**Severe forest fire in Alaska and global environmental changes**
# Vegetation recovery for four years after large-scaled wildfire in Alaska

**Team Ecology (P4)**
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## 1. INTRODUCTION

Wildfires take place in taiga, due mostly to lightning (Engelmark 1999). The initial stages after wildfires greatly determine the forest dynamics. On *Picea mariana* forests in Alaska, crown fire, that incompletely burned the ground-surface cover, is ordinal and promotes seedling regeneration (Bonan & Shugart 1989). *Picea mariana* develops aerial seedbank, and disperses more seeds after fire, and 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 the effects of large-scaled wildfire on revegetation, we have researched the followings from 2005 to 2008: 1) Detecting plant community recovery patterns with different fire severities, and 2) Characterizing regeneration dynamics after wildfire. Based on these results, we found out that recovery of *Sphagnum* mat was prerequisite for *P. mariana* forest regeneration, in particular, after severe wildfires.

## 2. STUDY AREA AND METHODS

A typical *P. mariana* forest on the north slope of Poker Flat, ca. 50 km north of Fairbanks, interior Alaska, is selected for monitoring, because of large and severe fire, slope direction, and accessibility. Wildfires (Boundary Fire) 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 and summer 2008. The total censuses were 7 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. 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 on the ground surface. H is burned totally, i.e., all stems were killed and > 80% ground surface was burned out. In each plot, we measured height and diameter at breast height (DBH) for all alive and dead stems ≥ 1.3 m in height. Fallen trees were included

on the measurement to reconstruct pre-fire forest structure. 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 [$15^{\circ}C/25^{\circ}C$ (12 hr/12 hr)] with continuous or 12-hr light.

In each plot, six 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 and 2008 (Frazer et al. 1999). Albedo was measured on each quadrat (Tsuyuzaki et al. in press), 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
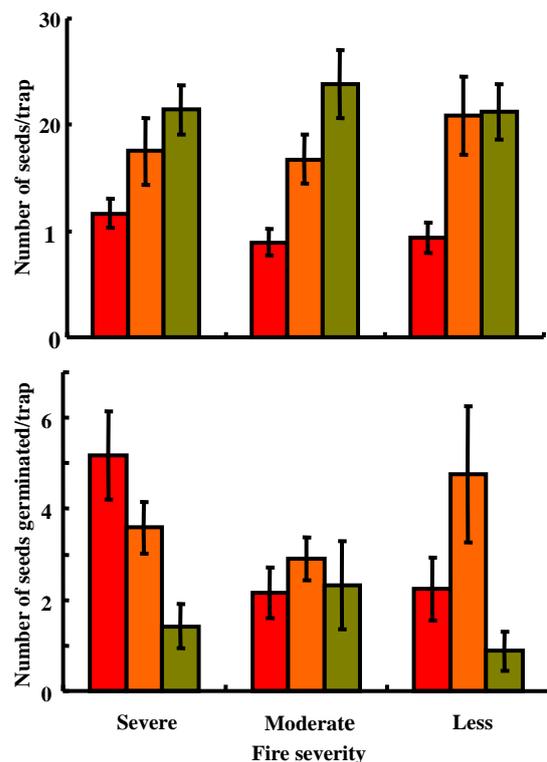


**Figure 1.** *Picea mariana* seeds captured by seed traps, and germinated in lab-experiment per seed trap. Mean is shown with SE. Duration: ■ = 2005-2006, ■ =2006-2007, and ■ = 2007-2008. In 2005 and 2006, the data were complied with spring and summer. Seed density was not different between three fire severities (Tukey's test), and the number of germinated seeds was different between years, and is not significantly different between severities.

recorded on burned (hereafter, i.e., BS) and unburned (US) ground surfaces, separately, at summer census. When a 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. Detailed statistical analysis is not described in this report, due to page limitation.

# 3. RESULTS

## 3.1 Fire severities

The altitude ranged from 244 m to 437 m, and the slopes faced $7.0^{o}$-$43.5^{o}$ from N to W with $4.8^{o}$-$19.0^{o}$ slope angles. Before the wildfire, 5-54 *P. mariana* stems $\geq$ 1.3 m, that accounted for 97% of total, had established in the plots, and 81% of them were burned and dead. The maximum tree height was 13.0 m. *Alnus crispa*, *B. neoalaskana* and *Salix* spp., established with low frequencies. The plant cover on the forest floor ranged from 0% to 100%, indicating that the floor was patchily burned with various scales and thus was suitable for this study.

The age of tree cores was up to 174, and was linearly correlated to height. The stem-diameter growth indicated that drastic events, such as wildfires, 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 in 2005, and from 45% to 82% in 2008. The relationships between albedo in 2005 ($x$) and 2008 ($y$) was expressed as: $y = 1.20x - 18.92$ ($r^2$ = 0.782, significant at $P < 0.01$). Plant cover on the forest floor decreased down to 40% by the fire even on L. Duff thickness ranged from 3 cm to 73 cm. On albedo, see Kodama's report and Tsuyuzaki et al. (in press). In summary, the albedo did not return to the pre-fire conditions until vegetation cover becomes higher enough to reflect radiation.

## 3.2 Seed dispersal and germination

In summer 2007, cones were counted for 12 *P. mariana* snags, and confirmed that the seeds were still available on the snags. Seed traps constantly captured *P. mariana* seeds until summer 2008 (Fig. 1). *B. neoalaskana* was second dominant in the traps (data not shown). The other seeds were recorded from forbs and grasses. Therefore, even after severe wildfire, seed immigration from the snags was not limited in the early stages. However, the germination of *P. mariana* annually decreased.

## 3.3 Plant communities in herb layer

For 3 years, there were > 44 taxa, consisting of 31 vascular plants (4 trees, 13 shrubs, 12 herbs, and 2 ferns) on the 96 quadrats. *Sphagnum* spp. were predominant on US, although the cover declined in 2008. Plant cover fluctuated little for trees, herbs and mosses on US, while shrub cover significantly increased on both US and BS. Shrubs, e.g., *Ledum groenlandicum*, *Vaccinium vitis-idaea*, and *V. uloginosum*, 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
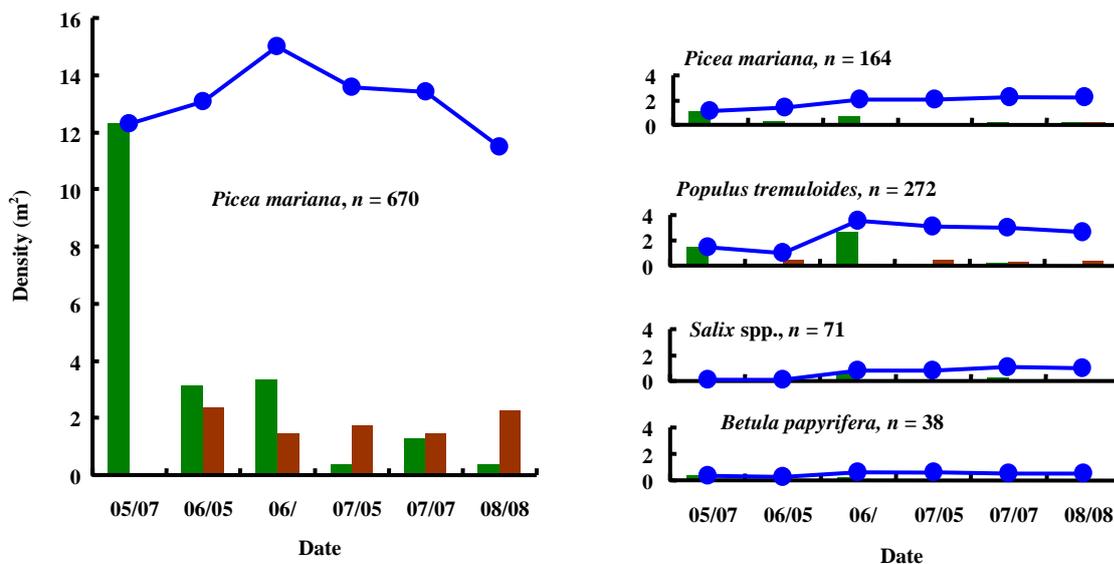


**Figure 2.** The fates of seedlings emerged from Summer 2005 to Summer 2008. Green and brown columns indicate recruits and deaths (/m$^2$) in each census period. Blue lines show the fluctuations of seedling densities. Total numbers of seedlings ($n$) from 2005 to 2008 are shown in each figure. On unburned surface, there were no seedlings for *P. tremuloides* and *Salix* spp., and were 3 for *B. neoalaskana*.
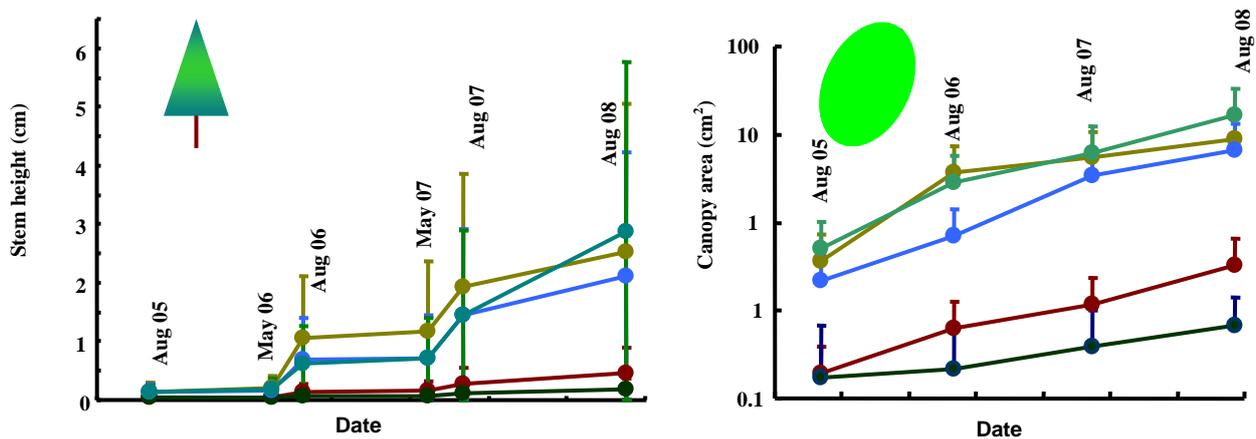
**Figure 3.** Changes in stem height and crown area on tree seedlings for four years surveyed. ● = *Picea mariana* on burned surface (BS), ● = *P. mariana* on unburned surface (US), ● = *Populus tremuloides* on BS, ● = *Salix* spp. on BS, and ● = *Betula neoalaskana* on BS. Height and crown area are 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 $P < 0.01$.

BS, mostly by broad-leaved seedlings. A grass, *Calamagrostis canadensis*, and a moss, *Ceratodon purpureus*, significantly increased in cover on BS for the four years. *Epilobium angustifolium* (fireweed) increased greatly in cover to 2006, but decreased gradually thereafter.

### 3.4 Seedling emergence, survival, and growth

In total, 1215 tree seedlings were marked for the four years (Fig 2). *P. mariana* was most abundant, i.e., 834 seedlings in the quadrats, and germinated more on US. Three broad-leaved tree taxa, *P. tremuloides*, *B. neoalaskana* and *Salix* spp., totaled 318 seedlings. All of these seedlings established on BS, except 3 *B. neoalaskana* seedlings on US. Stems ≥ 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 did not differ greatly between BS and US. On broad-leaved trees, the survival was more than 50% by 2008. Therefore, the survival rates were not low for all the species. This indicated that safe site for seedling emergence is rather important.

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

A few examples of the allometric equations are described below.

Stem height (*y*) and aboveground biomass (*x*)

*Picea mariana*

On US: $y = +0.508x - 0.326$

On BS: $y = +0.465x - 0.090$

*Populus tremuloides* on BS: $y = +0.593x - 0.428$

*Betula neoalaskana* on BS: $y = +0.532x - 0.330$

The differences were significant between BS and US for *P. mariana*, and between species on BS

(ANCOVA). We also evaluated the relationships between aboveground and belowground biomass, and between stem and leaf biomass. The significant differences in the slopes of allometry indicated that resource allocation differed between *P. mariana* and broad-leaved tree species on BS. 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 from 2005 to 2007 and the seedlings emerged well. However, the seed germination rates decreased in 2008. *P. mariana* provides viable seeds for several years, by producing semi-serotinous cones (Bonan & Shugart 1989). The cones on snags support this trend. The seed immigration was unlikely to be limited for *P. mariana* regeneration immediately after wildfire, although viable seeds decreased annually. The decline in viable seeds suggested that more seeds came from the aerial seedbank on the canopy. Between Yukon and British Columbia, seedling 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). Number of seedling recruits declined annually on Poker Flat, indicating

that 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. The seeds of these broad-leaved trees immigrated from the external environments, since the mature stems were least 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 those 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 (Tsuyuzaki et al. in press). 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, *Sphagnum* cover is likely to influence permafrost distribution. Therefore, a trigger on environmental changes is considered to be derived from *Sphagnum* layer. The dominance of *Sphagnum* spp. is related to *P. mariana* forest expansion (Fenton et al. 2007).

## 4.3 Regeneration patterns

The seedling survival did not differ greatly between *P. mariana* and broad-leaved trees, and the growth rates were significantly higher for 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 suggested that *P. mariana* has low allocation plasticity, and thus the growth is limited on the burned ground surface.

On Poker Flat, plant cover removal from the ground surface determines seedling colonization and vegetation recovery. 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. 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. To clarify the determinants on *Sphagnum* recovery, we set up litterbags to estimate *Sphagnum* litter decomposition in summer 2008. By combination with the measurements of *Sphagnum* growth, we estimate safe site for growth and turnover of *Sphagnum*.

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