Appendix A:

Supporting Methods

Study area

The dominant forest type in the study region is black spruce (*Picea mariana*) forest, with additional parts of the forested landscape dominated by white spruce (*Picea glauca*), Alaskan paper birch (*Betula neoalaskana*), and trembling aspen (*Populus tremuloides*) (Calef et al. 2005). Characteristic of northern boreal forests, the region experiences a sub-arctic, continental climate with cold winters (mean January temperatures of -23°C and -26°C in Fairbanks AK and Dawson City YT, respectively) and relatively warm summers (mean July temperatures of 16°C and 15.7°C) (Shulski and Wendler 2007, Environment Canada 2011). The area lies within the discontinuous permafrost zone, and permafrost underlies many of the study sites, with the depth of the active layer depending on soil texture and other local site conditions (Brown et al. 2014). Texture of near-surface mineral soil ranged from predominantly silt loams deposited as fine grain loess in areas not recently glaciated (e.g. Eagle Plains, Dalton, and portions of the Steese burns) to coarser gravelly and sandy soil types derived from exposed bedrock, till and glacio-lacustrine deposits (Taylor and portions of the Steese burns).

Seed collection and application

Conifer seed was collected >1 year prior to the experiment, and stored in a freezer at -10 °C until use. Aspen seed was collected immediately prior to seeding (described below), and paper birch seed was collected in August 2005 and sown in field plots either later that same month (in Alaska) or stored in the freezer for later sowing in 2007 (in Yukon). In the spring prior to applying seeding treatments in the field, we performed lab germination trials so that sown weights of seed could be translated to a known amount of viable seeds (Table 2). Germination trials were conducted on a subset of seeds of each species (excluding TA, see below) prior to sowing. For each species, 50 seeds (20 for Yukon white spruce) were placed on moist filter paper in each of 10 petri dishes. Dishes were exposed to 18 hours of light per day under grow lights and were watered daily with deionized water. Spruce seeds were allowed to germinate for 28 days and AB for 7 days. Seeds were considered germinated when the hypocotyl grew to twice the length of the seed coat (Leadem et al. 1997). Seeds of BS, WS, and AB were applied to field plots in late summer, to approximate the timing of natural seed dispersal (Zasada et al. 1992). Treatments were applied 1-3 years after fire at all sites (2005 in Alaska burns and 2007 (BS) and 2008 (AB, WS) in the Eagle Plains burn).

Unlike the other species, seeds of trembling aspen disperse in early summer and lose viability quickly when stored, therefore seed needed to be collected and sown in the same year. Aspen seed was collected in early June of 2005, while seeds were still contained in dehiscing catkins. We collected opened catkins from tree branches, air dried the catkins for 2-3 days in the lab, and then separated seeds from attached plumes and catkin scales by tumbling seed plumes in turbulent air until most seed had fallen through a fine mesh sieve at the bottom of the tumbling chamber. Extracted aspen seeds were stored at 4° C in a refrigerator until sowing ~2 weeks later. Aspen seed requires only a few days to germinate (Zasada et al. 1992); we tested a subset of seeds for germinability in the lab during a one week trial with 50 seeds laid out on moist filter paper in each of 10 petri dishes. Aspen produced abundant seed in 2005 and we seeded it in the Alaska burns in mid-June, 2005. Aspen seed production was very low in subsequent years, and we were unable to collect enough seed to apply this treatment at the Eagle Plains sites.

Characterization of environment

The location and elevation of sites were recorded with a hand-held GPS. We estimated soil moisture availability at each site by taking spot measurements of volumetric soil moisture in the upper 10 cm of mineral soil with a hand-held moisture probe (HydroSense probe, Campbell Scientific, Edmonton, AB, Canada or ECH2O EC-TM probe, Decagon Devices Inc., Pullman, WA, U.S.A). Measurements were made only after at least two consecutive days without precipitation. Moisture readings were made in mid-summer at 5-10 randomly selected locations per site in at least two of the seed monitoring years, and then averaged to obtain a single site-level estimate. Moisture measurements made at the same sites were significantly correlated ($r \geq 0.75$) between years and with an independent assessment of site drainage categories (Johnstone et al. 2008). Moisture and other environmental data are publicly available on the Bonanza Creek LTER data catalogue (www.lter.uaf.edu/data_detail.cfm?datafile_pkey=342).

We measured the distance from the plot edge to the nearest seed source in a living stand (>20 live trees), either directly for stands <200 m away, or indirectly from satellite imagery for more distant stands. We then translated distances into a series of semi-logarithmic, ordinal classes to account for differences in measurement precision (e.g. Johnstone et al. 2009). To estimate species basal area, we recorded the diameter at breast height for all pre-fire trees over 1.4 m height, standing or fallen, that were rooted within two 2 m x 30 m parallel belt-transects at each site. Trees alive at the time of burning were distinguished from those already dead based on deep charring of the stem bole. Basal stem sections of 5 randomly selected trees at each site were sanded in the lab, and annual growth rings were counted under a binocular microscope or with automated WinDendro software (Regent Instruments, Inc., Quebec, QC, Canada) to estimate pre-fire stand age.

We measured the thickness of the post-fire soil organic layer at 6 (Eagle Plains sites) or 11 (Alaska sites) random locations per site along the destructive sampling transects shown in Figure A1. We used a shovel or soil knife to extract a 20 cm x 20 cm plug of surface soil, sectioned the plug vertically, and measuring the depth of the organic layer as the distance from the surface of the mineral soil to the base of the green moss or litter layer.

For each individual seeding plot, we measured the percent cover of 5 substrate classes: live moss (grouped into sub-categories of *Ceratadon*-, *Polytrichum*-, or *Marchantia*-type bryophytes), lichen, vascular plant litter, burned moss or organic soil, bare mineral soil, or bare rock. Substrate was defined as the ground layer or seedbed on which dispersed seed was likely to land. Substrate covers greater than 5% were measured in increments of 5%, and below 5% were measured in increments of 1%. Measures of substrate cover were made in July 2006 at the Alaska sites, and July 2009 at the Dempster sites. Preliminary correlation matrix analyses indicated that our measures of moss cover were highly correlated with our measures of SOL thickness and soil moisture (linear regression model $R^2 = 0.45$, $p<0.0001$; with parameter estimates for SOL: $p<0.001$; soil moisture: $p<0.001$). As we expected SOL thickness and soil moisture to be direct drivers of seedling emergence, we chose to exclude our measure of moss cover.

Literature Cited

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Table A1. Details on the four burns sampled in the study, including location, year of burn, number of sample sites, range in time-since-last-fire, and environmental covariates (mean and standard error). Raw data from the Alaskan sites are archived on the Bonanza Creek LTER data catalogue.

	Dalton (AK)	**Steese (AK)**	**Taylor (AK)**	**Eagle Plains (YT)**
Location coordinates (Approx.)	66°05'N, 150°03'W	65°11'N, 147°15'W	63°41'N, 142°18'W	66°07'N, 137°16'W
Year and size of burn (area in thousands of hectares)	2004 196	2004 218	2004 527	2005 69
Number of sample sites	14	12	13	16
Time since last fire (range in years)	70-100	65-175	30-175	14-155
Organic layer (cm)	6.2 (1.8)	8.4 (1.4)	9.7 (1.6)	4.0 (0.9)
Moisture (%)	38.7 (5.3)	33.3 (4.3)	45.2 (4.0)	33.9 (3.0)
Elevation (m a.s.l.)	334 (40)	452 (74)	793 (37)	628 (6)
Basal area (m^2 ha^{-1})	3.8 (0.9)	3.5 (1.0)	8.1 (2.1)	8.5 (2.3)

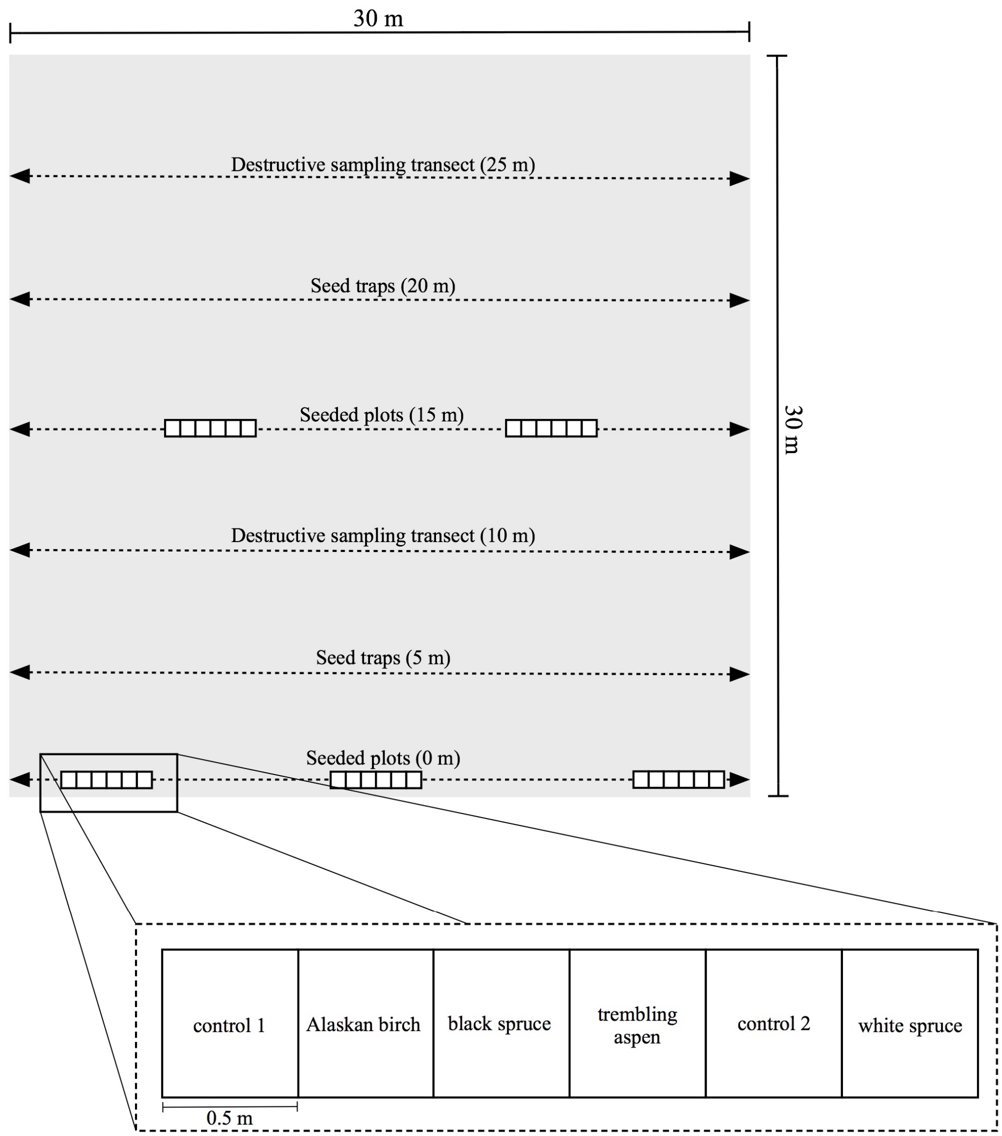

Figure A1. Schematic of experimental plot configuration showing the five blocks of seeding treatments within a site. Seeded blocks were placed along the 0 m and 15 m east-west transects. Species were randomly assigned to one of six subplots within each block, as shown in the example inset. Yukon blocks excluded 'control 2' and trembling aspen sub-plots. Sites in the Yukon differed as follows: a single seed trap transect was located at 15 m and the second seeded plot transect was located at 20 m. Destructive sampling at all sites included digging soil pits and sampling tree stem sections. Results from the seed trap transect are reported in Johnstone et al. (2009) and Brown and Johnstone (2012).

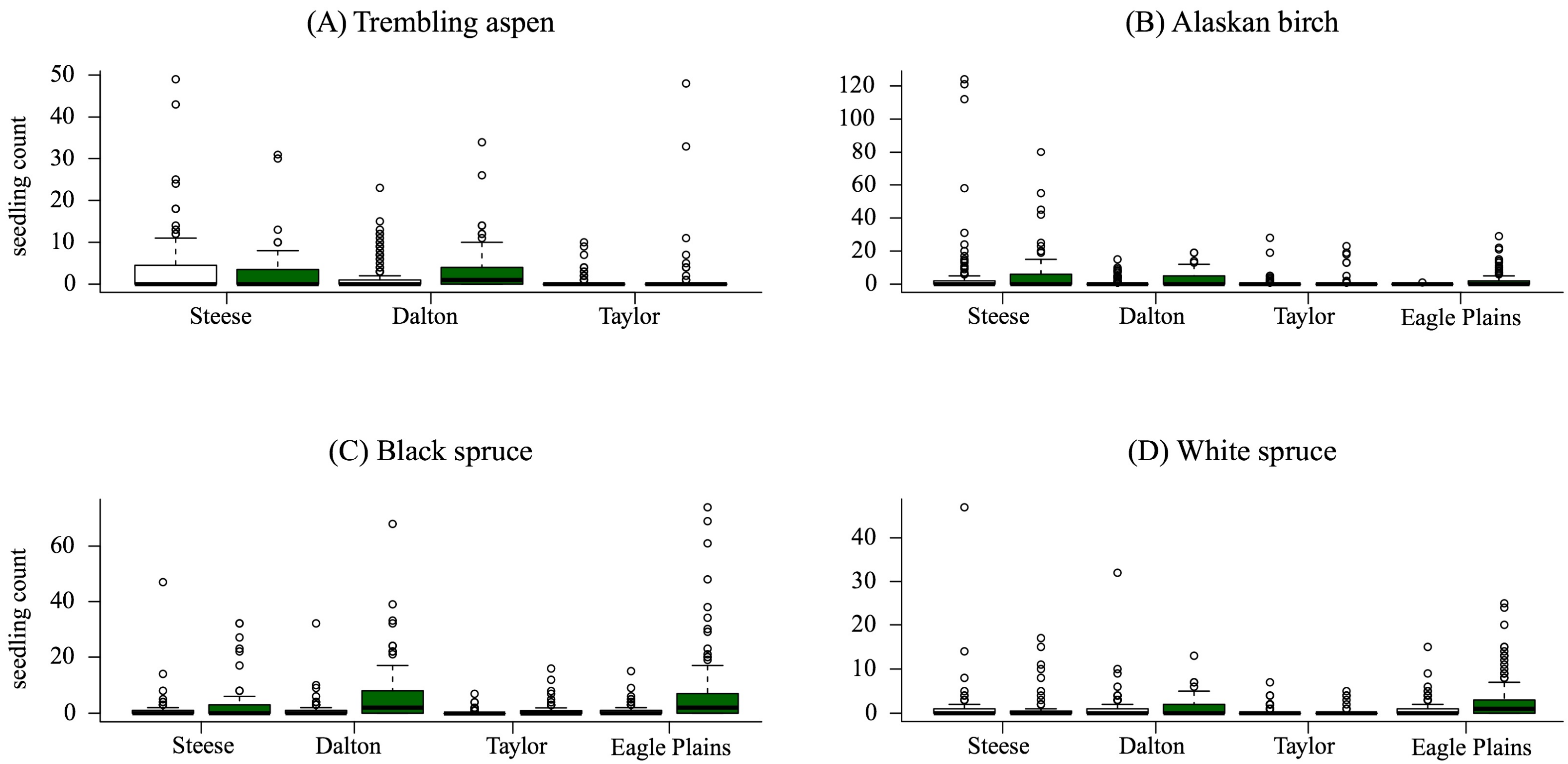

Figure A2. Boxplots of seedling counts of the four species used in the seeding experiments: A) trembling aspen, B) Alaskan birch, C) black spruce, and D) white spruce, separated into control (first box in pair, white) and seeded (second box in pair, green) plots within study regions. Regions are Steese, Dalton, and Taylor, Alaska, and Eagle Plains, Yukon Territory. Boxes enclose the second and third quartiles, with the median marked by a bold line and whiskers extending to 1.5 times the interquartile range. Additional circles mark points beyond this range.