

Effects of wildfire on revegetation in interior Alaska

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1. INTRODUCTION

Wildfires often take place in taiga, due to lightning (Engelmark 1999). The initial stages after the wildfires greatly determine the forest dynamics. In Alaska, ordinary wildfire has been crown fire that promotes taiga regeneration (Bonan & Shugart 1989), 'Crown fire' is that the ground- surface cover is incompletely burned.

Picea mariana develops aerial seedbank, and disperses more seeds after fire. In addition, *P. mariana* is adapted to establish wet and nutrient-poor habitat that is distributed more on north slopes in mountains (van Cleve et al. 1986). In discontinuous permafrost regions, the scenarios of succession differ between north and south slopes, due mostly to the presence of permafrost on the north slopes, and *vice versa*. Wildfire is likely to become larger and more intense (Dale et al. 2001). To predict large-scaled wildfire on revegetation, we have researched the followings: 1) Detecting plant community recovery patterns with different fire damages, and 2) Characterizing regeneration dynamics after wildfire, in particular, for tree species.

2. STUDY AREA AND METHODS

We selected a typical *P. mariana* forest on the north slope of Poker Flat, ca. 50 km north of Fairbanks, interior Alaska, USA, for monitoring revegetation, because of large and intensive fire, northward slope, and accessibility. Large wildfires stroke this region in summer 2004.

The field surveys were conducted in May (spring) and July-August (summer) in every year from 2005 to 2007. The total censuses were 6 times.

At the first census, we established 16 10 m × 10 m plots. Based on fire severities, plots were assigned as less-(L), moderately-(M), and heavily-(H) burned. Higher stem survival and moss cover characterized L. M was situated between L and H, i.e., most trees were dead but unburned plant cover remained somehow. H is totally burned, i.e., all stems were killed and > 80% ground surface was burned out. On each plot, we measured height and diameter at breast height (DBH) for all alive and dead stems ≥ 1.3 m in height, to reconstruct pre-fire forest structure. Therefore, fallen trees were included in the measurement. Outside the plots, 22 tree cores were sampled by a

borer or clippers in summer 2005.

Two seed traps (52 cm × 26 cm in surface area) were set up on each plot in summer 2005. Seeds were collected at every census. Seed germination test was performed in an incubator [15°C/25°C (12 hr/12 hr)] with continuous or 12-hr light.

In each plot, 6 1 m × 1 m quadrats were randomly set up. Canopy openness was estimated by photos taken on each quadrat at 1.3 m above the ground surface by a fish-eye lens in summer 2005 (Frazer et al. 1999). Albedo was measured on each quadrat (see Hydrology Team report), and duff thickness was estimated by a steel stake. At every census, vegetated area was estimated on each quadrat. The cover of each species was recorded on burned (hereafter, i.e., BS) and unburned (US) ground surfaces, separately, at summer census. When tree seedling was observed in the quadrats, the seedling was marked by a numbered flag, and was recorded on height, crown area and location. In summer 2007, > 20 seedlings for *P. mariana*, *Populus tremuloides* and *Betula neoalaskana* were excavated to investigate allometry on stem height and biomass.

(Generalized) linear models were used to detect relationships between dependent variables such as stem height and independent variables such as habitat and stem diameter. The differences in stem height and crown area were examined between habitats and between species by repeated measures ANOVA (Zar 1999). The numbers of captured and germinated seeds were compared between three habitats and between seasons by Tukey's test. Determinants on albedo were examined by a multiple regression with a backward procedure using incident radiation, canopy openness, burned area and plant cover. Allometric differences were compared by ANCOVA between habitats and between species.

3. RESULTS

3.1 Environments and fire severities

On the 16 plots, the altitude ranged from 244 m to 437 m, and the slopes faced 7.0°-43.5° from north to west with 4.8°-19.0° slope angles. Before the wildfire, 5-54 *P. mariana* stems ≥ 1.3 m, that accounted for 97% of total, had established in the plots, and 81% of them were burned and dead. The maximum height was 13.0 m. *Alnus crispa*, *B. neoalaskana* and *Salix* spp., established with low

frequencies. On the forest floor, the survived plant cover ranged from 0% to 100%, indicating that the floor was patchily burned with various scales and thus was suitable for this study.

The maximum age of tree cores was 174, and age was linearly correlated to stem height. The stem-diameter growth suggested that drastic events, such as fire, occurred 60 and 130-140 years before now. The forest regeneration before the 2004 fire was not simultaneously, and thus the previous fires were presumably crown fire.

The canopy openness ranged from 57% to 95% on the 80 quadrats. A forest unburned by the 2004 fire, of which height was comparable with the burned forest, had < 54% canopy openness. Plant cover on forest floor decreased down to 40% by the fire even on L, showing that the surveyed area received fire damage more or less. Duff thickness ranged from 3 cm to 73 cm, and was negatively correlated to burned area. The albedo was mostly determined by total plant cover, indicating that the albedo seemed not to return to the pre-fire conditions until vegetation cover becomes higher enough to reflect radiation.

3.2 Seed immigration on tree species

Seed traps constantly captured *P. mariana* seeds, of which total was 1069, until summer 2007 (Fig. 1). *B. neoalaskana* was second dominant in the traps, i.e., 756 seeds captured. The other seeds were recorded from forbs and grasses. *P. mariana* showed 21% seed germination percentage, except quite low percentage in summer 2007. *P. mariana* seeds immigrated even to H, showing that seed immigration was not restricted in the surveyed area.

3.3 Plant communities in herb layer

For 3 years, there were > 43 taxa, consisting of 31 vascular plants (4 trees, 13 shrubs, 12 herbs, and 2 ferns) on the 96 quadrats. As expected, *Sphagnum* spp. were predominant on US. Plant cover fluctuated little for trees, herbs and mosses on US,

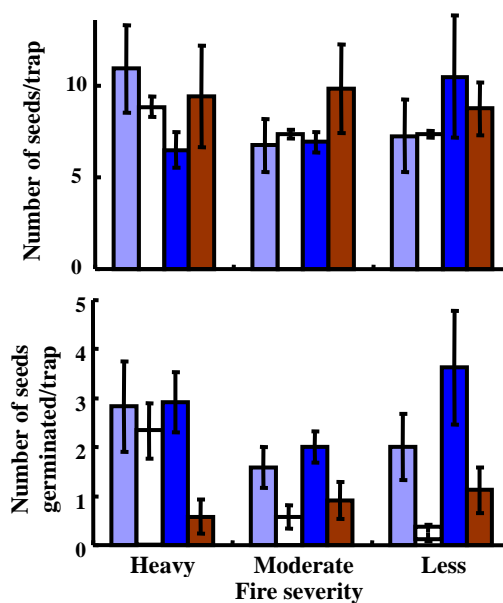


Figure 1. Numbers of *Picea mariana* seeds captured by seed traps, and germinated in lab-experiment. Mean is shown with SE. Duration: ■ = summer 2005-spring 2006, □ = spring-summer 2006, ■ = summer 2006-spring 2007, and ■ = spring-summer 2007. Number of captured seeds was not different between three fire severities (Tukey's test). The number of germinated seeds was different between seasons, and is not significantly different between severities.

while shrub cover significantly increased on both US and BS. By field observations, we confirmed that shrubs, e.g., *Ledum groenlandicum*, *Vaccinium vitis-idaea*, and *V. uliginosum*, came from legacies through the last fire. Since there were few seedlings on shrubs, vegetative reproduction was most important for shrub regeneration. Trees slightly increased in cover on BS, mostly by broad-leaved seedlings. Two herbs, *Epilobium angustifolium* and *Calamagrostis canadensis*, and a moss, *Ceratodon purpureus*, significantly increased in cover on BS.

3.4 Seedling emergence, survival, and growth

In total, 592, 509 and 79 seedlings emerged in

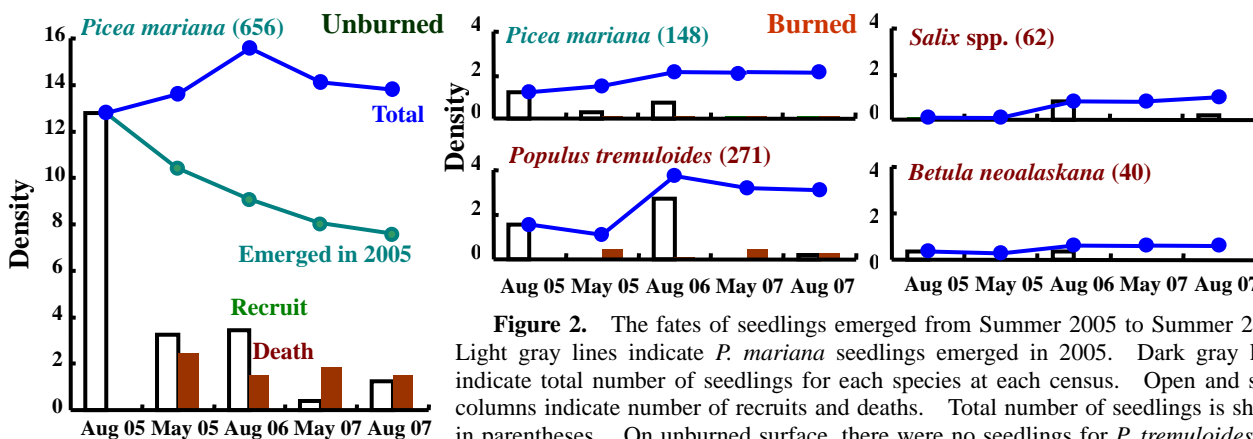


Figure 2. The fates of seedlings emerged from Summer 2005 to Summer 2007. Light gray lines indicate *P. mariana* seedlings emerged in 2005. Dark gray lines indicate total number of seedlings for each species at each census. Open and solid columns indicate number of recruits and deaths. Total number of seedlings is shown in parentheses. On unburned surface, there were no seedlings for *P. tremuloides* and *Salix* spp., and were 3 for *B. neoalaskana*.

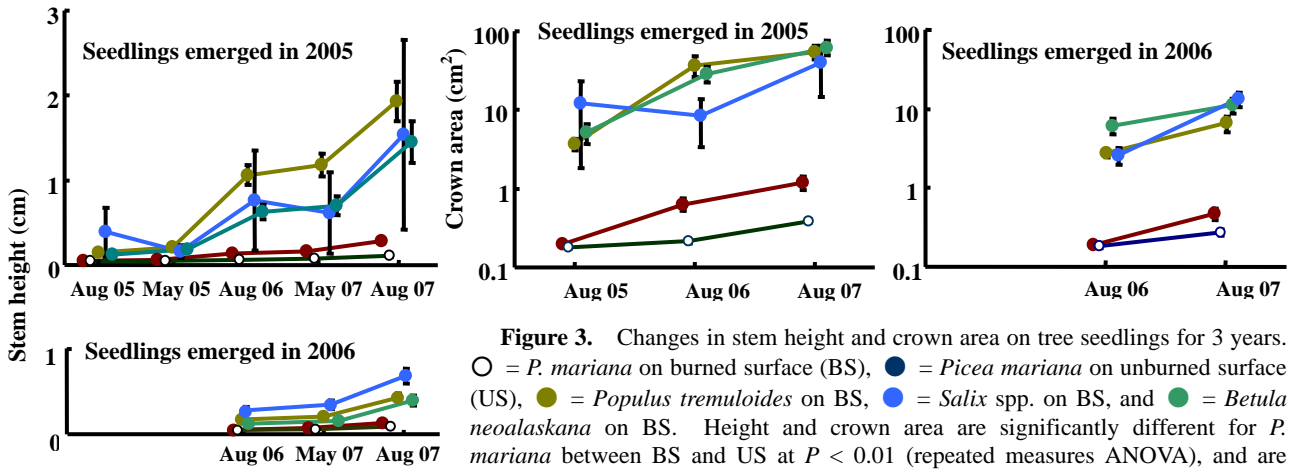


Figure 3. Changes in stem height and crown area on tree seedlings for 3 years. ○ = *P. mariana* on burned surface (BS), ● = *Picea mariana* on unburned surface (US), ● = *Populus tremuloides* on BS, ● = *Salix* spp. on BS, and ● = *Betula neoalaskana* on BS. Height and crown area are significantly different for *P. mariana* between BS and US at $P < 0.01$ (repeated measures ANOVA), and are different between *P. mariana* and broad-leaved trees at $P < 0.01$.

2005, 2006 and 2007, respectively (Fig 2). *P. mariana* was most abundant, i.e., 68% of total. *P. mariana* seedlings emerged more on US, i.e., 82% of them emerged there.

From broad-leaved tree species, *P. tremuloides*, *B. neoalaskana* and *Salix* spp., 376 seedlings were recorded. All of these seedlings established on BS, except 3 *B. neoalaskana* seedlings on US. Stems \geq DBH for broad-leaved tree species were less in the surveyed plots, indicating that these seeds came from the external environments.

On *P. mariana* seedlings emerged in 2005, seedling survival averaged 85% on BS and 82% on US (Fig. 2), indicating that the survival was better on US. On the survival rates on the BS by 2007, *P. tremuloides* showed 58%, *Salix* spp. 80%, and *B. neoalaskana* 85%. Therefore, the survival rates were not low for all the species.

Stem growth, evaluated by height and crown area, was significantly higher for the three broad-leaved trees than for *P. mariana* (Fig. 3). Furthermore, on *P. mariana*, stem growth was significantly slower on the US than on BS.

The significant differences in the slopes of allometry indicated that resource allocation differed between *P. mariana* and broad-leaves tree species on

BS (Fig. 4). Broad-leaved trees allocated more to belowground than to aboveground, and to stem than to leaf. Furthermore, broad-leaved trees allocated aboveground biomass more to height growth than *P. mariana*. These results indicated that broad-leaved trees acquired light more effectively than *P. mariana*, and did not have to allocate more to aboveground organs. One cause seemed to be lower allocation plasticity of *P. mariana*, showing from the biomass allocation did not differ between the two habitats. In conclusion, the establishment of broad-leaved trees proceeded if the ground was burned completely.

4. DISCUSSION

4.1 Seed immigration and seedling establishment

P. mariana seeds were captured fluently by seed traps after 2005 and the seedlings emerged well. *P. mariana* provides viable seeds for several years, by producing semi-serotinous cones (Bonan & Shugart 1989). The seed immigration was unlikely to be limited for *P. mariana* regeneration immediately after wildfire, although viable seeds decreased in 2007. The decline in viable seeds suggested that more seeds came from the aerial seedbank on the canopy. Between Yukon and British Columbia, seedling

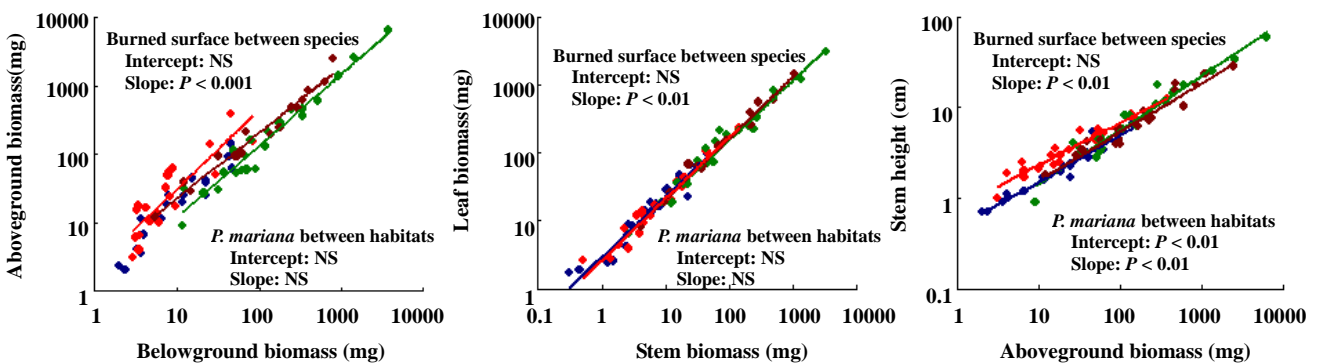


Figure 4. Allometry between belowground and aboveground biomass, between stem and leaf biomass, and between aboveground biomass and stem height. ● = *Picea mariana* on burned surface (BS), ● = *Picea mariana* on unburned surface (US), ● = *Populus tremuloides* on BS, and ● = *Betula neoalaskana* on BS. The differences are investigated by ANCOVA.

recruitment on *P. mariana* is highest in the first 5 years after fires, while additional establishment is not observed after 10 years (Johnstone et al. 2004). On Poker Flat, number of seedling recruits declined in 2007, 3 years after the fire. Tree regeneration patterns on *P. mariana*, should be determined for the first several years after fire.

All broad-leaved trees observed in Poker Flat produce long-distance wind-dispersed seeds. Most seeds for broad-leaved trees immigrated from the external environments, since the mature stems were less distributed in the surveyed area. These mean that seed supply will persist for broad-leaved trees. Furthermore, the intensive forest fire, that removes duff layer, promotes the seedling establishment of broad-leaved trees.

4.2 Environmental changes

If moss mat, mostly consisting of *Sphagnum*, remains on the ground surface after wildfire, soil temperature keeps low. However, the complete removal of moss mat promotes soil temperature increase and/or melting permafrost (Yoshikawa et al. 2002). Albedo also declines by fire, and is mostly determined by plant cover on the ground surface in Poker Flat. Fire severity, in particular, on the forest floor, must be mentioned to predict regeneration. Surface temperature increases after fire, due to increase in canopy openness and decrease in albedo on a *P. mariana* forest (Chambers et al. 2005). In addition, the *Sphagnum* cover seems to influence permafrost distribution (see Hydrology Team report). A trigger on environmental changes is considered to be in *Sphagnum* layer.

In *P. mariana* forest, the ground surface is often dominated by *Sphagnum* spp., that explain 80-90% aboveground biomass (Bonan & Shugart 1989). To predict carbon balance as well as regeneration pattern, we have to mention *Sphagnum* layer more details. The keystone species on the north slopes of interior Alaska must be *Sphagnum* spp.

4.3 Regeneration patterns

The seedling survival did not differ greatly between *P. mariana* and broad-leaved trees, and the growth was extremely higher on broad-leaved trees. Mean annual biomass increment is higher in dry sites than in wet sites along a chronosequence on *P. mariana* forests in Manitoba, Canada, but carbon pools in bryophyte, understory and forest floor are less for the dry sites (Wang et al. 2003). The allometric relationships indicated that *P. mariana* has lower allocation plasticity than broad-leaved trees, and thus the growth is limited on the burned ground surface.

On Poker Flat, plant-cover removal on the ground surface determines colonization patterns on trees.

The recovery of a few shrubs and herbs were also determined by the presence/absence of *Sphagnum* mat. Canopy openness influences the distribution pattern and productivity of herbaceous plants on the forest floor (Whigham 2004). However, initial tree composition after fire had little effects on understory composition in the coniferous forests of eastern Canada, while soil burn severity affected temporal changes in understory species (Lecomte et al. 2005). Those suggest that forest regeneration after large-scaled fire differs from weak fire, including crown fire. Fire severity may change successional sere on *P. mariana* forests towards mixed conifer and/or broad-leaved forests.

To clarify plant community-climate interactions with micro-and macro-spatiotemporal changes, we need further observations on: 1) changes in plant community structures for longer term, 2) seedling survival and growth related to *Sphagnum* recovery, and 3) determinants on *Sphagnum* recovery.

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