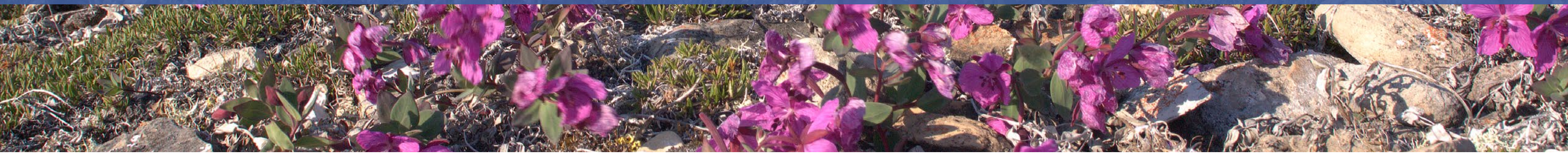
FIRE IN THE ARCTIC:

The effect of wildfire across diverse aquatic ecosystems of the Northwest Territories



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Abstract

During the summer of 2014, the southern Northwest Territories (NWT) experienced an unprecedented wildfire season, with burned areas spread across two ecoregions (the Taiga Plains and Taiga Shield) and a landscape underlain by a mosaic of permafrost coverage, vegetation type, and previous fire history. Our study was conducted across the Dehcho, Tłı̨chǫ-Wek’èezhii, and Akaitcho Regions of the NWT, which encompass the most significantly burned areas from the 2014 fire season. Within these regions, we worked in paired burned–unburned catchments on the Taiga Plains and Taiga Shield to examine responses to fire within ground and surface waters. We additionally examined water quality across a series of 50 catchments that were stratified across ecoregion and by fire history, and varied in within-catchment characteristics such as wetland extent. This sampling scheme — which covers as significant a range of landscape variability as possible — is allowing us to differentiate the effects of wildfire from other landscape variables that cumulatively impact aquatic ecosystem health. While wildfire had a clear effect on the chemical composition of pore waters, this effect was diminished at the stream outlet and at the landscape scale. Rather than having an overriding effect on water quality, wildfire appears to be one of many landscape variables that act in concert to determine water quality in the southern NWT.

Introduction

During the summer of 2014, the southern Northwest Territories (NWT) experienced an unprecedented wildfire season, with a burn footprint that spread across two ecoregions (the Taiga Plains and Taiga Shield), and a landscape underlain by a mosaic of permafrost coverage, vegetation type, and previous fire history (Fig. 1, 2). Our study was conducted across the Dehcho, Tłı̨chǫ-

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Wek'èezhii, and Akaitcho Regions, which encompass the most extensively burned areas from the 2014 fire season. We undertook a tiered *hillslope - to catchment - to landscape* approach to understand how the effects of fire cascade through aquatic ecosystems, from the smallest scale (hillslope pore waters) to the largest scale (the southern NWT landscape). To do this, we coupled intensive measurements of pore-water and stream-outlet chemistry in selected burned and unburned catchments with a series of extensive measurements across 50 catchments that varied by within-catchment fire extent, ecoregion, and characteristics such as wetland extent (Fig. 2). This design is allowing us to explore the mechanistic effects of wildfire on stream water quality, while also differentiating these effects from other landscape variables that cumulatively affect the characteristics of aquatic ecosystems.

Previous research has shown that wildfire can substantially alter the chemistry of downslope freshwater ecosystems. For example, combustion of organic layers and loss of vegetation can increase nutrients (Betts and Jones 2009; Fig. 2) and toxins like mercury (Kelly et al. 2006) but decrease organics (Betts and Jones 2009) in recipient aquatic ecosystems, although results can also be mixed (e.g., Olefeldt et al. 2013). Following wildfire, the burn scar is also more susceptible to permafrost thaw than adjacent undisturbed areas, because the loss of tree canopy allows greater energy loading at the ground surface, while the blackened ground also absorbs more energy. The resultant deepening of active layers can further affect the chemistry of water flowing from land to streams, as soils that were previously frozen become available for contact with water. In On the Taiga Shield, soils typically consist of organic horizons down to bedrock, with thin mineral soils. In contrast, deep peatlands are abundant on the Taiga Plains, but the underlying soil is composed of thick mineral tills. Thus, the effect of wildfire might be expected to fundamentally differ between these two regions, with increases in organics where deepening or lengthening flow paths enable access to organic soils, and increases in inorganic nutrients (e.g., nitrate and phosphate) and ions where water is routed through inorganic horizons. Deepening thaw can also encourage the establishment of *taliks* (i.e., a perennially thawed layer between the overlying active layer and underlying permafrost; Gibson 2017), which can enable the flow of water and associated chemical constituents throughout the year. These wildfire-associated changes in water chemistry are important because changes in within-stream concentrations of nutrients, organics, sediments, and contaminants may in turn alter the ecological functioning of freshwater systems (see, for example, Minshall et al. 2001, Allen et al. 2005, Kelly et al. 2006, Smith et al. 2011, and Silins et al. 2014).

Figure 1: Images of burned regions on the Taiga Shield (a; Boundary Creek) and Taiga Plains (b; Spence Creek); potential nutrient effects downstream of a burn scar (c; algal mats in Notawohka Creek that are not common elsewhere); and recovery from burn two years post-fire (d; stream draining to Lac La Martre, Whatì).

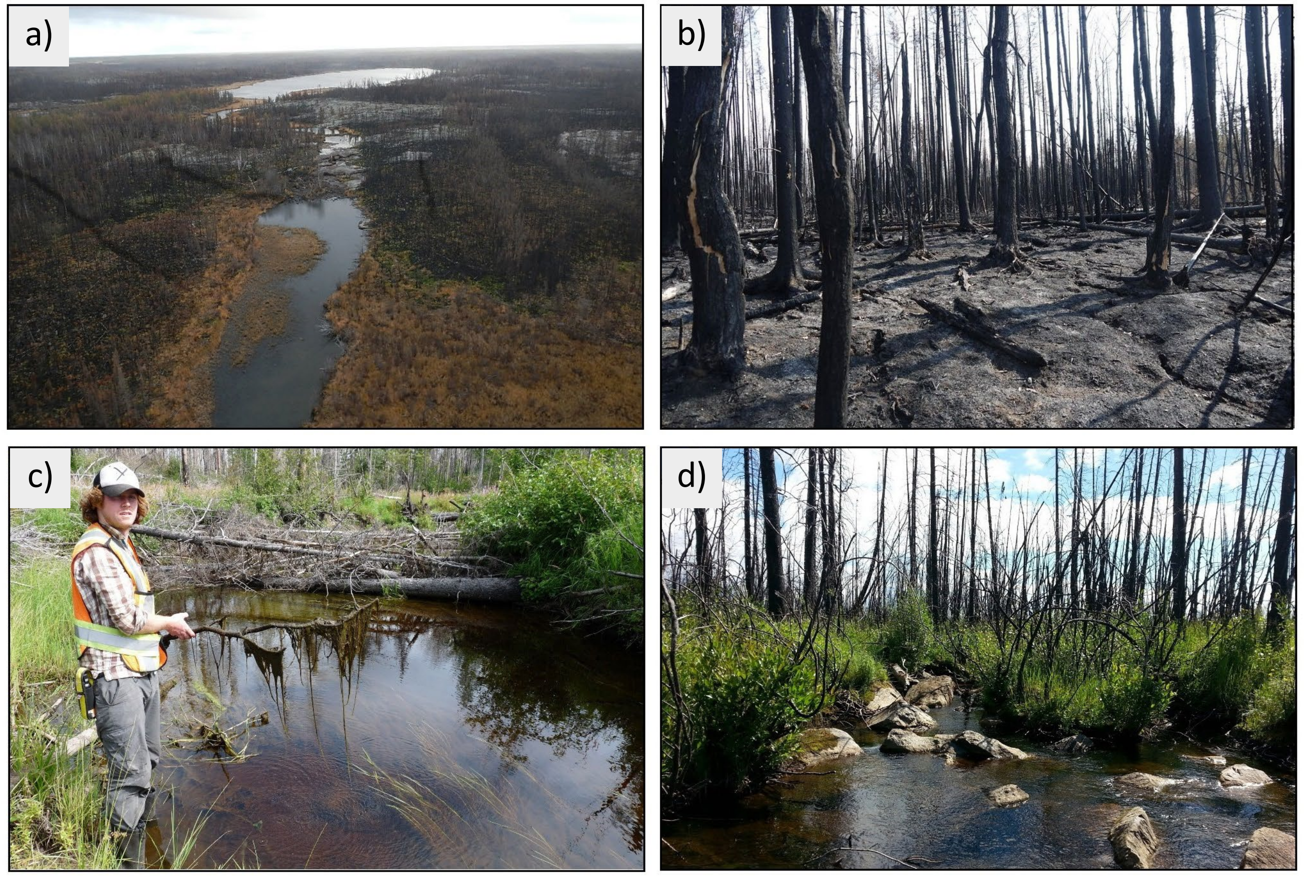
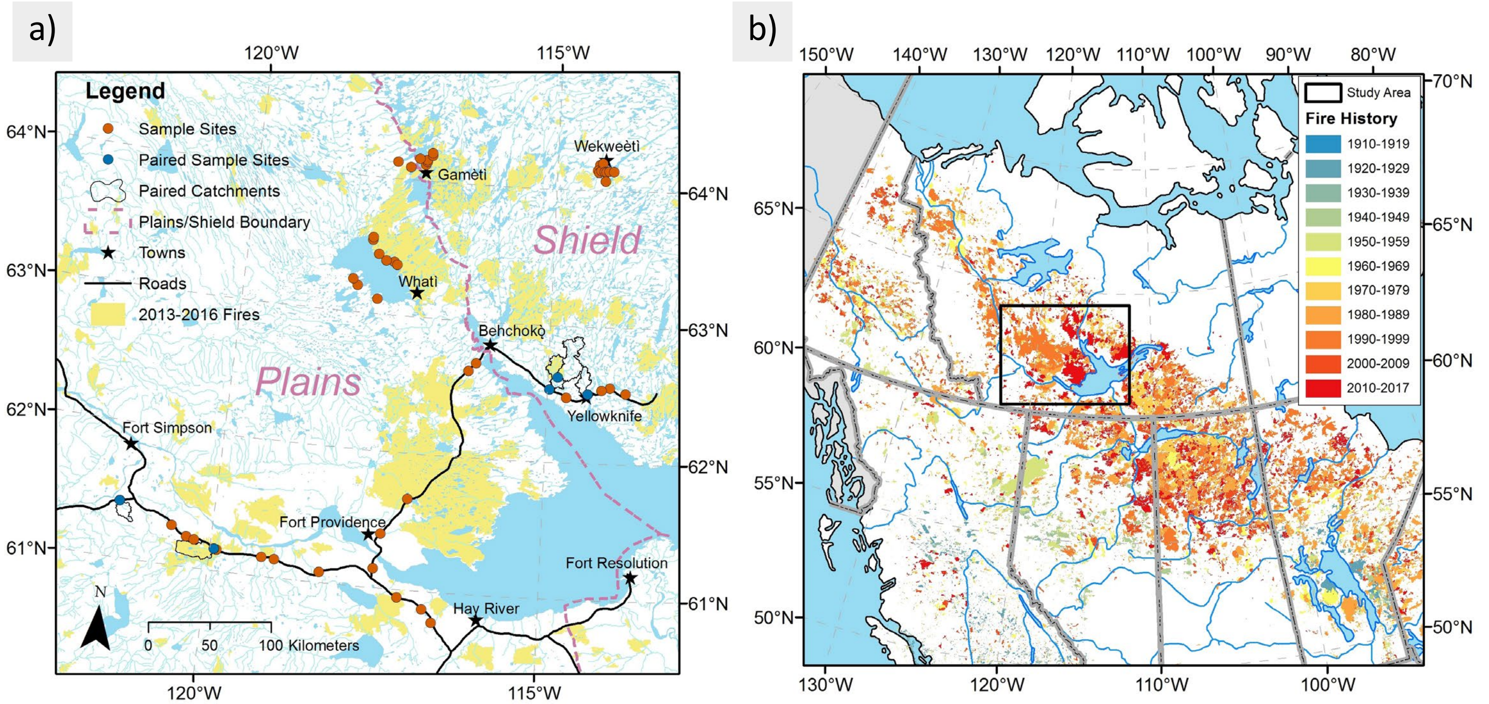


Figure 2: (a) Sampling locations superimposed on the 2013–2016 fire perimeters (the paired burned-unburned catchments that were the focus of our intensive measurements are indicated in blue; the 50 synoptic sampling locations are indicated in orange) and (b) Fire history for the region, with the more detailed area of panel (a) indicated by a box.



Although the influence of wildfire on water chemistry has been investigated in some northern hillslope systems and within small Subarctic catchments, including in Alaska (Betts and Jones 2009, Koch et al. 2014), it has been poorly studied in the NWT. This is of concern from an NWT-specific perspective, because the Subarctic landscape is composed of a diversity of region-specific landscape features, which may act cumulatively and in distinct ways to influence downslope water chemistry. Given that wildfire frequency is increasing in northern Canada (Kasischke and Turetsky 2006; Flannigan et al. 2009), it is imperative that we undertake region-specific assessments of its effect on aquatic and other ecosystem components. Such targeted assessments will help to predict how fire might affect aquatic ecosystems across diverse landscape types, and thus, also understand changes in natural resources (food webs, fish) and infrastructure (drinking water) that might result.

Methods

Our cascading *hillslope - to catchment - to landscape* design took a three-tiered approach. First, we worked within targeted burned and unburned sites on the Taiga Plains (Notawohka and Scotty Creeks) and Taiga Shield (Boundary and Baker Creeks; Fig. 2) to examine the effects of wildfire on ground temperature, snow accumulation, frost-table depth, and the chemical composition of water available for runoff downslope to streams (i.e., mobile pore water). Second, we undertook frequent measures of stream-outlet chemistry within these paired catchments, to better understand the fine-scale response of catchments to wildfire. Finally, we undertook a synoptic survey of 50 burned and unburned catchments (Fig. 2) during June-July of 2016 and May-June of 2017, with a subset of these catchments being additionally sampled in August and September of 2016. This work was carried out as a collaborative effort between academic researchers, Federal government scientists, and aquatic scientists from the Government of the Northwest Territories (GNWT). Residents of the communities of Jean Marie River, Fort Simpson, Whatì, Wekweètì, and Gamètì were also integral to project planning and sample collection, as outlined below.

To target water available for movement downslope, porewater samples were collected at the water table using MacroRhizon samplers (0.15 µm pore size; Rhizosphere Research Products, Wageningen, the Netherlands) (Burd et al. 2018) or by filtering water collected from pit samples (Sartorius 0.45 µm). Samples for this component were analyzed at the University of Alberta, either in individual laboratories or at the CALA-accredited (ISO 17025) Biogeochemical Analytical Service Laboratory (BASL). Our targeted paired burned-unburned catchments were sampled weekly for four weeks following the onset of flow in the spring, and monthly thereafter in each of 2015, 2016, and 2017. Paired catchment-outlet samples were collected using protocols established by the GNWT Water Resources Division, and the samples were analyzed at the GWNT Taiga Environmental Laboratory. Pre-existing (Baker Creek, unburned) and project-specific (Boundary Creek, burned) meteorological stations on the Taiga Shield collected air temperature, relative humidity, net radiation, wind speed, and rainfall, and were coupled with frost-table measurements in burned and unburned terrains in Baker, Boundary, and Scotty Creeks.

For our 50-site synoptic surveys, we accessed all possible streams located near Highways 1 and 3, and additionally worked with the communities of Whatì, Wekweètì, and Gamètì to access stream sites from the lakes on which these communities are located. Sampling locations were stratified across burned and unburned terrains. Chemistry samples were collected following standard protocols, field-filtered (pre-combusted Whatman GF/F filters, 0.7 µm pore size), and stored chilled, in the dark, for later analysis at the University of Alberta's BASL.

To allow us to calculate constituent export and normalize total constituent flux by watershed area (i.e., yield; Tank et al. 2012), we also measured discharge at each site. Of the four paired catchment sites, discharge data are actively collected by the Water Survey of Canada at Scotty and Baker Creeks. For Boundary and Notawohka Creeks, discharge was determined using in-stream pressure transducers and the development of stage-discharge rating curves. For the 50 synoptic sites, point discharge was measured concurrent with water chemistry sample collection using a FlowTracker2 hand-held Acoustic Doppler Velocimeter (SonTek Inc., San Diego, CA) and the cross-sectional area-velocity method.

Catchment boundaries were delineated from a 20-metre digital elevation model (http://geogratis.gc.ca), using ArcGIS (10.5) with the hydrology toolbox. Catchment-outlet coordinates acquired during sample collection were used as pour points for the delineations. Catchment delineations were used to derive catchment characteristics, including slope and percent cover of various landscape types (Canadian Land Cover, circa 2000 (Vector) - GeoBase Series). Catchment fire scar areas were extracted from National Fire Database GIS layers provided by the Canadian Forest Service.

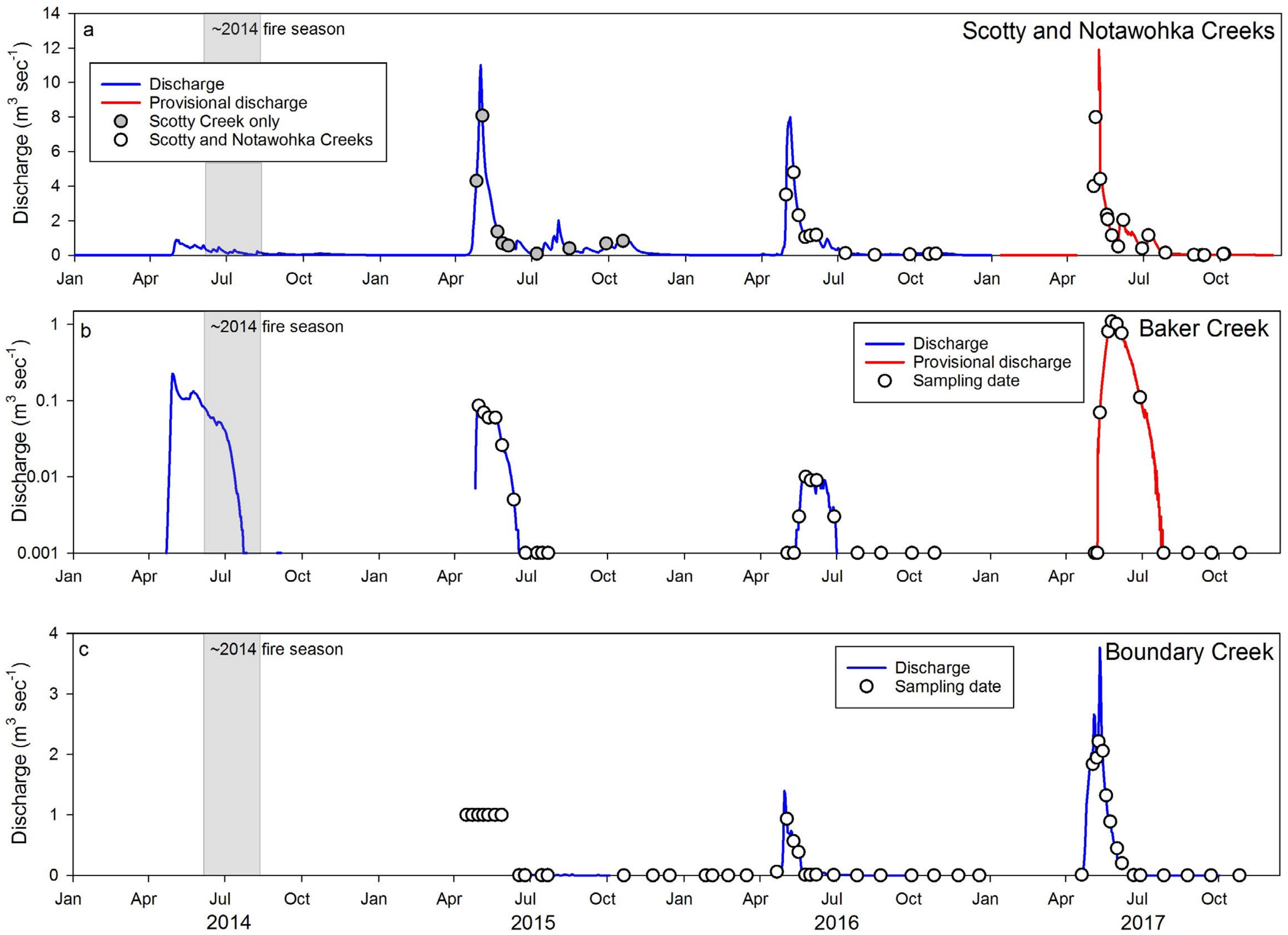
Preliminary results

Collaboration with government partners and community assistance allowed us to achieve strong temporal and spatial coverage in our sampling efforts. Our paired catchment work successfully captured initial spring flows in 2015, which represented the first runoff pulse following the 2014 wildfire season (Fig. 3). Subsequent sampling enabled excellent coverage of the spring freshet in 2016 and 2017, and continued collection throughout each of the three sample years in cases where flows continued under ice (e.g., Boundary Creek; Fig. 3). Our synoptic survey effectively captured a range of landscapes within each of the Taiga Plains and Taiga Shield. For example, the within-watershed coverage of lakes and wetlands varied from levels near zero percent to greater than 80% of the catchment, while mean catchment slope — an important regulator of water residence on the landscape — varied across a substantial gradient in each of the two ecoregions (Fig. 4). Wildfire-affected catchments were well distributed across these landscape gradients, and encompassed about half of the catchments surveyed. Shield and Plains regions differed in their proportion of lakes, wetlands, and mean catchment slope, following the underlying differences between these physiographic regions.

Burned and unburned sites clearly differed in their water chemistry at the plot scale, but these differences appeared to diminish with movement through the hydrologic network (Fig. 5). For example, using dissolved organic carbon (DOC) as a model chemical species, our results show elevated DOC concentrations in burned pore waters of the Taiga Plains (Fig. 5a), but that this signal dampens at the catchment outlet, where the increase in DOC export over the full season in paired burned-unburned catchments was much more modest (Fig. 5b). Across the 50 synoptic sites that were sampled mid-summer 2016, this difference disappears, with no overriding effect of wildfire on DOC concentration (Fig. 5c) across the wide variety of watersheds that we sampled (Fig. 4). This overall finding of weak to no effects of wildfire at the synoptic scale was consistent across other key water-quality parameters. For example, nutrients, which drive primary production at the base of aquatic food webs (total dissolved nitrogen; total dissolved phosphorus; Fig. 5d and 5e), and ions, which can be indicative of changing (deepening and/or transitioning to perennial) flow paths on land (using calcium as an example; Fig. 5f), also showed no difference between burned and unburned catchments. Although in some cases there were differences in chemical constituents between ecoregions (e.g., Fig. 5f), wildfire did not override other variable landscape characteristics to cause a clear effect on water chemistry across the synoptic sites that we investigated.

It is worth noting that the synoptic study results that we present were collected during relatively low-flow mid-summer conditions, when connectivity between streams and the landscape can be low, and also two summers following the 2014 burn season (i.e., for samples collected during summer 2016; Fig. 1d shows a typical catchment two years post-fire). Our paired catchment work did suggest that constituents including DOC, ions, and selected metals were elevated in the spring runoff period immediately post-fire (see, for example, the evidence of increased nutrients immediately post-fire in Fig. 1c). However, this effect was short lived. Across the southern NWT, it appears that wildfire is but one of

Figure 3: Sampling dates (circles) superimposed on discharge hydrographs for the paired catchment sites to show sample coverage across varying flow conditions: (a) Scotty and Notawohka Creeks sampling dates superimposed on the Scotty Creek hydrograph, (b) Baker Creek sampling dates superimposed on the Baker Creek hydrograph (note log scale), and (c) Boundary Creek sampling dates superimposed on the Boundary Creek hydrograph.



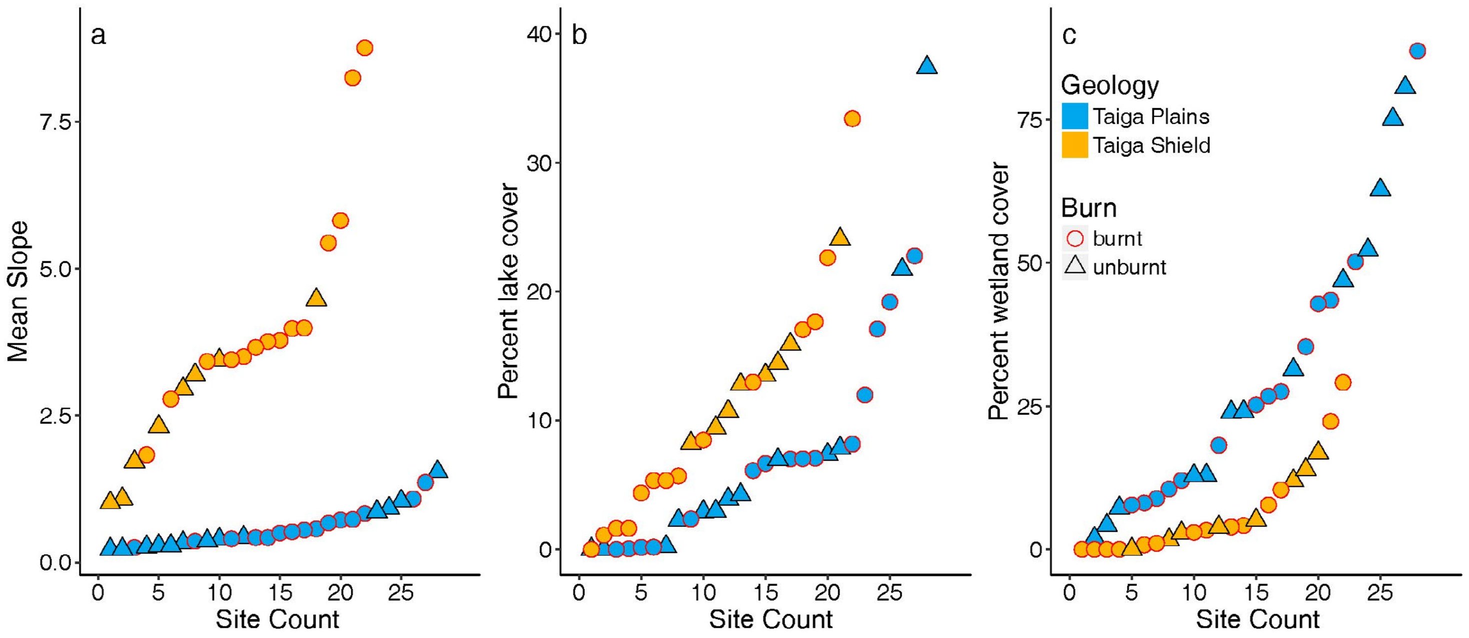


Figure 4: The distribution of synoptic sampling sites across a range of landscape conditions (each point shows an individual catchment): (a) slope, (b) percent lake cover, and (c) percent wetland cover for sites on the Taiga Plains (blue) and Taiga Shield (orange). Within each landscape type, burned sites are shown as circles outlined in red and unburned sites are shown as triangles outlined in black. Individual sample sites are ordered by increasing coverage of the within-catchment landscape condition; note the differences in scale on the y-axis.

many landscape controls on the functioning of aquatic ecosystems, and that this disturbance does not have an overriding effect on water quality at the multi-year scale.

Conclusions

The results of this project indicate that fire does not have a long-lasting effect on downstream water chemistry in streams across the southern NWT. This result is somewhat contradictory to studies from Subarctic Alaska and non-permafrost affected boreal regions in Alberta, which have shown clear effects of wildfire on stream water nutrients, organics, and toxins (Betts and Jones 2009, Kelly et al. 2006). Instead, this research may add to other emerging studies that are showing aquatic ecosystems to be relatively resilient to the effects of wildfire in their catchments (e.g., Lewis et al. 2014), and suggests that — over yearly time scales — the effects of wildfire are relatively small compared to other spatially variable drivers of water chemistry, and therefore difficult to differentiate from background variability.

Community considerations

The 2014 wildfire season burned 3.4 million hectares of land (Fig. 1). Because the area of disturbance was largely in the more densely inhabited southern NWT, fires affected the majority of NWT residents, resulting in road closures, multiple community evacuations, and significant concern about the ecological and human health effects of this catastrophic disturbance (Baltzer and Johnstone 2015). This concern led to a collaborative workshop that assembled Territorial government scientists and managers, academic scientists, and Federal government scientists. It was this workshop that was the genesis for this work. Our research occurred in direct collaboration with staff of the GNWT Water Resources Division, who helped with the study design and played a key role in field efforts. Their central involvement in these efforts has been critical for ensuring that Territorial priorities are being met as part of this research effort.

We used a variety of avenues to enable linkages between our research and local communities. Our sampling in the Tłįchǫ region (summers of 2016 and 2017) was facilitated by local community directors, and occurred in association with local guides who were instrumental in finalizing site-selection decisions and assisting with our access to local lands. Work in the Dehcho occurred in collaboration with members of the Jean Marie River First Nation who assisted with sampling a local stream (Spence Creek) that burned extensively during the 2014 fire. We have found these partnerships to be critical for ensuring that sampling efforts are appropriately targeting areas of concern. These linkages are also ongoing in associated projects.

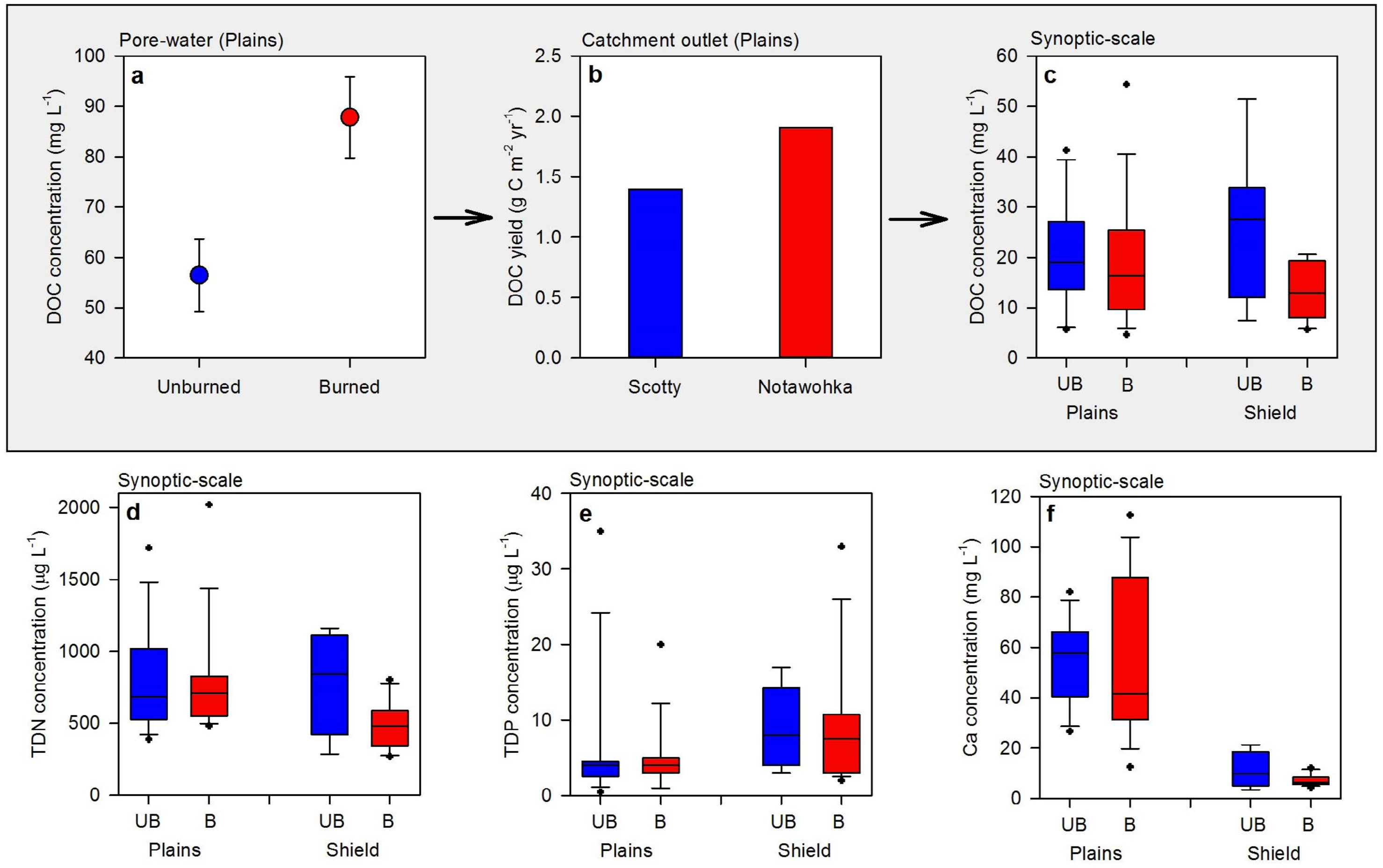


Figure 5: Constituent concentrations and yields (area-normalized exports) across burned (B) and unburned (UB) sites, for sampling at scales ranging from pore waters to the broad landscape: (a) pore-water concentrations of dissolved organic carbon (DOC) in burned and unburned plots of the Scotty Creek catchment; (b) catchment-outlet DOC yields for Scotty Creek (>99.8% unburned) and Notawohka Creek (>90% burned) through the entire 2016 season; (c) synoptic-scale DOC concentrations from across the 50 catchments for samples collected during summer 2016; and (d, e, f) synoptic-scale total dissolved nitrogen (TDN), total dissolved phosphorus (TDP), and dissolved calcium (Ca) concentrations, all from summer 2016.

Acknowledgements

This research would not have occurred without the assistance of community directors in the Tłįchǫ region (April Alexis and Shirley Dokum, Whatì; Gloria Ekendia-Gon, Gamètì; Adeline Football, Wekweètì) and Chief Gladys Norwegian in Jean Marie River. These individuals identified community members who were instrumental in guiding our use of local lands and assisting us to identify streams within each of the communities where we conducted this work. Wayne and Lynn McKay were also critical for our paired sampling on the Taiga Plains. In the Tłįchǫ region, we were fortunate to have Lloyd Bishop (Whatì), Alfred Arrowmaker (Gamètì), and William Quitte (Wekweètì) directly involved in our sampling efforts.

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