

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

Team Ecology (Reference#: P4@TSUYUZAKI)

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1. INTRODUCTION

Wildfire becomes large and severe and thus burns out the ground surface (Dale et al. 2001), while crown fire, incompletely burned the ground-surface cover, is common and promotes seedling regeneration in *Picea mariana* forests (Bonan & Shugart 1989, Engelmark 1999). Due to the complete removal of ground surface, microenvironments such as albedo, soil moisture and thaw depth of permafrost will be

altered. *P. mariana* develops aerial seedbank that disperses seeds mostly after wildfires, and adapts to establish on wet, nutrient-poor ground surface (Chapin et al. 2006). In discontinuous permafrost regions, the scenarios of succession differ between north and south slopes, because of the presence of permafrost mostly on the north slopes, i.e., *P. mariana* forests develop more on the north slopes. Through changes in microclimate after severe wildfire, vegetation recovery and successional sere is likely to be distorted. Therefore, to confirm the regeneration patterns, annual monitoring has been conducted in a *P. mariana* forest.

We have researched the followings from 2005 to 2010 after the 2004 wildfire that was large and severe: 1) Detecting plant community recovery patterns with different fire severities in relation to seed immigration, vegetation composition, and tree seedling establishment, and 2) Characterizing regeneration dynamics.

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. A wildfire (Boundary Fire) stroke this region in the summer of 2004. The field surveys were conducted in spring and summer from 2005 to 2007 and in summer from 2008 to 2010. The total censuses were 9 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. H is burned totally, i.e., all stems were killed and > 80% ground surface was burned out. M was situated between L and H, i.e., most trees were dead but unburned plant cover remained somehow on the ground surface. 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 also measured to reconstruct pre-fire forest structure. Outside the plots, 22 tree cores were sampled by a borer or clippers in summer 2005. The locations,

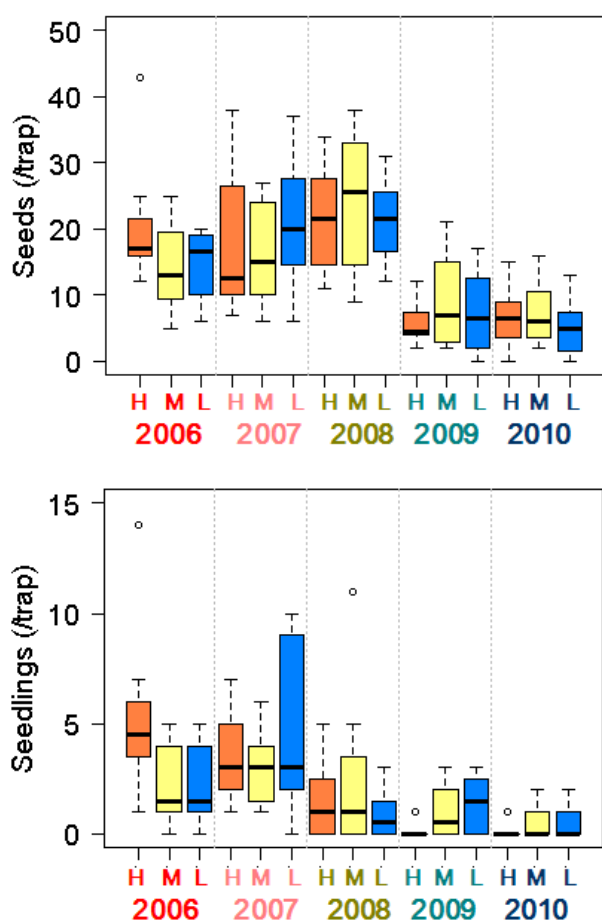


Figure 1. Box-whisker plots on *Picea mariana* seeds captured by seed traps (top), and germinated in lab-experiment (bottom). In 2005 and 2006, the data were compiled with spring and summer. Seed density was not different between three fire severities (Tukey's HSD test), and the number of germinated seeds was different between years, and is not significantly different between severities.

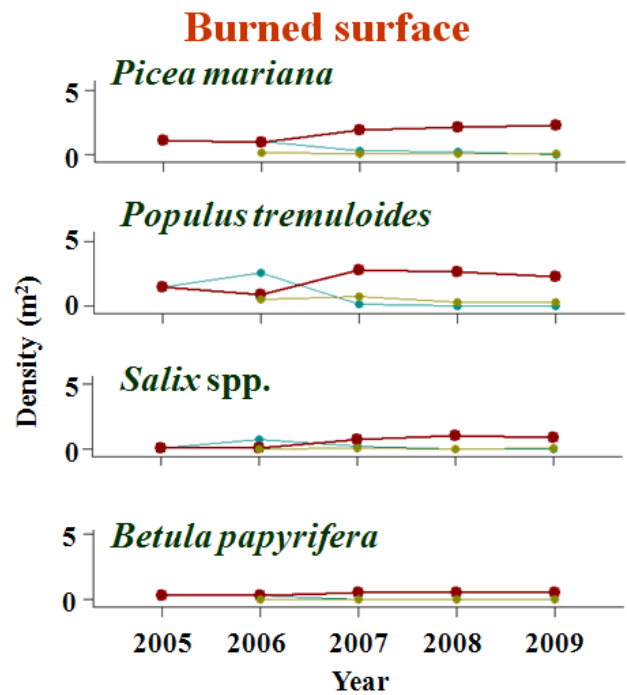
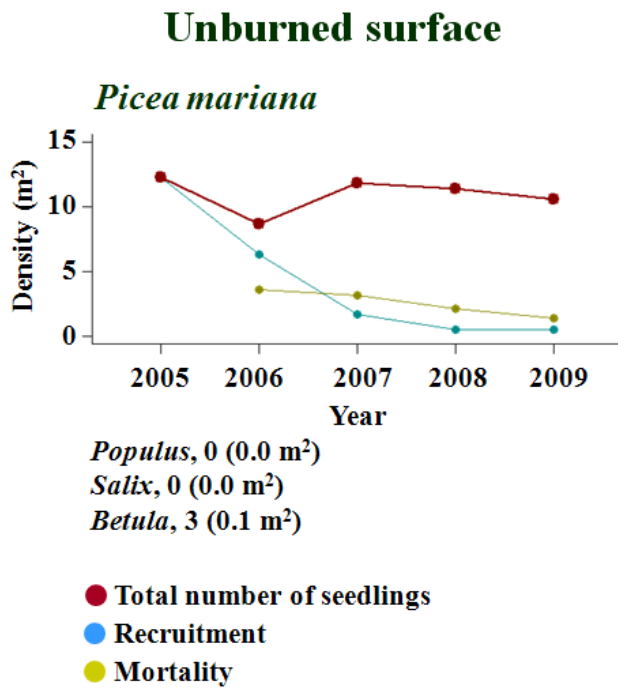


Figure 2. Annual recruitment and mortality of tree species in burned and unburned surfaces on Poker Flat, interior Alaska, after the 2004 wildfire (Boundary Fire) from 2005 to 2009.

aspects and slope gradients were determined by a portable GPS and laser compass.

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. Vegetation was annually monitored in all the quadrats. The environments were monitored in five of six quadrats, as needed. For examples, canopy openness was estimated in summer 2005 and 2008, and albedo was annually measured (Tsuyuzaki et al. 2009), and duff thickness was estimated by a steel stake. The cover of each species was recorded on burned (hereafter, i.e., BS) and unburned (US) ground surfaces, separately, at summer censuses. 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.

Twenty litterbags containing dead *Sphagnum* were established on the slope in summer 2008 to estimate litter decomposition rates. Ten bags were set up on BS and the remainders were on US. Five bags were recovered from each habitat in 2009 and 2010, respectively.

Of 96 quadrats, 80 quadrats were used for investigating relationships between forest-floor vegetation and the environmental factors, by

non-metric multi-dimensional scaling (NMDS). Based on vegetation and environmental factors (burned area, canopy openness, elevation, slope gradient, aspect, and years after wildfire), NMDS extracted significant environmental factors and revegetation patterns.

3. RESULTS

3.1 Fire severity

The altitude ranged from 244 m to 437 m, and the slopes faced 7.0°-43.5° from N to W with 4.8°-19.0° slope angles. By the 2004 wildfire 81% of stems were burned and dead. The maximum tree height was 13.0 m, with the maximum age of 175.

The canopy openness ranged from 57% to 95% in 2005 and from 45% to 82% in 2008. 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. Albedo is positively correlated with total plant cover in quadrats (refer to Kodama's report and Tsuyuzaki et al. 2009). 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.

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. The number of seeds were estimated by:

$$y = -26700 + 32200 \cdot \ln(x) \quad (r^2 = 0.715, n = 8),$$

where y is estimated number of seeds, and x is stem height.

P. mariana seeds were captured by seed traps until summer 2008 (Fig. 1). Even after severe wildfire, seed immigration from the snags was not limited for a few years after the wildfire. However, the seeds captured by seed traps decreased abruptly in 2009 from everywhere. In addition, the germination of *P. mariana* annually decreased, in particular, on H. If this trend was true, the regeneration success of *P. mariana* was mostly determined for a few years after wildfires.

3.3 Plant communities on forest floor

Although the unburned surface was mostly covered with *Sphagnum* spp. soon after the 2004 wildfire (Table 1), the cover declined gradually due probably to desiccation and fire damage. The cover increased least in most plots, with a few exceptions. In contrast, *Ceratodon purpureus* increased frequency and now established in 80% of quadrats. *Polystichum formosum* followed *C. purpureus*, i.e., showed 45-70% in frequency, and increased annually in cover.

Of herbs and ferns, *Carex bigelowii* and *Calamagrostis canadensis* were most common and had the highest cover of herbs. These two species are monocotyledons. *Epilobium angustifolium* became dominant in 2006, but thereafter decreased in cover.

Shrubs, represented by *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. Shrubs annually increased the cover. The most of these plants survived through the wildfire, and reproduced vegetatively.

Although *P. mariana* slightly increased the cover, the cover increase was mostly derived from survived saplings that showed 0.6% in 2005. The cover of broad-leaved trees was less than 0.1% in 2005, showing that most broad-leaved trees regenerated from seedlings. The cover of broad-leaved trees exceeded the cover of *P. mariana* in 2008.

NMDS indicated that burned area was the most significant determinant on forest-floor vegetation structures (Fig. 3). The scores of quadrats aggregated in the right side of figure 3 meant the quadrats on less-burned surface, and *vice versa*. The scores of less-burned quadrats fluctuated less, indicating that the vegetation structures changed little. The scores of burned quadrats shown on left-side in the figure fluctuated greatly along axis II, showing that the vegetation structures annually changed but did not go towards the scores of less-burned quadrat. In total, the vegetation structures changed annually on burned surface, but did not recover to the pre-burned vegetation structures.

Species scores supported these patterns (Fig. 3). Broad-leaved trees established more on burned quadrats, while shrubs established more on unburned quadrats. The establishment of mosses had a contrast between *Sphagnum* and the others. The establishment of *Sphagnum* was completely

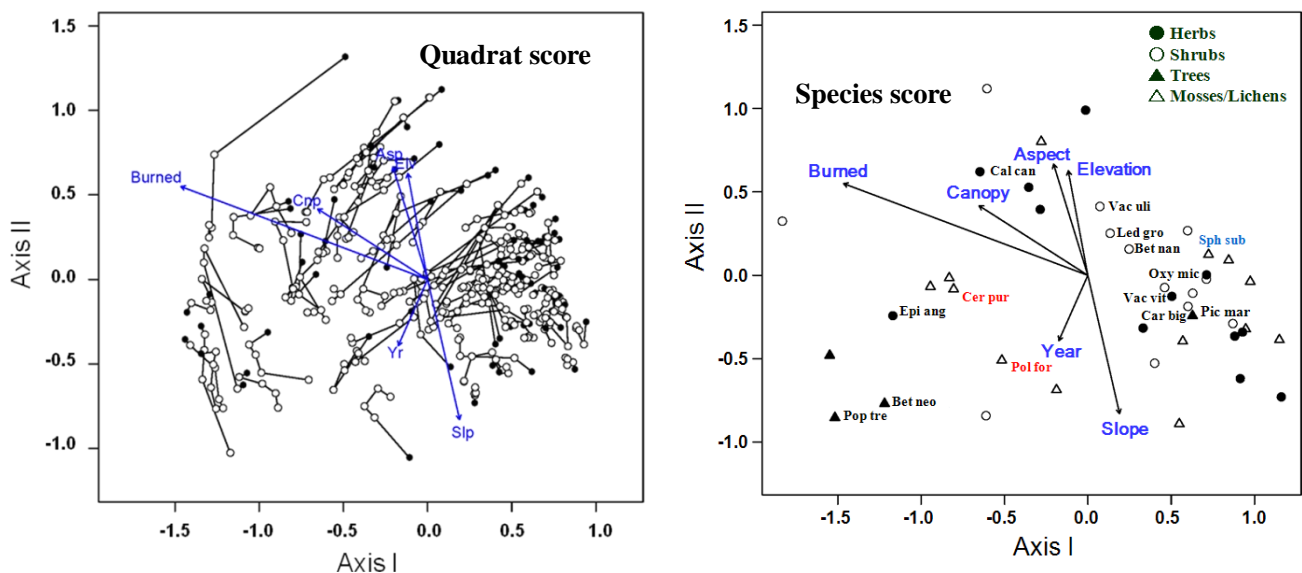


Figure 3. NMDS ordination diagram. (Quadrat scores) The connected lines show the same quadrats surveyed from 2005 to 2009. NMDS scores at the first survey, i.e., in 2005, are shown by solid circles, and the others are by open circles. Environmental factors: Yr = years after wildfire, Brn: burned area (%), Cnp = canopy openness (%), Elv = elevation (m), Slp = slope gradient ($^{\circ}$), and Asp = aspect ($^{\circ}$). (Species score) Car big = *Carex bigelowii*, Cal cas = *Calamagrostis canadensis*, Epi ang = *Epilobium angustifolium*, Led gro = *Ledum groenlandicum*, Vac vit = *Vaccinium vitis-idaea*, Vac uli = *Vaccinium uliginosum*, Bet nan = *Betula nana*, Oxy mic = *Oxycoccus microcarpus*, Pic mar = *Picea mariana*, Bet neo = *Betula neoalaskana*, Pop tre = *Populus tremuloides*, Pol for = *Polystichum formosum*, Sph sub = *Sphagnum subsecundum*, and Cer pur = *Ceratodon purpureus*.

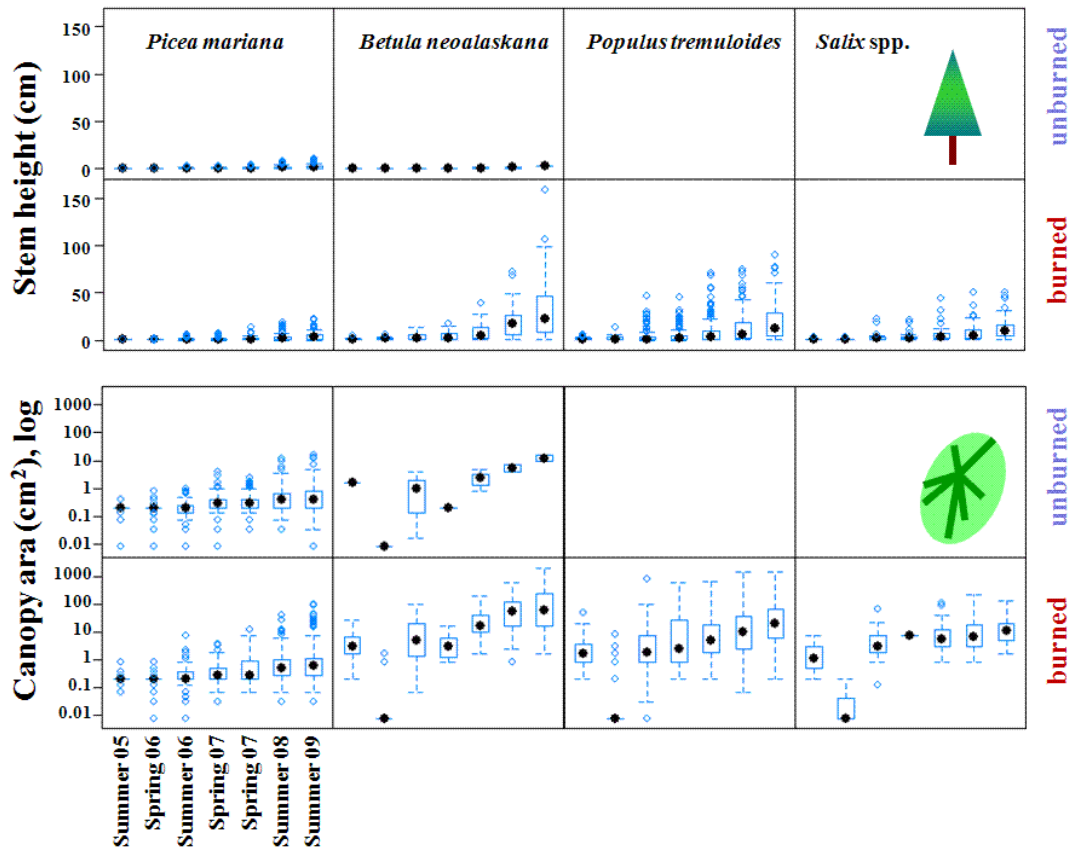


Figure 4. Changes in stem height and crown area on tree seedlings for five years surveyed. Height and crown area are significantly different for *P. mariana* between BS and US at $P < 0.01$ (repeated measures ANOVA), and are different between *P. mariana* and broad-leaved trees at $P < 0.01$.

dependent on unburned surfaces. In contrast, *C. purpureus* and *P. formosum* established more on burned surfaces. These facts indicated that moss communities were differentiated by severity.

3.4 Tree seedling establishment

In total, 1246 tree seedlings were marked for the five years. *P. mariana* was most abundant, i.e., 860 seedlings in the quadrats, and germinated more on unburned surface. Three broad-leaved tree taxa, *P. tremuloides*, *B. neoalaskana* and *Salix* spp., totaled 386 seedlings. All of these broad-leaved tree seedlings established on burned surface with a few exceptions. Stems \geq DBH on broad-leaved tree species were least in the surveyed plots, showing that the seeds of broad-leaved trees immigrated from the external environments.

On *P. mariana* seedlings emerged in 2005, seedling survival did not differ greatly between burned and unburned surfaces. On broad-leaved trees on burned surface, the survival was more than 63% by 2009. The survivals of *P. mariana* were 79% on burned surface and 47% on unburned surface. In total, the survival of *P. mariana* was higher on burned surface than unburned surface, and was higher than broad-leaved trees on burned surface. However,

total number of seedlings was more for broad-leaved trees. Therefore, the density of survived seedlings on burned surface was higher on broad-leaved trees than on *P. mariana*.

Stem growth, measured by height and crown area, was significantly higher on the three broad-leaved trees than on *P. mariana* on burned surface (Fig. 4). In addition, on *P. mariana*, stem growth was significantly slower on unburned surface than on burned surface.

For estimating carbon fixation by tree seedlings, the following allometric equations were obtained. Aboveground biomass (mg) (y) is predicted by stem height (cm) (x) and aboveground biomass (y)

Picea mariana

$$\text{on US: } y = +0.508x - 0.326$$

$$\text{on BS: } y = +0.465x - 0.090$$

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

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

The differences were significant between burned and unburned surfaces for *P. mariana*, and between species on burned surface (ANCOVA, $P < 0.05$). The significant differences in the slopes of allometry indicated that resource allocation differed between *P. mariana* and broad-leaved tree species. Broad-leaved trees allocated more to belowground

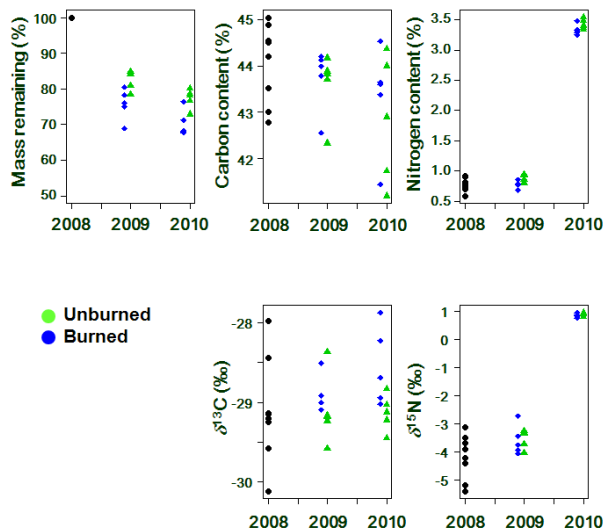


Figure 5. *Sphagnum*-litter decomposition rates expressed by weight remaining, N content, and $\delta^{15}\text{N}$. The relationship between N content and weight remaining is also shown.

than to aboveground, and to stem than to leaf. Broad-leaved trees allocated aboveground biomass more to height growth than *P. mariana*, indicating that broad-leaved trees obtained light energy more effectively than *P. mariana*, and did not allocate more to aboveground.

3.6 Litter decomposition

Litter decomposition was faster on burned surface than unburned surface (Fig. 5), suggesting that burned surface accelerated litter decomposition. In addition, N content in litter seemed to become lower on burned surface. The concentrations of C and $\delta^{13}\text{C}$ did not change greatly for the two years, while these of N and $\delta^{15}\text{N}$ increased across the time. However, $\delta^{13}\text{C}$ tended to be higher on BS than on US.

4. DISCUSSION

4.1 Seed immigration and seedling establishment

P. mariana seeds were captured fluently by seed traps by 2008 and germinated. However, the numbers of dispersed and germinated seeds decreased in 2009. Also, number of germinated seeds gradually decreased in severely-burned sites. *P. mariana* provides viable seeds for a few years, by producing semi-serotinous cones (Bonan & Shugart 1989). Seed production estimated by tree height supports this. The seed immigration was unlikely to be limited for *P. mariana* regeneration immediately after wildfire. However, viable seeds decreased annually, and were lowest in 2009. 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* was 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. Therefore, 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 and litter deposits

If moss mat, mostly consisting of *Sphagnum*, remains on the ground surface after wildfire, soil temperature keeps low. However, the complete removal of *Sphagnum* moss mat promotes soil temperature increase and 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. 2009). Fire severity, in particular, on the forest floor, must be mentioned to predict the regeneration. Surface temperature increases after wildfire in a *P. mariana* forest, due to increase in canopy openness and decrease in albedo (Chambers et al. 2005). In addition, *Sphagnum* cover influences permafrost distribution. Therefore, a trigger on environmental changes is considered to be in *Sphagnum* layer. The dominance of *Sphagnum* spp. is related to *P. mariana* forest expansion (Fenton et al. 2007).

4.3 Regeneration patterns

Although the seedling survival on burned surface was higher on *P. mariana* than on broad-leaved trees, the growth rates were significantly higher on broad-leaved trees. After disturbances, including wildfire, in northern Ontario, broad-leaved trees, represented by *Populus tremuloides*, trees increased the relative dominance, and needle-leaved trees, including *P. mariana*, decreased it (Ilisson & Chen 2009). 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 low allocation plasticity, and the growth is reduced 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.

4.4 Conclusions, perspectives and future plans

By monitoring for six years, four findings were summarized. (1) Seedling regeneration patterns of *P. mariana* were determined soon after wildfires, because of the limitation of seed immigration. (2) *P. mariana* established more on unburned and burned surfaces, and broad-leaved trees were restricted to establish on burned surface. (3) Broad-leaved trees grew up faster than *P. mariana*. (4) The regeneration of *P. mariana* forests is restricted by the dominance of burned surface.

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, and 2) seedling survival and growth related to the determinants on *Sphagnum* recovery. To predict not only regeneration pattern but also carbon balance, we have to mention *Sphagnum* layer more details. The keystone and umbrella species on the north slopes of interior Alaska must be *Sphagnum* spp.

During 2011 and 2013, the monitoring should be continued to increase the accuracy. Since seed immigration and emergence were determined a few years the wildfire (confirmed by monitoring for 6 years), we focus more on seedling mortality and growth. Furthermore, we have a plan to restore *P. mariana* regeneration by introducing *Sphagnum* propagules that is a key to promote the regeneration. The restoration through *Sphagnum* recovery has been widely used in boreal peatland (Rochefort et al. 2003). Such restoration techniques should be validated over a wide area, by using remote sensing data. Note that we are able to assist the other projects, by collecting vegetation data.

REFERENCES

- Bonan GB, Shugart HH. 1989. Environmental factors and ecological processes in boreal forests. *Ann. Rev. Ecol. Syst.* **20**, 1-28
- Chambers SD, Beringer J, Randerson JT, Chapin III FS. 2005. Fire effects on net radiation and energy partitioning: contrasting responses of tundra and boreal forest ecosystems. *J. Geophys. Res.* **110**, doi: 10.1029/2004JD005299
- Chapin III FS, Oswald MW, van Cleve K, Viereck LA, Verbyla DL. 2006. Alaska's changing boreal forest. Oxford University Press, New York.

- Dale VH, Joyce LA, McNulty S, Neilson RP, Ayres MP, Flannigan MD, Hanson PJ, Irland LC, Lugo AE, Peterson CJ, Simberloff D, Swanson FJ, Stocks BJ, Wotton BM. 2001. Climate change and forest disturbances. *BioScience* **51**, 723-734
- Engelmark O. 1999. Boreal forest disturbances. In: Walker LR (ed.). Ecosystems of the world 16: Ecosystems of disturbed ground. Elsevier, Amsterdam. pp. 161-186
- Fenton, N.J., Beland, C., de Blois, S., Bergeron, Y. 2007. *Sphagnum* establishment and expansion in black spruce (*Picea mariana*) boreal forests. *Can. J. Bot.* **85**: 43-50.
- Ilisson T, Chen HYH. 2009. Response of six boreal tree species to stand replacing fire and clearcutting. *Ecosystems* **12**, 820-829
- Johnstone JF, Chapin III FS, Foote J, Kemmett S, Price K, Viereck L. 2004. Decadal observations of tree regeneration following fire in boreal forest. *Can.J.For.Res.* **34**, 267-273
- Lecomte N, Simard M, Bergeron Y, Larouche A, Asnong H, Richard PJH. 2005. Effects of fire severity and initial tree composition on understorey vegetation dynamics in a boreal landscape inferred from chronosequence and paleoecological data. *J. Veg. Sci.* **16**, 665-674
- Rochefort L, Quinty F, Campeau S, Johnson K, Malterer T. 2003. North American approach to the restoration of *Sphagnum* dominated peatlands. *Wetlands Ecol. Manage.* **11**, 3-20
- Tsuyuzaki S., Kushida K., Kodama Y. 2009. Recovery of surface albedo and plant cover after wildfire in a *Picea mariana* forest in interior Alaska. *Climatic Change* **93**, 517-525
- Wang C, Bond-Lamberty B, Gower ST. 2003. Carbon distribution of a well-and poorly-drained black spruce fire chronosequence. *Global Change Biol.* **9**, 1066-1079
- Whigham DF. 2004. Ecology of woodland herbs in temperate deciduous forests. *Ann. Rev. Ecol. Syst.* **35**, 583-621
- Yoshikawa K, Bolton WR, Romanovsky VE, Fukuda M, Hinzman LD. 2002. Impacts of wildfire on the permafrost in the boreal forests of Interior Alaska. *J. Geophys. Res.* **107**, 8148, doi:10.1029/2001JD 000438

- Attention -
 Collected data are saved in the ftp server:
<ftp://hosho.ees.hokudai.ac.jp/pub/tsuyu/Alaska/>
 Please use them freely!
 Also, voucher specimens are stored in SAPS.

Activities (2008-2011)

Publications

- Kimura H, Tsuyuzaki S. (in press) Fire severity affects vegetation and seed bank in a wetland. *Appl. Veg. Sci.*
- Kushida K, Kim Y, Tsuyuzaki S, Fukuda M. 2009. Spectral vegetation indices for estimating shrub cover, green phytomass and leaf turnover in a sedge-shrub tundra. *Int. J. Remote Sensing* **30**, 1651-1658
- Tsuyuzaki S, Kushida K, Kodama Y. 2009. Recovery of surface albedo and plant cover after wildfire in a *Picea mariana* forest in interior Alaska. *Climatic Change* **93**, 517-525
- Tsuyuzaki S, Sawada Y, Kushida K, Fukuda, M. 2008. A preliminary report on the vegetation zonation of palsas in the Arctic National Wildlife Refuge, northern Alaska, USA. *Ecol. Res.* **23**, 787-793
- Tsuyuzaki S, Sento N, Fukuda M. 2010. Baidzharakhs (relic mounds) increase plant community diversity by interrupting zonal vegetation distribution along the Arctic Sea, northern Siberia. *Polar Biol.* **33**, 565-570