The effects of intensive forest fire on revegetation in interior Alaska (mid-term report, February 2006)

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Abstract: To detect the effects of large-scaled fire on the revegetation of *Picea mariana* forest, we set up 16 10 m × 10 m plots at Poker Flat near Fairbanks, Alaska, USA, in the spring of 2005. Forest fire occurred in this region in the summer of 2004. Owing to the fire, stem density declined 9%-100% and canopy openness increased in the plots surveyed. The ground cover mostly consisting of *Sphagnum* was burned by the fire, and remained patchily. Burned ground surface in the plots ranged from 3% to 100%. The relationship between the height of survived trees and age determined by tree core samples was positively and linearly correlated. The frequency of tree stems gradually decreased with increasing tree height. Those results suggested that tree recruitment had gradually occurred so far. We set up six 1 m × 1 m quadrats in each plot, and recorded plant cover on each species and marked all seedlings in each quadrat. Of vascular plants, small shrubs, such as *Betula nana* and *Ledum groenlandicum*, and sedges (*Carex* spp.), that recovered vegetatively, were common on the unburned ground surface, while *Epilobium angustifolium* were common on burned surface. In addition, even on the burned ground surface, shrubs, e.g., *Betula nana* and *Ledum groenlandicum*, and perennial sedges, such as *Carex bigelowii*, could survive vegetatively throughout the fire with low cover. We found out the safe sites for seedling emergence varied greatly between tree species. *Picea mariana* germinated on *Sphangum* mat while *Betula papyrifera* and *Populus tremuloides* emerged on bare ground where the aboveground cover including duff was completely removed by the fire. The surveys on the relationships between revegetation patterns and its related environmental factors will be continued.

Key words: forest fire, *Picea mariana* forest, plant cover, seedling emergence, *Sphagnum*

Introduction

Natural forest fires with different interval, intensity and scale operate plant community structures and functions in various regions, since the above-and below-ground environments, i.e., light and nutrient, alter greatly by fire (Johnson 1992; Kenae et al. 2004). In particular, fires take place frequently in taiga regions, e.g., Siberia and Alaska, due to lightning (van Cleve et al. 1986; Engelmark 1999). In these regions, the distribution pattern of permafrost is consistent roughly with the distribution of ecosystems. *Picea mariana* is adapted to establish wet and nutrient-poor habitats that are distributed more in north slopes of mountains (van Cleve et al. 1986).

On forest regeneration, the initial stages are particularly important to determine the patterns and dynamics. In Alaska, ordinary forest fire is categorized into crown fire (Bonan & Shugart 1989). That means that the ground surface cover is not greatly declined by fire. In discontinuous permafrost region, the scenarios of succession differ greatly between north and south slopes, due partly to the presence of permafrost on north slope and the absence on south slope (van Cleve et al. 1986). Soil properties are also different between south and north slopes in an interior Alaska (Ping et al. 2005). In total, *Picea mariana* forest develops more on north slopes, while mixed white spruce forest establishes on south slopes.

The frequency, intensity and scale of fire will be altered by global warming (Dale et al. 2001; Hinzman et al. 2005). Furthermore, permafrost thaw accelerates in boreal peatlands in the last century (Camill 2005). Therefore, we have mentioned the effects of large-scaled fire on the regeneration of *Picea mariana* forest on north slope. The major objectives of this research are: 1) Detecting the characteristics of plant community recovery after large-scaled wildfire, 2) Characterizing the characteristics of plant community dynamics, including succession and revegetation, after the wildfire in a discontinuous permafrost zone, and 3) The final goal is generalizing the patterns by comparing with the other references. This mid-term report is situated in a comprehensive research on forest community dynamics after large-scaled fire (Team Leader, M. Fukuda, ILTS, HU). For the progress of this project, we summarize our researches in 2005, although we have to say every study has been ongoing.

Study area and methods

Study area

Poker Flat, approximately 50 km north of Fairbanks, interior Alaska, USA, was selected for the present survey, because of large-scaled and intensive fire, north slope, and high accessibility and convenience. The forest fire was recorded in the summer of 2004.

In this region, there are three types of upland taiga forests: *Picea mariana*, *Picea glauca*, and *Betula-Populus* (Kielland 1998). Of these forest types, *Picea mariana* forest is characterized by the predominance of *Picea mariana* on nutrient-poor habitats (Bonan & Shugart 1989).

On the north slope of Poker Flat, mono-specific dominant tree was *Picea mariana*. This forest is situated in the northern part of the Alaskan boreal forest, above the boundary between continuous and discontinuous permafrost zones. On the forest floor excluding vascular plants, peat moss (*Sphagnum* spp.), feather moss (*Thuidium abietinum*) and lichens (mostly *Cladina* spp.) were common.

Field methods

On a north-faced slope at Poker Flat, 16 10 m × 10 m plots were established in the spring of 2005. The location of each plot was recorded on latitude, longitude and altitude by a portable GPS receiver (PokeNavi-Mini, Empex, Tokyo). Slope aspect and gradient were measured in each plot by a transit compass (Electronic Total Station ET2, Topcon, Tokyo).

On each plot, we measured tree height and diameter at breast height (= 1.3 m) for stems ≥ 1.3 m in height. The diameter was measured by a tape or a pair of calipers. On this survey, all stems including alive and dead stems were measured to reconstruct forest structure before the fire. The fallen trees with 1.3 m in height were included in the measurement. Cross-sectional area at breast height was calculated based on diameter at breast height. Stem volume was calculated by the assumption of conical-shaped stem.

The burned area on the ground surface was visually estimated in each plot. In addition, to clarify seed immigration patterns, we set up two seed traps made of plastic on each plot in the summer of 2005. The design of trap is illustrated by Terry's Lab.

In each plot, six 1 m × 1 m quadrats were randomly set up. Of the six quadrats, five quadrats are used for non-destructive monitoring on plant communities, and the remainder is for the measurements on belowground properties by destructive measurements. On the five monitoring plots at every census, the vegetated area was measured to evaluate plant cover recovery. Then, cover on each species was recorded separately between burned and unburned areas on each quadrat. Duff (or moss-organic layer) thickness was measured by a steel stake. When the stake hit parental rock or frozen soil layer, the length of stake penetrated into duff was recorded. In each quadrat, three replicates of the thickness measurement were made on burned and unburned areas.

Two photos were taken on each quadrat by a fish-eye lens at cloudy day to estimate canopy openness. The position of camera was adjusted to 1.3 m in height. Canopy openness was measured from the photos, using a freeware Gap Light Analyzer ver. 2.0 (Frazer et al. 1999).

When tree annual seedling was observed in the quadrats, each seedling was marked by a numbered flag and was recorded on height, crown diameter and location.

From the outside of the plots, 22 tree cores were collected at 10-30 cm above the ground surface by an increment borer or by clippers. Tree ring width was measured under a stereomicroscope at 0.01-mm intervals.

Statistical analysis

The relationships between dependent factors (e.g., tree height) and independent factors (e.g., DBH) were preliminarily examined by linear

Photo 1. An example of a 10 m × 10 m plot established for the long-term monitoring. The ground surface was burned patchily, and all *Picea mariana* trees were dead in this plot, while moss cover remained patchily. This plot is categorized into moderately-burned site.

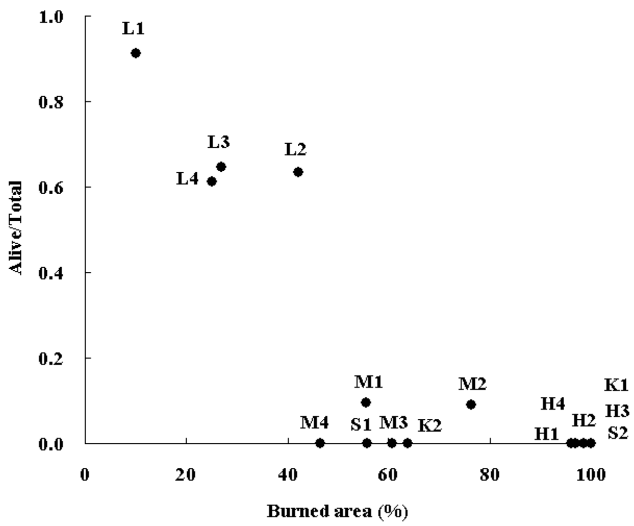

Fig. 1. Relationship between burned area and tree survival rate in the 16 plots. Plot codes assigned by fire intensities and/or the other remarks: H = heavily-burned, M: moderately, L = less, K = Kodama, S = Sawada.

regressions (Zar 1999). The difference in seedling density between unburned and burned areas was examined by χ^2-test. More robust analyses will be performed finally.

Results

Environments and fire intensities

The altitudes on the plots were between 244 m to 437 m. The slopes on all the plots faced 7.0°-43.5° from north to west. The slope gradient ranged from 4.8° to 19.0°. Frozen soil layer was detected in two plots located on the bottom of the slope at the summer survey, while the frost layer was indefinite in the other plots.

Even though the stems of *Picea mariana* were killed by the fire in 2004, the most of stem were standing because the fire burned stem surface layers up to a few centimeters deep in most cases. While, a few stems on the other tree species might be lost due to the fire. Therefore, we were able to reconstruct pre-fire forest structure well.

Table 1. The forest structures before and after the 2004 fire on the north slope of Poker Flat. Pre-fire forest structure is estimated by the sum of alive and dead stems, and post-fire one is determined by alive stems. Each numeral shows mean with standard error per plot. Ranges (minimum to maximum) are shown in parentheses.

	Pre-fire	Post-fire
Picea mariana		
Stem density	24.3 ± 3.9	5.3 ± 2.7
	(5-54)	(0-30)
Total cross-sectional area at breast height (cm^2)	439 ± 74	112 ± 58
	(95-1090)	(0-665)
Total stem volume (m^3)	9.2 ± 2.0	2.3 ± 1.4
	(1.0-28.0)	(0.0-16.9)
Others		
Stem density	0.8 ± 0.6	0.2 ± 0.2
	(0-7)	(0-2)
Total cross-sectional area at breast height (cm^2)	7 ± 6	2 ± 3
	(0-77)	(0-32)
Total stem volume (m^3)	0.0 ± 0.1	0.1 ± 0.1
	(0.0-0.6)	(0.0-1.4)

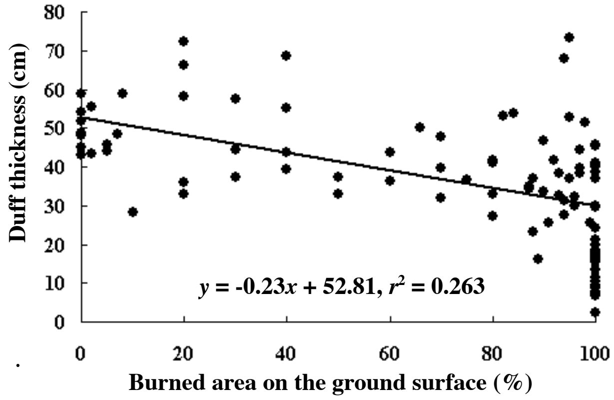

Fig. 2. Relationship between burned area and mean duff thickness in 80 1 m × 1 m quadrats.

Picea mariana was predominated in all the plots before the fire (Table 1), although the stem density and volume varied greatly. Namely, there were 5-54 *Picea mariana* tree stems ≥ 1.3 m in height on the plots, of which averaged density was equivalent to ca. 2400 stems/ha. On *Picea mariana*, total cross-sectional area at breast height and stem volume were 439 ± 74 cm^2 (mean ± standard error) and 9.2 ± 2.0 m^3, respectively. Three other tree species, *Alnus crispa*, *Betula papyriferea*[1] and *Salix* sp., were recorded with low frequency. Total number of alive and dead stem with ≥ 1.3 m in height on *Picea mariana* was 389, and that of the other tree species was only 13. Therefore, 96.8% of tree stems were *Picea mariana* before the fire. The maximum tree height was 13.0 m by *Picea mariana*.

Owing to the fire, 81.3% of *Picea mariana* stems were burned and dead, and the total stem volume declined about 77.9%. The ground surface was mostly covered by *Sphagnum* spp. By the fire, the plant cover on the forest floor, in particular, the cover of moss represented by *Sphagnum*, declined variously, i.e., 0%-100%

[1] This may be incorrect, and may be *Betula neoalaskana* Sarg. *B. neoalaskana* is similar to, but smaller (< 13 m in height) than, *Betula papyrifera*. *B. neoalaskana* twigs are densely covered with resin-glands.

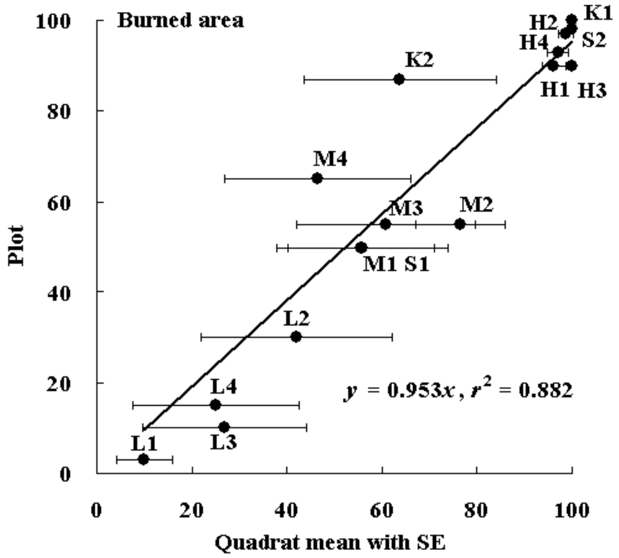

Fig 3. Relationship between averaged burned area of six 1 m × 1 m quadrats and whole burned area in the 10 m × 10 m plot. Error bars indicate standard error. Plot codes in the figure, refer to Fig. 1.

(Fig. 1). This result indicated that the forest floor was patchily burned with various scales. The thickness of duff layer ranged from 2.6 cm to 73.3 cm, and was negatively related to burned area (Fig. 2). Although the linear regression was statistically significant, the variation and/or range of duff thickness varied greatly.

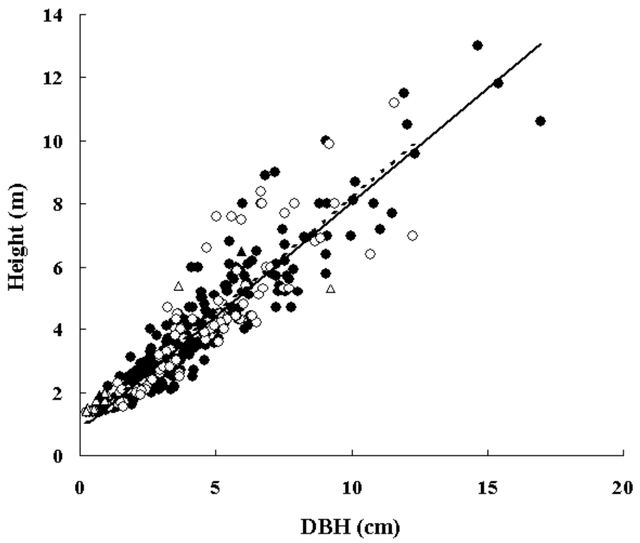

Fig. 4. Relationships between diameter at breast height (DBH) and tree height. Closed and open circles indicate alive and dead *Picea mariana* trees, respectively. Closed and open triangles indicate the other alive and dead trees, respectively. Solid and interrupted lines indicate linear regression lines on alive and dead *Picea mariana*, respectively. The regressions are obtained from *Picea mariana*.

For the further studies, we classified into three intensities of forest damages by the fire, i.e., less-, moderately-, and heavily-disturbed areas, based on burned area and ratio of alive trees (Fig. 3). Less-disturbed plot (hereafter, i.e., L) is characterized by high *Sphagnum* cover retaining on the ground surface and higher tree stem survival (Fig. 1). Moderately-disturbed plot (M) is situated between less-disturbed and heavily-disturbed areas, i.e., most trees were killed (Fig. 1) but the ground surface plant cover remained somewhat (Fig. 3). The burned area in plot was linearly correlated to mean burned area in quadrats on each plot. However, the variance of mean of burned area in quadrats fluctuated greatly, in particular, in moderately burned plots. Heavily-disturbed plot (H) is completely burned by the fire, i.e., all stems were killed and the more than 80% of ground surface was burned. Based on those investigations, we assigned L1, L2, L3, and L4 to category L, M1, M2, M3, M4, S1 and K2 to M, and H1, H2, H3, H4, K1 and S2 to H.

Canopy openness ranged from 57% to 95% on the 80 quadrats. The control forest, i.e., unburned in 2004, where the forest height was similar with the examined burned-area showed the canopy openness was less than 54%. Even on L plots, plant cover on forest floor declined up to 40% by fire (Fig. 3) and 5-40% of tree stems were killed (Fig. 1). Those results indicated that the surveyed area received fire damage, to some extent even on the less disturbed area, that increased canopy openness. Therefore, changes in the effects of solar radiation will be able to be monitored along fire-intensity gradient.

Tree age and size

Of 22 tree cores sampled, the maximum age was 174 with the height of 9.1 m. The relationship between tree height (m, independent variable x) and age (yr, dependent variable y) was explained well by a linear regression ($y = +0.049x + 0.050$, $r^2 = 0.78$, significant at $P < 0.01$). Stem height on *Picea mariana* was linearly related to diameter at breast height (Fig. 4). In addition, various sizes of stems were observed in the forest (Fig. 1). Not only large stems but also small ones were killed haphazardly by the last fire. Those indicated that the forest regeneration pattern before the 2004 fire was not simultaneously, and/or the previous forest fires killed randomly the established stems.

The stem-diameter growth has a peak at 40-60 years before 2005 on a few stems (Fig. 5), suggesting that drastic events, such as fire, occurred around 60 years before the present date.

Plant communities in herb layer

We have collected 96 quadrat data in the spring and summer of 2005, because quadrats used for destructive measurements had not been utilized. By the field observations and measurements, we have confirmed that a few shrub species could survive throughout the latest fire even on burned surface, e.g., *Betula nana* and *Ledum groenlandicum*[2]. The data will be analyzed by ordination techniques and others to extract significant environmental factors on plant community structures and to predict revegetation patterns. All voucher specimen will be kept in the Hokkaido University Museum (SAP).

Photo 2. An example of 1 m × 1 m quadrat for monitoring temporal changes in plant cover and seedling establishment. *Picea mariana* stem, that produced numerous cones, overlaid on the quadrat. *Ledum groenlandicum* recovered vegetatively on burned surface.

Seedling establishment patterns

In the spring of 2005, we marked 109 seedlings in the quadrats surveyed. Most seedlings were *Epilobium angustifolium*. The minorities were *Populus tremuloides* and *Calamagrostis cadandensis*. The seedling survival rate was ca 40% by the summer, while an individual of *Epilobium angustifolium* flowered in the summer.

In the summer, we marked 575 tree seedlings in the quadrats (Table 2). The first leading species was *Picea mariana*. The seedlings of this species appeared on both burned and unburned ground surfaces, but the density was significantly higher on unburned surface. In contrast, *Populus tremuloides* and *Betula papyrifera* established only on burned surface, although there was only 1 stem ≥ 1.3 m high on *Betula papyrifera* and no stems ≥ 1.3 m high on *Populus tremuloides* in the 16 plots surveyed. The relationship between micro-topography and seedling emergence will be determined, using fine scale photos taken by Sawada JJ (see his MS in this report).

[2] Note: The synonym of this species is *Ledum palustre* L. var. *groenlandicum* (Oeder.) Hulten.

Table 2. Numbers of seedlings recorded in burned and unburned areas. Density (/m^2) is shown in parentheses. Significant differences in seedling densities between burned and unburned areas are examined by χ^2-test for *Picea mariana* ($P < 0.01$). The significance test was not conducted for the other three species.

Habitat	Unburned	Burned
Picea mariana	353 (13.7)	105 (1.9)
Betula papyrifera	0	20 (0.4)
Populus tremuloides	0	96 (1.8)
Salix sp.	0	1 (0.0)
Total	353 (13.7)	222 (4.1)

Discussion

Fire patterns and forest structure

In the plots surveyed, the forest fire intensities were diverse from mild to severe. Mean annual biomass increment is higher in dry sites than in wet sites along a chronosequence on *Picea mariana* forests in Manitoba, Canada, but carbon pools in bryophyte, understory and forest floor are less for the dry than for wet sites (Wang et al. 2003). In *Picea mariana* forest, the ground surface is mostly covered by mosses, represented by *Sphagnum* spp., that may explain 80-90% of the aboveground biomass (Bonan & Shugart 1989). Forest fire, in particular, on north slopes in interior Alaska, usually occurs as crown fire and thus moss mat is removed incompletely (Bonan & Shugart 1989). When moss mat remains on the ground surface after fire, soil temperature keeps low. However, the complete removal of moss mat should promote soil temperature increase and/or melting permafrost (Yoshikawa et al. 2002). In permafrost-free areas, surface soils become dry because infiltration is not restricted (Hinzman et al. 2005). Those suggest that the patterns of removal and recovery of ground surface cover by fire are prerequisite to predict the fates of seedling emergence and growth.

Since global warming has modified climate and its related factors, including frozen layer in soils (Dale et al. 2001; Camill 2005), fire may become larger and more intense. Initial tree composition after fire had little effects on understory composition in the coniferous forests of eastern Canada, while soil burn severity significantly affected temporal changes in understory species (Lecomte et al. 2005). Those suggest that forest regeneration patterns after large-scaled fire differs from fires that have usually occurred so far.

Tree ring growth suggested that a fire might occur on Poker Flat approximately 60 years before the latest 2004 fire, although the intensity was not severe. We may confirm if changes in annual tree ring growth are related to the

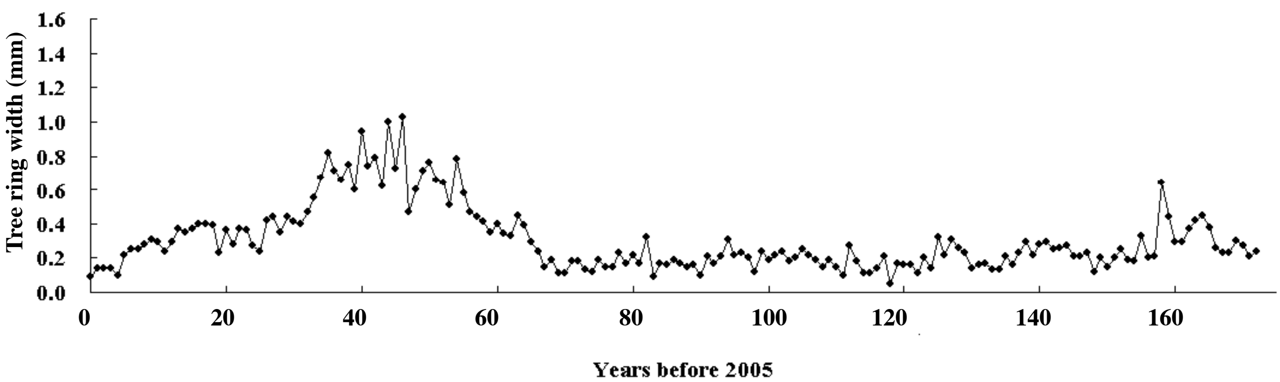

Fig. 5. An example of annual growth of tree ring on *Picea mariana*. The tree core was sampled from a tree with 8 m in height and 10.1 cm in diameter at breast height. The peak of growth is observed 40-60 years before 2005.

previous fire(s). In addition, based on the yearly fluctuation patterns of tree ring growth, we will examine if the estimation of fire intensity is possible on the forest level. Canopy openness influences the distribution pattern and productivity of herbaceous plants in the forest floor (Reich et al. 2001; Whigham 2004). We are monitoring canopy openness and its related factors, such as leaf area index and direct solar radiation.

The safe sites for seed germination differed between *Picea mariana* and broad-leaved tree species. Seedling recruitment on *Picea mariana* is highest in the first five years after fires, while additional establishment is not observed after 10 years (Johnstone et al. 2004). *Picea mariana* is well-known as producing serotinous or semi-serotious cones (Bonan & Shugart 1989), while the most of all broad-leaved tree species, i.e., *Betula*, *Populus*, *Salix* and *Alnus*, produce a great amount of long-distance, wind-dispersed seeds in the most of years. Therefore, the yearly fluctuation of seedling emergence should be monitored on those tree species.

The age structure of *Picea mariana* was not homogenous in the present study area. To clarify the determinants on the forest development, we have a plan to monitor the relationships between seedling establishment and various environmental factors. The most of environmental factors that are possible determinants on plant community recovery have been measured by the members in this project, e.g., soil temperature, albedo, microtopography, micro-climate, soil profile and ground surface stability. Those environmental factors, such as direct solar radiation, albedo and snow-cover period, interact with the plant communities (Liu et al. 2005).

Future plans

Based on the present results, we have a plan to monitor the following five subjects in 2006 and 2007. 1) plant community structures in the plots and quadrats, 2) safe sites for seedling establishment, 3) the effects of *Sphagnum* mat on the growth of seedling and sapling, and 4) canopy development, by fish-eye photos, 5) temporal changes in seed immigration, and seedling establishment. The other measurements described above well be conducted, *pro re nata*.

We believe that those investigations can clarify plant community-climate interactions with micro-and macro-scaled, spatio-temporal changes not only in boreal forests but also in various ecosystems after disturbances.

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