Ecological Recovery after Fire in the Tundra Plains Ecoregion

by Angel Chen

INTRODUCTION

THE ARCTIC IS WARMING AT TWICE THE AVERAGE global rate and mean summer temperature has increased significantly in more than 50% of the region (Serreze et al., 2000; Xu et al., 2013). Under warming conditions, disturbances such as fire are expected to become more common (Flannigan et al., 2006). Shifting fire return intervals are altering the structure and function of subarctic ecosystems, and an increase in the frequency of tundra fires is expected to have similar consequences (Flannigan et al., 2006). Unlike plants in subarctic forests, fast-drying Arctic vegetation such as mosses, lichens, and resinous shrubs do not require an extensive drying or drought period to become highly susceptible to fire (York et al., 2017). Fire causes a rapid change in physical, chemical, and biological properties and affects conditions both above and below the ground (Racine et al., 2006). There is limited understanding of the ecological significance of tundra fires (Wein, 1976), but as they are becoming more pervasive, research is required to better characterize ecological recovery following tundra fire.

Fire is an important driver of local and landscape-level change in tundra ecosystems, yet it is difficult to understand and predict how pre-fire vegetation composition affects ecological response (Racine et al., 2006; Morgan et al., 2014). Heterogeneous landscapes undergo non-uniform burns, causing some areas to burn severely, while adjacent areas may remain undisturbed (Allen and Sorbel, 2008). Burn severity is a term commonly used in fire research to measure the ecological change caused by burning and the subsequent response of ecosystems (Racine et al., 2006; Allen and Sorbel, 2008; Boelman et al., 2011). Burn severity and its contributing factors can vary considerably across location and scale (Morgan et al., 2014). As a result, burn severity and heterogeneity are rarely quantified and reported in the literature (Morgan et al., 2001).

Existing literature on tundra fires suggests that there are multiple recovery trajectories following fire. In some cases, tundra fire has resulted in a shifting community composition towards increased graminoid dominance (Barrett et al., 2012; Narita et al., 2015), as well as shrub dominance (Racine et al., 2004; Rocha and Shaver, 2011), which has led in some cases to the development of novel plant communities (Lantz et al., 2013). Racine et al. (2004) reported shrub cover density in the Seward Peninsula was higher than it had been in pre-fire conditions even two to three decades after fire, and Narita et al. (2015) found that the active layer was strongly correlated to vegetation structure 10 years after fire, suggesting that the impacts of fire on tundra ecosystems can persist over the long term.

Burn severity is an important metric in fire ecology for quantifying the ecological change caused by wildland fire (Racine et al., 2006; Allen and Sorbel, 2008; Boelman et al., 2011). The composition of tundra communities is spatially heterogeneous, and fires typically burn in a non-uniform manner, leaving some areas severely burned while adjacent areas may remain undisturbed (Allen and Sorbel, 2008). Tsuyuzaki et al. (2018) found that different vegetation communities developed in response to tundra fires of moderate and high severity.

This research aims to investigate how Arctic tundra ecosystems are responding to fire disturbance by evaluating the effects of tundra fire on plant community composition and environmental conditions. Specifically, I am testing two hypotheses: (1) that the effects of tundra fire would still be observable on the landscape six years after the fire as differences in vegetation structure between the burned and unburned areas; and (2) that the development of plant communities after tundra fire is controlled by burn severity. This article presents my observations and preliminary findings on the recovery of six tundra and forest-tundra sites that burned in 2012 in the Tundra Plains Ecoregion, Northwest Territories.

METHODS

Study Area

Field surveys were conducted in the Tuktoyaktuk Coastal Plain and Anderson River Plain Ecoregions of the Northwest Territories. Located within the Southern Arctic Ecozone and influenced by continental and coastal Low Arctic climates, the Tundra Plains Ecoregion is characterized by short dry summers and long cold winters (Rampton, 1988). The mean annual temperature is −11˚C, while the mean July and January temperatures are 7˚C and −28˚C, respectively (Ecosystem Classification Group, 2012). The mean annual precipitation is 130 – 190 mm in approximately equivalent quantities of rain and snow. Permafrost forms are continuous and variable in the Tundra Plains, and Cryosols are the main soil order (Ecosystem Classification Group, 2012). Vegetation is dominated by dwarf and low-shrub tundra on uplands and sedge-moss-shrub tundra in moist areas, with forest tundra present at the southern periphery (Rampton, 1988).

The six fires surveyed in this study burned in June and July 2012 (Fig. 1). Three of the fires were located within the Low Arctic tundra zone, where plant communities are dominated by dwarf birch, (*Betula glandulosa*), willow (*Salix* spp.), and various low shrubs. The three other fires were located south of the tree limit in the forest-tundra transition zone, where scattered spruce (*Picea glauca*) cover can also be present.

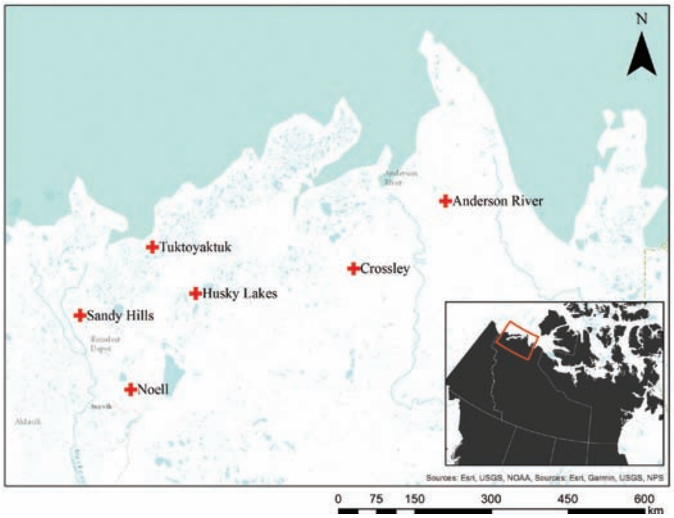

FIG. 1. Location of the six fire sites studied in the Northwest Territories.

Field Sampling

Using pre and post-fire Landsat imagery, a normalized burn ratio (NBR) was calculated for each fire to derive burn severity. Severity thresholds adapted from the three-class severity classification outlined by Epting et al. (2005) were used to define unburned, moderate-severity, and high-severity areas. Severity classifications were used to establish 180 plots, which were surveyed in June and July 2018. Each fire site contained 10 plots selected from each severity classification. Unburned plots outside of burned areas were used as proxies for pre-fire vegetation.

Field sampling was used to measure differences in plant community composition, vegetation structure, thaw depth, and soil chemistry between the severely and moderately burned areas and the unburned control sites. Nested 4 m^2 and 0.25 m^2 quadrats were used to sample the vegetation in each plot. Quadrats that measured 0.25 m^2 were used to estimate percent cover of dwarf shrub, graminoid, herbaceous, and nonvascular species, and the larger quadrats (4 m^2) were used to estimate percent cover of upright shrubs and trees and to measure soil chemistry, moisture, and thaw depth. Soil samples were collected and used to prepare pore water extracts for measuring electrical conductivity and pH. Soil moisture was measured both in the field by means of a handheld soil moisture probe and in the lab by oven-drying samples of known mass at 200˚C and then calculating volumetric water content. Thermistors attached to data loggers were deployed within a high-severity plot and an unburned plot at each fire site to record temperatures in the air, near the surface (5 cm), and at the top of the permafrost layer (100 cm) at two-hour intervals (Fig. 2).

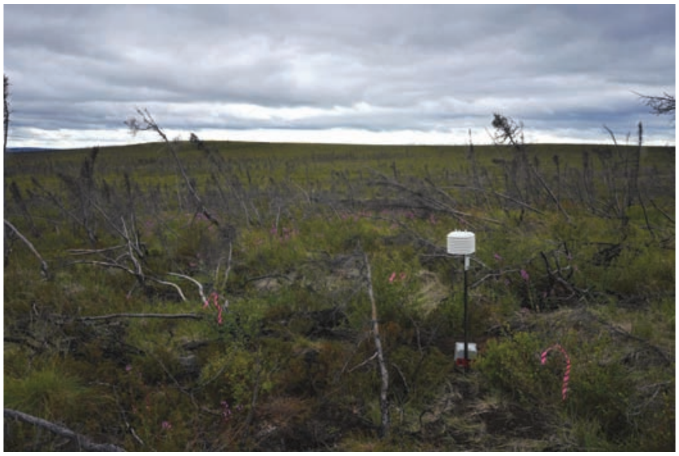

FIG. 2. Thermistors and data logger deployed to measure air, near-surface, and top-of-permafrost temperatures in a high-severity burn plot at a forest-tundra burn site.

Unmanned aerial vehicle (UAV) surveys were conducted to measure vegetation height, green vegetation fraction, and char index. At each site, a DJI Phantom 4 Advance multirotor UAV was used to survey each burn site at 1.5 cm and 5 cm resolutions to capture landscape-scale recovery characteristics. Five ground control points with known coordinates were placed for each UAV survey to increase GPS accuracy for post-processing using two Emlid Reach Global Navigation Satellite System Receivers (Fig. 3).

PRELIMINARY RESULTS

Six years post-burn, the impacts of fire on vegetation and soils were still visible at all six fire sites, but there was considerable heterogeneity within and between different classes of disturbance. Preliminary results indicate differences in plant community composition and soil properties between burn severity classes. In total, 37 species and families were encountered across the six fire sites. Diversity varied among the six fire sites: the highest diversity was found in unburned plots, and the lowest, in high-severity burn plots. Bare ground was most frequently observed in high-severity burn plots, where the organic layer was completely lost in some plots and minimal regrowth had occurred in the six years since the burn (Fig. 4). Vegetation in unburned plots was dominated by *Betula glandulosa*, *Vaccinium vitus-idaea*, *Ledum decumbens*, graminoids, *Empetrum nigrum*, *Eriophorum* spp., *Salix* spp., and *Rubus chamaemorus*. High severity plots were dominated by graminoids, *Betula glandulosa*, *Vaccinium vitus-idaea*, *Ledum decumbens*, *Eriophorum* spp., *Vaccinium uliginosum, Salix* spp., and *Epilobium angustifolium*. Cover of shrubs and lichens was lower in burned plots than in unburned plots, while the cover of bryophytes and graminoids was higher in burned plots than in unburned plots. *Epilobium angustifolium* was not present in any unburned plots, but was present in 12% of moderate- and high-severity burn plots. Ongoing analysis of UAV imagery and ecological data explores the relative influence of topography, burn severity, and soil properties on the nature and rate of ecological recovery.

FIG. 3. Emlid Reach used to log GPS coordinates of ground control points for unmanned aerial vehicle surveys.

FIG. 4. Bare ground in a high-severity plot at a forest-tundra burn site.

SIGNIFICANCE

Fire is an agent of change that is expected to become more severe under changing climate, resulting in more ignitions, longer fire seasons, and increased area burned (Flannigan et al., 2006). Unlike tree species, which require decades to centuries to dominate a landscape, tundra shrubs can proliferate and modify ecosystems more rapidly (Lantz et al., 2013; Epstein et al., 2014). Brown and Johnstone (2011) have recognized that changes in post-fire succession can further shorten the fire return interval and accelerate the environmental consequences of fire. Accurate prediction of fire activity and influence is a priority in resource management and research. An improved understanding of the importance of tundra burn severity is critical to these predictions (Morgan et al., 2014). By identifying the factors that control ecological recovery, my work will improve our ability to predict how more frequent tundra fires and changing fire dynamics will affect the long-term structure and function of Arctic ecosystems.

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