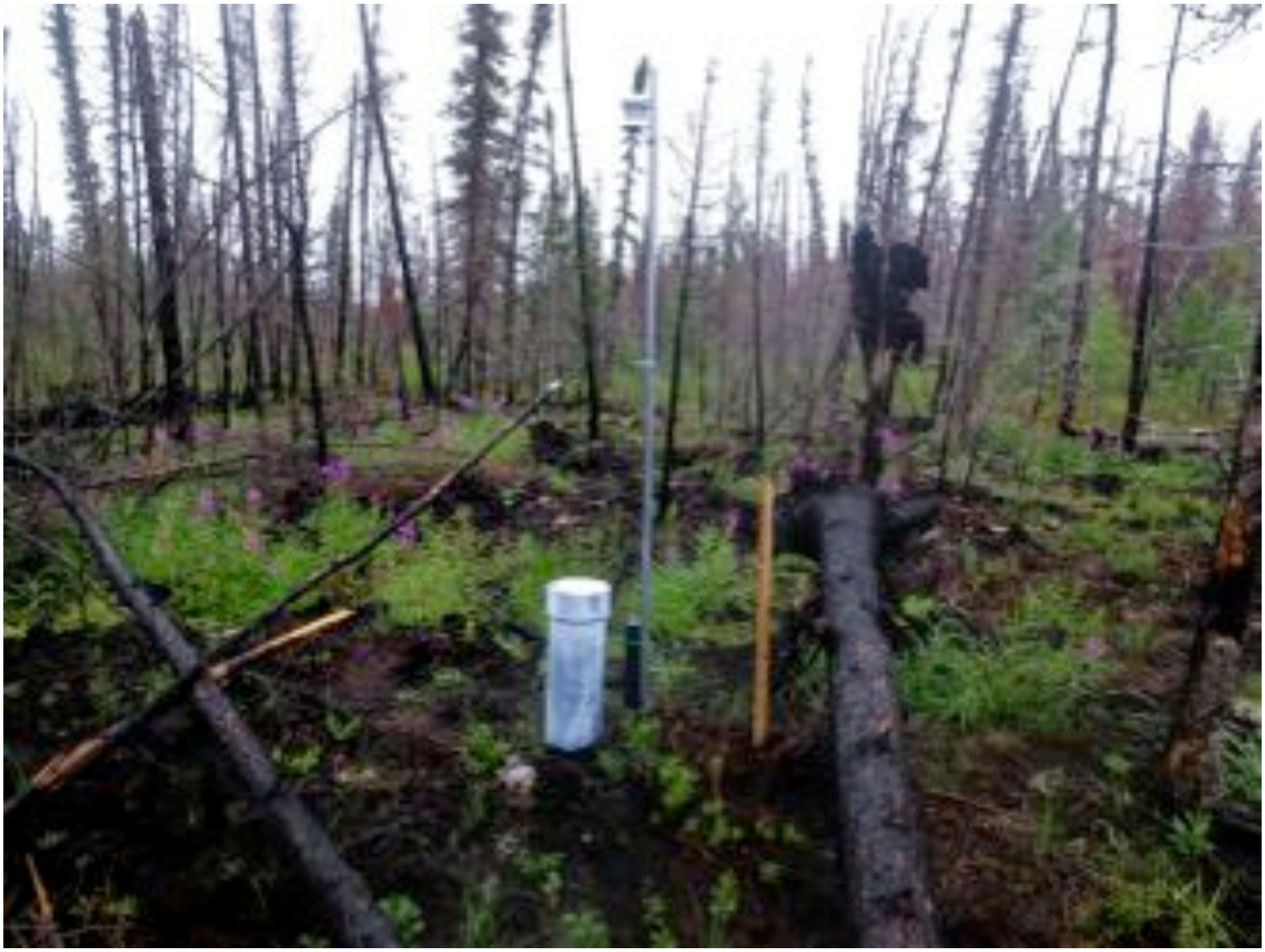

Figure 8. Permafrost monitoring station. *The image depicts a micrometeorological station recording air and surface ground temperatures. The white casing contains deeper thermistors measuring a vertical profile of permafrost temperatures. The wooden stake is equipped with ibuttons recording temperature continuously, which allow for the determination of timing, depth and duration of snowcover. This station was positioned in the middle of an ERT transect as depicted in figure 9*.

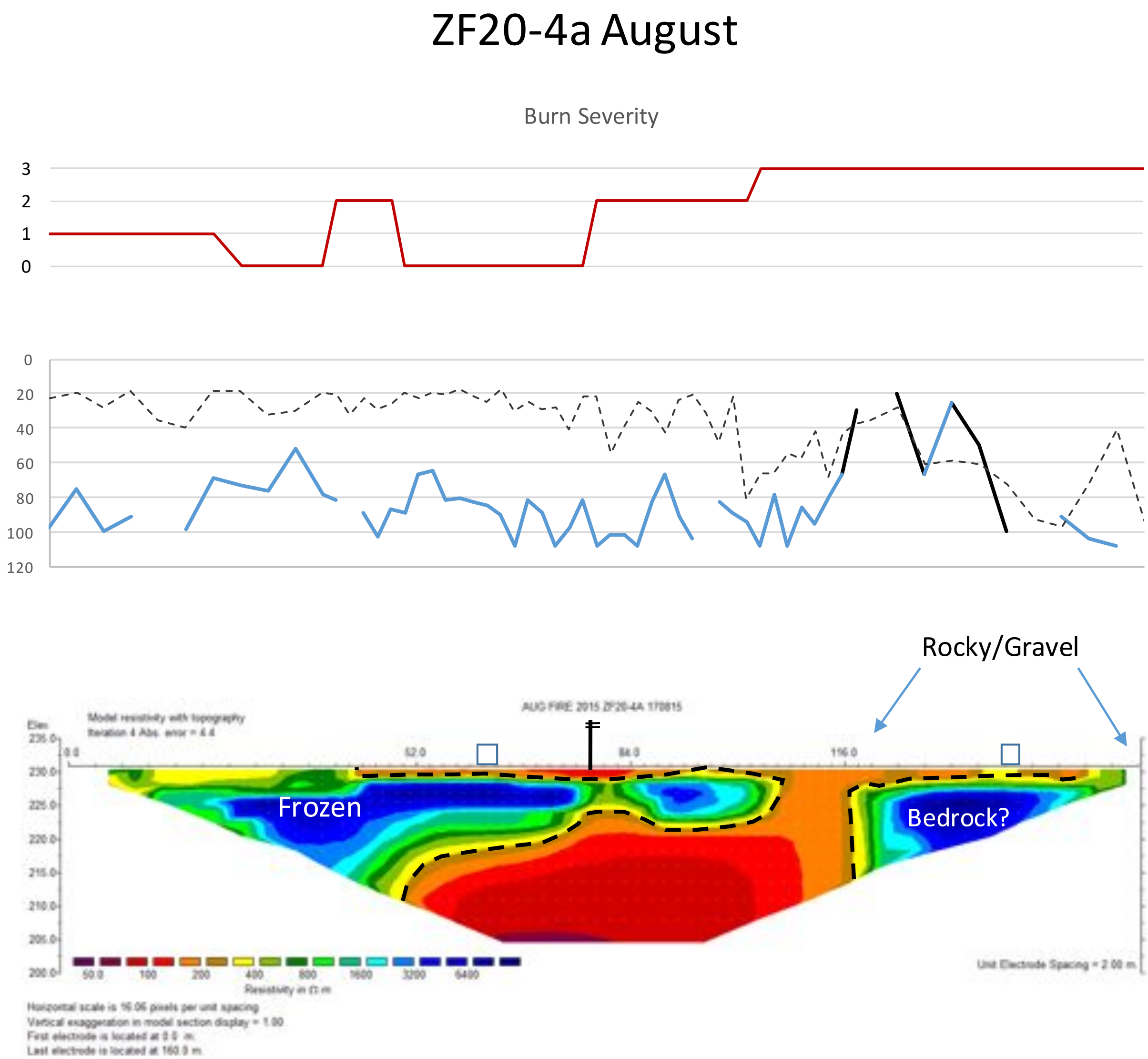

Figure 9. Example of an Electrical Resistivity Tomography transect. *Top panel: a burn severity index for the site across the 160 m transect. Middle panel: Results from manual frost table measurements with dashed lines indicating June frost table depths, the blue line shows maximum thaw depth measured at the end of August and the black portions correspond with points where the probe hit rock. Bottom panel: an ERT profile for the transect recorded on August 17, 2015. Cool colors correspond to high electrical resistivity, which can indicate ice or bedrock, while warm colors correspond to areas of low (thawed, moist areas). The weather station and ground thermal monitoring depicted in Fig. 8 are shown in the middle of the transect as a green box and a black tower.*

5f. Additional sites: Due to concern about the low number of peatland areas represented in our random sampling design (probably due to our requirement for these to be accessible), we selected areas to sample four plots from a 2013 burn (Sambaa Deh) and one plot from a 2011 burn (Jean Marie). We also sampled 11 plots in unburned areas (no obvious burn scar) to be able to calibrate our measurements of the burned plots.

Sambaa Deh (2013 burn): 2 plots in peatlands, 2 plots in mesic.

Jean Marie (2011 burn): 1 plot in peatland.

Unburned controls: 3 plots in Gameti; 3 plots in Wekweeti (Shield); 3 plots along highway 3 (Plains); 2 plots in Kakisa (Plains).

6. Sampling summary

In total, 230 permanent transects were established in 2015. Table 1 provides a summary of these sites, their distribution across fire scars, forest conditions, date of burn and fire history. These results are further summarized in Figures 10-12, which graphically depict sampling across several of the key contrasts.

Table 1. Sample site information. *Sample site selection was based on ecoregion, Canadian Landcover class information (LCC05 Class), date of burn (early, mid, late) and whether the site was a "reburn" based on fire history information (note that our tree ring based estimates of stand age will provide a continuous value of time since burn). Field-based leading tree species information is provided. Plots were stratified within sites across the moisture classifications depicted in Fig. 2. Note that where detailed Forest Resource Inventory (FRI) was available, leading species rather than LCC05 categories were used for site selection.*

Fire ID	Ecoregion	LCC05 class	Date of burn	Leading species	Reburn?	#Sites	#Plots
SS033	Plains	Conifer: medium	Early	Black spruce	N	4	12
		Conifer: Low	Early	Black spruce	N	2	6
		Conifer: medium	Early	Black spruce	Y	2	3
		Conifer: Low	Early	Black spruce	Y	2	4
ZF020	Plains	FRI available	Early	Black Spruce	N	4	11
		FRI available	Early	Jack Pine	N	3	9
		FRI available	Late	Black spruce	N	3	9
		FRI available	Late	Jack pine	N	4	10
ZF046	Plains	FRI available	Early	Jack pine	N	3	9
		FRI available	Late	Jack pine	N	3	9
		FRI available	Early	Jack pine	Y	3	9
		FRI available	Late	Jack pine	Y	3	9
ZF033	Plains	Conifer: Sparse	Mid	Jack pine/black spruce	N	3	9
		Conifer: medium	Mid	Jack pine/black spruce	N	3	9
		Conifer: Low	Mid	Jack pine/black spruce	N	3	9
ZF044	Shield	Conifer: medium	Early	Jack pine/black spruce	N	3	9
		Conifer: Low	Early	Jack pine/black spruce	N	3	9
		Conifer: Low	Late	Jack pine/black spruce	Y	3	9
ZF026	Shield	Conifer: Sparse	Early	Black spruce	N	3	9
		Conifer: Sparse	Early	Black spruce	Y	3	9
		Conifer: Low	Early	Black spruce	N	3	9
		Conifer: Low	Early	Black spruce	Y	3	9
ZF104	Shield	Conifer: medium	Mid	Jack pine/black spruce	Y	2	4
		Conifer: Low	Mid	Jack pine/black spruce	Y	2	4
		Conifer: medium	Mid	Jack pine/black spruce	N	4	8
		Conifer: Low	Mid	Jack pine/black spruce	N	4	8

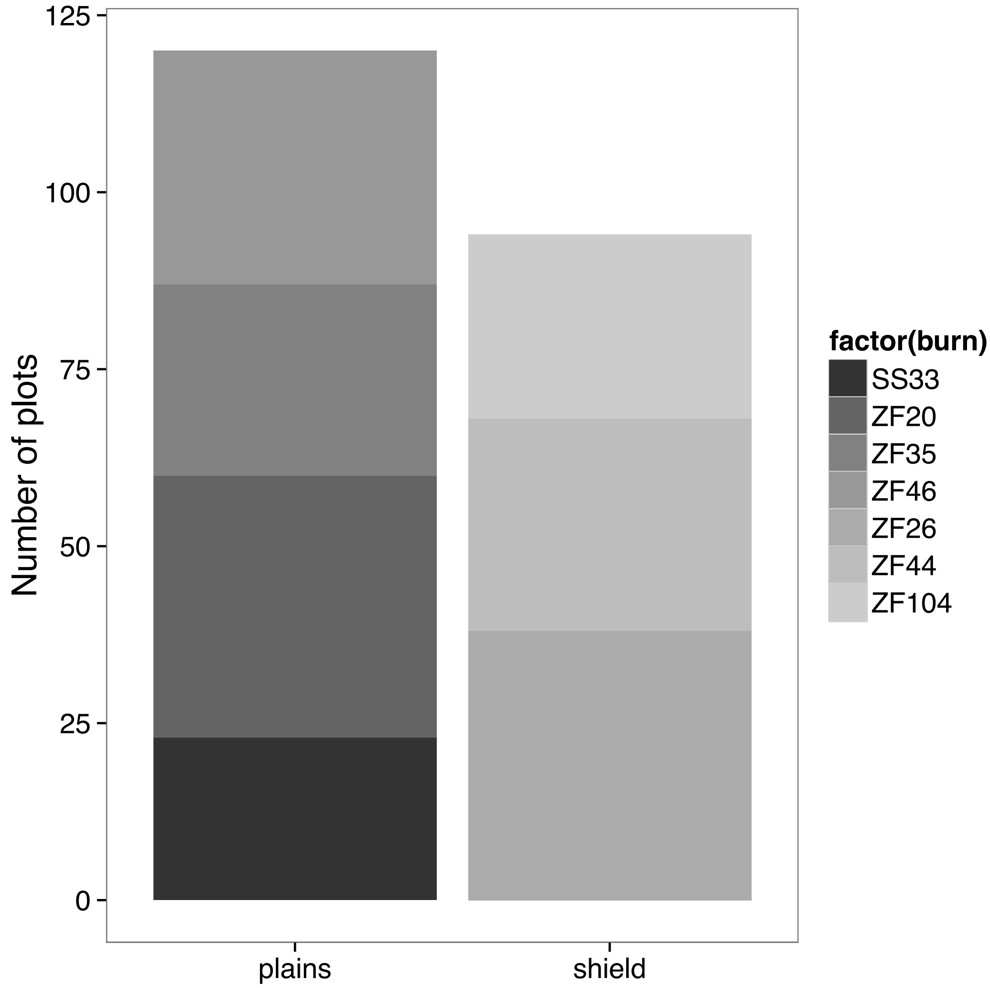

Figure 10. Sampling effort by ecoregion and fire. *Taiga Plains (plains) and Taiga Shield (shield) sampling effort (number of plots); greyscale corresponds to different fires as denoted in the legend. Details of the sampled plots are given in table 1.*

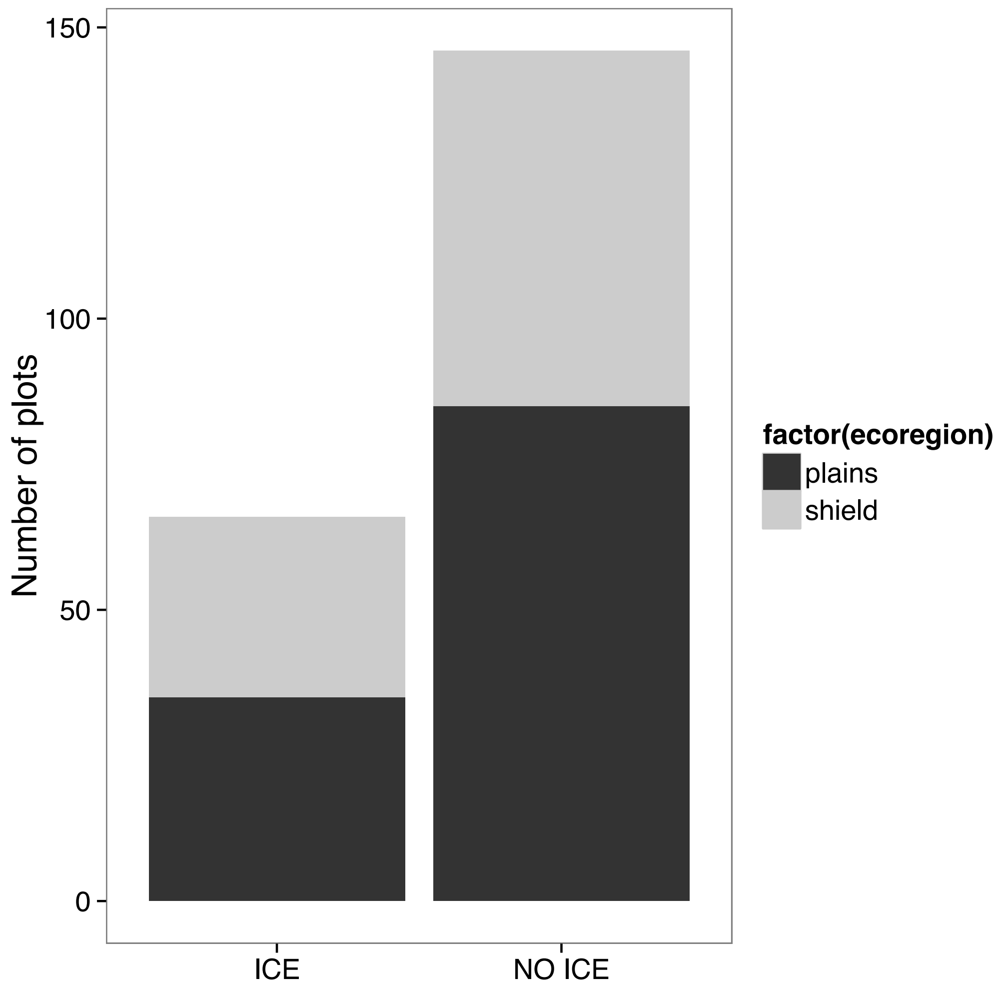

Figure 11. Frequency of near-surface permafrost sites within 2015 sampling. *Sites end of season ice (permafrost) are denoted by ICE while those in which we were unable to detect ice with a 2m frost probe or where rock was hit are denoted by NO ICE. Taiga Plains (plains) and Taiga Shield (shield) are differentiated with greyscale as denoted in the legend.*

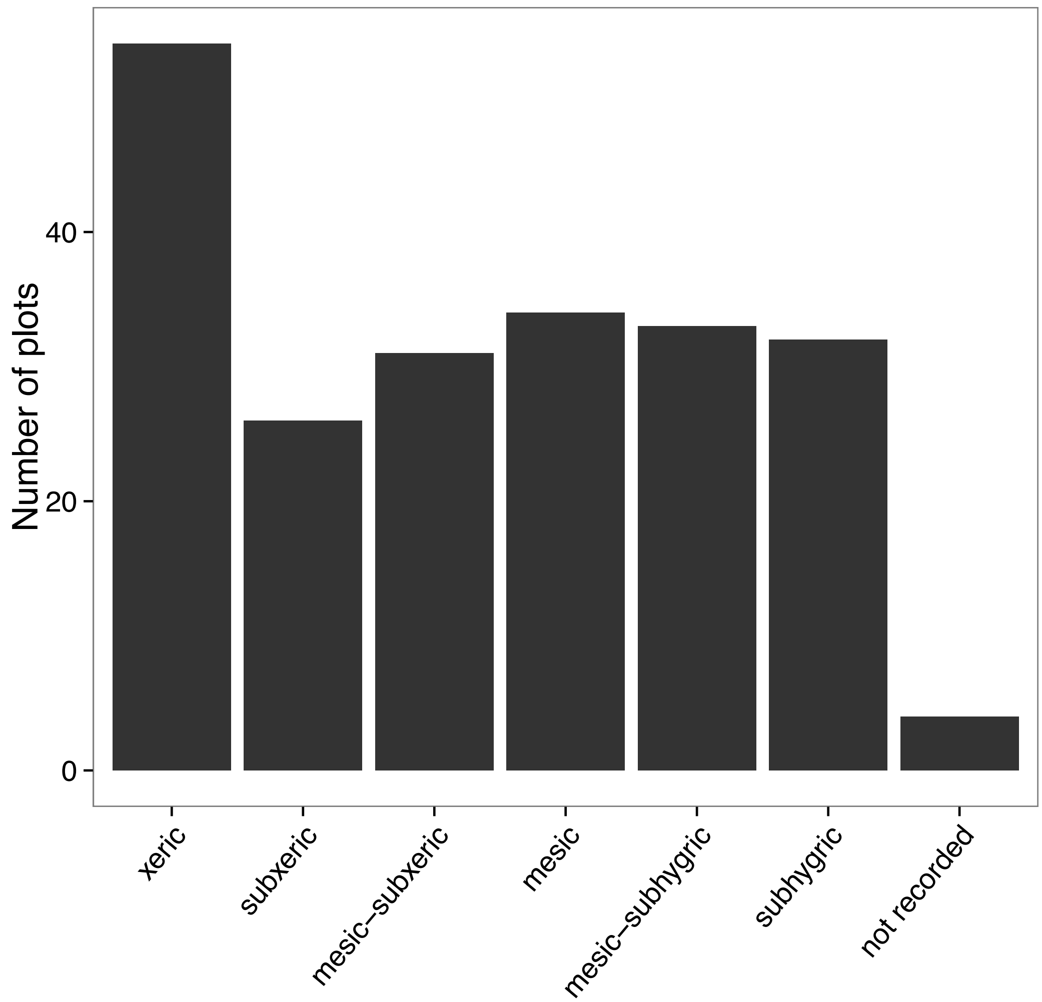

Fig 12. Distribution of sampling effort across moisture classes. *Moisture classes correspond to those described in Fig. 2.*

7. Summary of outreach and community engagement:

- We have been working closely with both the GNWT and the Wek'èezhìi Renewable Resources Board in the development of the research program
- During the field season of 2015 our crew worked with three communities: Kakisa, Gamètì, and Wekweètì. In each community, several community members were hired to facilitate the research for periods ranging from a few days to two consecutive weeks. The research would not have been nearly as successful were it not for this great community involvement.
- In August 2015, members of our team (Baltzer, Reid) were invited to attend the 10th Anniversary Celebration of the Tłı̨cho Land Claims Agreement in Behchokǫ̀. We shared a research display with Dr. Allice Legat who is conducting complementary Tłı̨cho Ecological Knowledge research on the return of caribou after fire. We had lots of great interest and discussions about the project while manning the booth and felt privileged to be part of this celebration (Fig 13).
- In August 2015, our crew hosted the Youth Leadership Summit, a ground of young adults from all three Territories organized by Ecology North. We spent a day with this group discussing the role of fire in the boreal and showing them the methods we were using to characterize the post-fire conditions. This was a huge success (Fig 14)
- In September 2015, the Wek'èezhìi Renewable Resources Board published an article on our research program on the WRRB website (http://www.wrrb.ca/news/impacts-wildfire-extent-and-severity-caribou-habitat-woodland-barren-ground)

- In January 2016, Baltzer will participate in the Dehcho Regional Results Workshop on behalf of the team and discuss fire research to date to communities.

Figure 13. *Allice Legat stands in front of a research display that jointly presented the Tłįcho Ecological Knowledge and western science approaches for tackling questions about recovery of caribou habitat following wildfire. Photo credit: Jennifer Baltzer.*

Figure 14. *Xanthe Walker (right) discusses properties of soils with the Youth Leadership Summit group at a fire site near Kakisa, NWT. Photo credit: Alison White.*

8. Future Field Plans:

The efforts described above are part of several longer-term, multi-investigator projects and as such sampling will be ongoing though with different foci. Some key areas of investigation for the coming summer include:

- Expansion of sampling into historic fire scars (1994/95, 1979/80, sites of older known fire history, and sites without a recorded fire history). This will provide key information about the rates of recovery of forests following fire in the NWT and associated changes in habitat conditions for caribou and other wildlife.
- Completion of soil calibrations. There is a need for additional unburned control sampling to calibrate our adventitious root measurements and carbon stock information in sites with no fire history.
- Establishment of seeding experiments. To better understand controls on tree seeding regeneration post-fire, we will establish seeding experiments in road accessible sites spanning the range of fire severity and in sites with and without permafrost.
- Establishment of sampling sites in holdover fires. The 2014 fire year resulted in several holdover fires that reignited in 2015. We know little about post-fire conditions in these holdover fires. Pending Polar Continental Shelf Project funding, we will access these sites and implement our transect protocol.
- Sampling of selected new 2015 fires in order to flesh out our range of sampling conditions. For example, we intend to sample the 2015 fire at the end of the Ingraham Trail to have a southern-most Taiga Shield sampling location and a road-accessible Shield site, which can be used for more high intensity monitoring.
- Ongoing permafrost monitoring and establishment of additional ERT and ground thermal monitoring sites. During 2016, we will also undertake permafrost coring to measure deep carbon stocks and ground ice content.
- Integration of field data into models of land cover change for improved prediction of changing forest cover under future scenarios of climate warming and altered fire regime.