Monitoring the Influence of the Large Alaskan Forest Fires in 2004 on the Terrestrial Environment

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<td>15:45-16:00</td>
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<td>16:30-16:45</td>
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<tr>
<td>09:00-10:00</td>
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*Presentation held in IARC Conference Room 401*
Spectral characteristics of ground components one year after fire in an interior Alaskan black spruce forest

Keiji KUSHIDA
Institute of Low Temperature Science
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Abstract

Our final goals are to understand component spectral characteristics of black spruce fire chronosequence in interior Alaska, and to model and evaluate detectability of vegetation changes after fire and according carbon budget changes from remotely sensed data. In 2005, the spectral reflectances in 350 – 2500 nm were measured at 80 points (155 samples) in an interior Alaskan black spruce forest (Poker Flat site), which was burned in the summer of 2004, and analyzed the spectral separativeness of the representative ground components (burnt sphagnum mosses, damaged sphagnum mosses, live sphagnum mosses). The points were situated in or around the sixteen 10 m × 10 m plots established by Tsuyuzaki et al. For observing damaged sphagnum mosses and live sphagnum mosses, surface undergrowths on the mosses of the measurement points were removed. The spectral reflectances at all of the points were measured under entirely diffuse illumination conditions. When the solar illumination was specular, an artificial shadow was made on the objects and the reference panel. The spectral reflectances of 21 cases were observed under both specular and diffuse illuminations. As a result, we obtained spectral characteristics of burnt sphagnum mosses, damaged sphagnum mosses, and live sphagnum mosses, and the three had a significant difference. Further, the aerial ratio of the ground components were estimated by using the spectral characteristics and Landsat ETM+ imagery (resolution: 15 m – 30 m) taken on 4 Aug. 2004. The results can be used for base information to interpret MODIS (250 m – 1 km), and ALOS (2.5 m – 10 m) satellite data.

1. INTRODUCTION

Recent increase of forest fire in boreal forests in North America and Siberia causes environmental changes in the ecosystems, affecting global climate warming through greenhouse gases emission during the combustion and carbon dioxide and methane release after the fire (Hinzman et al., 2003). Remotely sensed data is useful for fire detection in a wide area, and hence, contribute to the estimation of the fire influence. For this purpose, not only burnt area estimation, but also monitoring of ecosystem and greenhouse gases budget changes after the fire is necessary.

Detection algorithms for boreal forest fires using NOAA AVHRR have been studied and the detachabilities have been evaluated (Flannigan et al., 1986; Cahoon et al., 1992;
Kasischke et al., 1993; Cahoon et al., 1994; Chuvieco et al., 1994; French et al., 1995; Fang and Huang, 1998; Galindo et al., 2003; Soja et al., 2004; Sukhinin et al., 2004; Kucera et al., 2005). These algorithms were based on thermal and mid-infrared bands, and in some cases, the thermal and mid-infrared bands were combined with visible to near-infrared bands to evaluate turning black from vegetation colors.

On the other hands, burn severity or vegetation recovery mapping of boreal forest fires with satellite remote sensing data have been studied since more recent time and in less number of studies in spite of the importance from the viewpoint of the greenhouse gas budgets. One of the reasons for this is that NOAA AVHRR, which covers continental scale twice a day, does not have 2 μm and adjacent wavelength bands, which is effective for the characteristics of burnt scars. Nevertheless, Landsat TM and ETM+, which cover every area in the globe once fourteen days with 30m resolutions, has the 2.09 – 2.35 μm band (Band 7). White et al. (1996) and van Wagtendonk et al. (2004) used the Landsat band as to evaluate the burn in the USA mainland. There are very few studies on burn severity or vegetation recovery mapping in boreal forests except in interior Alaska (Eptinga et al., 2005). They used Landsat TM and ETM+ for fire severity mapping, and proposed an appropriate remote sensing index for estimating a ground-observed composite burn index (CBI). The CBI was originally proposed as a general index for burn severity evaluation in Montana, and not specialized for the effect on the greenhouse gases emission from boreal forests, though Eptinga et al. (2005) modified the index for use in Alaskan boreal forest. In this study, we based on the field spectral observation of ground components as to evaluate burn severity of interior Alaskan black spruce forest. The ground components have different net primary productivities (NPP), and hence, area ratios of the ground components contribute to the carbon budget of the ground. Moreover, the area ratios influences not only carbon budget just after fire, but also recoveries of the vegetation.

The objectives are to understand component spectral characteristics of black spruce forest in interior Alaska, and to evaluate the burn severity with indicated relationship with carbon budget from remotely sensed data.

2. METHODS

The spectral reflectances in 350 – 2500 nm were measured in a black spruce (Picea mariana) forest (Poker Flat site) burnt in the end of June 2004. Almost the entire forest floor was once covered with a moss (Sphagnum spp.) seat, and burnt into patches of mosses, damaged mosses, and burnt scars in 10 cm – 10 m scales. We measured spectral reflectance at 80 points (155 samples) in 7 – 13 August 2005 in the site (Table 1). The points were situated in or around the sixteen 10 m × 10 m plots established by Tsuyuzaki et al. (in this proceedings). We set the three ground components as moss damaged moss, and burnt. A GER
2600 spectral radiometer (GER Corp., New York) was used, and reflectances of 0.15-m-diameter circles to the nadir direction at wavelengths in the 1.5-nm interval in 350 – 1050-nm and the 11.5-nm interval in 1050 – 2500 nm were observed by measuring emissions from the objects and a standard reflectance panel named Spectralon (Labsphere, Inc., North Sutton, United States) alternately at least 5 times. The time period of one emission measurement is about 3 – 5 s. When the solar illumination was fluctuating, the reflectance measurements at one point were repeated up to 10 times, five measurements that have similar reflectance values were chosen, and the others were eliminated. The coefficient of variations of the reflectance factors measured at each of the points were less than 3% in 350 – 1050 nm and less than 15% in 1050 – 2500 nm after diminishing noises by integrating each five neighbor wave bands. Each reflectance measurement consisted of 118 sampled wave bands. For observing “Moss” and “Damaged moss” (Table 1), surface undergrowths on the mosses of the measurement points were removed. All of the spectral reflectance was measured under entirely diffuse illumination conditions. When the solar illumination is specular, an artificial shadow was made on the objects and the reference panel. The spectral reflectances of some points were observed under both specular and diffuse illuminations (Table 1). The reflectance panel is corrected with a BaSO₄ standard.

3 RESULTS AND DISCUSSIONS

As a result of the component spectral measurements, the three components, which are moss, damaged moss, and burnt, were different spectral characteristics as shown in Fig.1. The averages include all the samples of direct and scattered solar illumination, and vegetation on the mosses removed and not removed. The burnt area has low reflectance throughout the observed wavelength, though in wavelength corresponding to Landsat ETM+ band 7, the burnt area had higher reflectance than the moss and lower reflectance than the damaged mosses. Table 2 shows the component reflectances in Landsat ETM+ bands. Among the six Landsat ETM+ bands (band 6 is thermal band), the bands 7 and 4 are the two of the most appropriate to distinguish the three components. The index calculated by dividing the band 7 by the band 4 gave separation between the moss and the group composed by the damaged mosses and the burnt. The use of the band ratio can reduce the atmospheric effect in satellite observations more than single bands and used as a burnt severity index in the previous studies (White et al., 1996; van Wagendonk et al., 2004; Eptinga et al., 2005), though the separation between the damaged mosses and the burnt was difficult using the index. By assuming the three components distributes horizontally and eliminating the effect of burned trees, from the result of the spectral measurements, we obtained the follows:

\[ C_m = 0.027B_4 - 0.021B_7 + 0.17, \]
\[ C_{dm} = 0.04B_4 + 0.14B_7 - 3.9, \]
\[ C_b = -0.067B_4 - 0.12B_7 + 4.7, \]  

where, \( C_m \), \( C_{dm} \), \( C_b \) are area ratios of the mosses, the damaged mosses, and the burnt, and \( B_4 \) and \( B_7 \) are atmospherically corrected reflectance in Landsat ETM+ bands 4 and 7. These parameters were used for mapping the burned severity on Landsat ETM+ imagery taken on 4 Aug. 2004 (path: 68, row: 15).

**Table 1.** Number of samples for spectral observation

( ) denotes the number of samples for observations under both specular and diffuse illuminations.

<table>
<thead>
<tr>
<th>Plot</th>
<th>Burnt scar</th>
<th>Vegetation on burnt scar</th>
<th>Damaged moss</th>
<th>Vegetation on damaged moss</th>
<th>Moss</th>
<th>Vegetation on moss</th>
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</thead>
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<tr>
<td>L1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>L2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>L3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5(4)</td>
<td>5(4)</td>
</tr>
<tr>
<td>L4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>M1</td>
<td>1(1)</td>
<td>4(2)</td>
<td>4(1)</td>
<td></td>
<td></td>
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<tr>
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<td>2(2)</td>
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<td></td>
<td></td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>M4</td>
<td>2</td>
<td></td>
<td></td>
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<tr>
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<td>1</td>
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</tr>
<tr>
<td>H3</td>
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<td></td>
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<td></td>
<td>5</td>
<td></td>
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<tr>
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<td>13(10)</td>
<td>20(9)</td>
<td>21(6)</td>
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Fig. 1. Spectral characteristics ground components of interior Alaskan black spruce forest one year after fire

Table 2. Field-observed spectral characteristics one year after fire of black spruce forest in Landsat ETM+ bands (Average±S.D., Unit: %, Numbers of samples are; Moss: 42, Damaged moss 33, Burnt: 38)

<table>
<thead>
<tr>
<th>Band</th>
<th>Wavelength</th>
<th>Moss</th>
<th>Damaged moss</th>
<th>Burnt</th>
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</thead>
<tbody>
<tr>
<td>Band1</td>
<td>0.45 ~0.52 μm</td>
<td>5.2 ± 2.1</td>
<td>5.8 ± 1.8</td>
<td>4.0 ± 1.5</td>
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<tr>
<td>Band2</td>
<td>0.53 ~0.61 μm</td>
<td>9.8 ± 4.4</td>
<td>8.1 ± 3.6</td>
<td>5.5 ± 2.2</td>
</tr>
<tr>
<td>Band3</td>
<td>0.63 ~0.69 μm</td>
<td>14.7 ± 10.0</td>
<td>18.8 ± 7.1</td>
<td>9.0 ± 4.0</td>
</tr>
<tr>
<td>Band4</td>
<td>0.75 ~0.90 μm</td>
<td>42.3 ± 14.6</td>
<td>16.8 ± 8.2</td>
<td>12.3 ± 6.7</td>
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<tr>
<td>Band5</td>
<td>1.55 ~1.75 μm</td>
<td>23.0 ± 9.9</td>
<td>28.8 ± 11.1</td>
<td>21.2 ± 10.8</td>
</tr>
<tr>
<td>Band7</td>
<td>2.09 ~2.35 μm</td>
<td>19.2 ± 9.6</td>
<td>31.7 ± 10.0</td>
<td>25.5 ± 7.1</td>
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<tr>
<td>Band4</td>
<td>0.45 ——0.45 μm</td>
<td>0.45 ± 0.05</td>
<td>2.1 ± 0.6</td>
<td>2.4 ± 0.8</td>
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</table>

Band7  | Band4
4 CONCLUSIONS

We measured spectral reflectance from three main components one year after interior Alaskan black spruce fire, and proposed Landsat ETM+ band 7 divided by Landsat ETM+ band 4 as an index that indicate the area ratio of the ground components and evaluate burnt severity from the viewpoint of the carbon budget and the forest recovery. The index was used for evaluating the fire severity of 2004 interior Alaskan forest fire with a Landsat ETM+ image.

In the previous study, we built a remote-sensing method for determining leaf area index (LAI) and ground cover mosses/lichens in interior Alaskan spruce forests by field component spectral observation and radiative transfer modeling based on the spectrum (Kushida et al., 2004). The method was applied to evaluate annual net ecosystem productivity (NEP) distribution in a black spruce forest, interior Alaska, by accounting for net primary productivity (NPP) of the vegetation compositions and soil respiration observation synchronized to the spectral observation. Along this methodology, inclusion of ground component spectrum just after fire and knowledge on carbon budget based on the component contributes to evaluate the fire severity in the context of carbon budget. The results can be used for base information to interpret MODIS (250 m – 1 km), and ALOS (2.5 m – 10 m) satellite data.

REFERENCES


Abstract:

In 2004 and 2005, many large-scale forest fires had occurred in Alaska. Many severe damages occurred in Alaska, nevertheless this is a good chance for scientists to investigate various phenomena arose as a result of forest fire from various points of view. Before large fires occurred, only a few burnt areas can be accessible by car from Fairbanks. But after large fires, we can easily visit several burnt sites.

2004 Boundary fire, 2005 Fish Creek fire and 2007 Eagle Summit were chosen as investigation areas. In these forest fire or burnt areas, thickness and weight measurement in burnt or unburned forest floor, sampling of vegetation, situation observation and counting of stand and fallen trees in severely burnt area, surface temperature measurement on burnt and unburned forest floors, smoke observation near actual fire site, observation of slow flame propagation at actual fire site, observation of forest fire site in steep slop, observation of landslide due to forest fire in steep slop and observation of highland tundra fire were carried out.

One spot of Poker flat area within 2004 Boundary fire region were investigating intensively by more than ten Japanese researchers of various research fields from 2005. We also joined this intensive field investigation. Two 20 x 20 m research areas were chosen in unburned and partially burnt respectively. Each research areas were also divided into four areas. Measurement and sampling were carried out in the center of each four divided areas. Thickness and weight measurement were done by making 20x20 cm size hole in the forest floor at the center of each divided areas. Sample of vegetation, mainly moss litter and duff, were chosen from 20x20 cm cut blocks. As a preliminary result of measurement, thickness of moss litter in partially burnt area is 40% thinner than that of unburned area. Carbon content (t/ha) of moss litter in partially burnt area is 23% smaller than that of unburned area.
Abstract
Impacts of boreal forest fires have absorbed intensive attention because of huge fires in these years in Alaska as well as Siberia. To reduce impacts of forest fire in boreal forest area, the early fire detection is one of essential components in firefighting activity because of difficulties of fire suppressing in remote area without water. Here, we developed fire detection information system from receiving AVHRR to output fire detection map and validated the early detection algorithm using AVHRR satellite imagery. Forest fires were detected using an algorithm; two-dimensional histogram method by Prof. Kudo. This algorithm uses a threshold on mid-infrared band 3 and a two-dimensional histogram of visible band 1 and thermal infrared band 5 as a looking up table; these detection criteria corresponds becoming to burnt to black, thermal emission by burning. As a ground truth data, we collected reports of fires observed by local firefighters in Siberia and reports of JAL passenger flights. We compared satellite detected pixels with location of reported fires. We aggregated this comparison by fires to estimate the fire detection rate and early fire detection rate. We found the fire detection rate was surprisingly different between fires reported by firefighters and by passenger flights. Finally, we found the reason of the different fire detection rate as scale of fires observed. This implies difficulty on forest fire detection especially for small sized forest fires, and also implies the importance of ground truth data especially reported by fire fighters. We are planning extend the area collecting ground truth data delivered from local firefighting agencies in Alaska and Siberia from this summer season to validate the forest fire detection algorithms using AVHRR and MODIS. As a preparation, we made a system to detect forest fires every day automatically for area of entire Alaska last summer.

1 Introduction
Recently, burnt area of boreal forest fire is rapidly increased comparing to 5 decades as well known. Boreal forest fires cause not only these direct emissions, but also methane emission through permafrost melting and continuous carbon dioxide emission accompanied by organic matter decomposition after severe fire. To reduce those impacts, suppression of fires would be important in such difficult condition, especially early detection of forest fire is very important for us to suppress boreal forest fire. Both in Siberia and in Alaska, firefighting agencies utilize airplanes
for firefighting. Especially in Siberia, government has a large firefighting agency, Avialesookhrana, as an air fire fighting agency. This agency has 4 thousand firefighters and covers all Russian territory. Firefighters jumps into burning forest with a parachute or slide down along rope. Then, they need to firefighting without water. For example, they cut off trees to make a fire prevention band and sometimes make an against fire to stop the fire expansion. However, budget of the Avialesookhrana is 32million USD [Hodges, 2002] and is less than firefighting cost used by Alaska Fire Service in 2004, although Avialesookhrana covers 10 times more than forest area protected by Alaska Fire Service [Kakizawa, 2002]. This budget constraint implies that efficient firefighting activity is massively important.

In this study, we evaluate a fire detection algorithm on NOAA AVHRR imagery with Russian practical fire detection by using airplanes and airplane detection by Japan Airlines (JAL) and we performed a fire detection using MODIS imagery on Alaska to extend the research area from Siberia to Alaska.

**Part I Validation of fire detection algorithms**

**2 Methods and objectives**

NOAA AVHRR satellite imagery was collected and stored into the database during June 9th to August 7th, that covers 1000 km x 1000 km square area centered at Yakutsk in west Siberia. We collected satellite imagery received in Krasnoyarsk, Russia and in Sendai, Japan. Total number of satellite imagery was 545 with duplex pass and 249 without duplex of same pass received by different stations.

As well as satellite imagery, we collected ground truth data from two sources. The first is local firefighting agencies in west Siberia and the second is JAL passenger flight between Japan and Europe through Siberia. Each data source reports ground truth data as following ways.

As for local firefighting agencies, firefighter send observation data of forest fire to a local firefighting agency, and then the agency sent reports to co-researchers in Yakutsk, Irkutsk and Krasnoyarsk. Then, co-researchers register those reports via web database system in Hokkaido University. This database was shared with all of our co-researchers. Observation report was collected from 9th June to 7th August. As for reports from pilots on flight via Siberia, if a pilot of JAL passenger flight finds a fire in Siberia from sky, the pilot sends a report to the company office in Tokyo via short wave radio communication. Then, the communicator registers the report via web database system in Hokkaido University. Observation report was collected from 1st June to 31st July.

The number of reports delivered from each source was 750 and 101 respectively, and the number of reports excluding duplex of same fire from each source was 83. The numbers of these data are shown in Table 2. Location of all reports in our study area is shown in Figure 1.
Table 1: Numbers of reports of boreal forest fires in Siberia region, and duration of collecting reports.

<table>
<thead>
<tr>
<th>Data Source (in 2003)</th>
<th>Duration</th>
<th>Number</th>
<th>Exclude duplication</th>
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<tbody>
<tr>
<td>NOAA AVHRR Imagery</td>
<td>Jun., to 10. Aug. 1.</td>
<td>545</td>
<td>249</td>
</tr>
</tbody>
</table>

Figure 1: Plot of forest fire reports reported by Russian firefighting agencies and JAL passenger flights from 2003 to 2005. (Red star plots correspond to Russian agencies and black diamond plots correspond to reports from JAL passenger flights projected on Miller Cylindrical.)

Figure 2  An example of comparison of a time series of satellite imagery with a ground observation (We compared a forest fire observation data with a series of satellite imagery from 5 days before the observation to 5 days after observation. In this case, 9 scenes were compared with a forest fire observation and corresponding hotspots were detected on 4 scenes.)
3. Results

We compared 214 reports delivered from local firefighting agencies and 19 reports delivered from JAL with satellite imagery of Yakutsk area. Number of pairs of ground truth data and satellite imagery was 5560 for Russian local agency and 504 for JAL. For Russian agency, reported ground observation point is not used to forest fire detection in 53.5%, that includes not covered by satellite imagery (32.1%) and Cloud covers ground (21.4%) according false color AVHRR imagery. Thus, 46.5% of pairs are valid for ground observation for ground truth data delivered by Russian agencies in this study. Hotspots are detected, in 379 satellite imagery 14.7% among 2586 valid pairs.

Although the rate of detecting hotspot is limited, we can find forest fire in better rate using a series of satellite imagery. Therefore, we aggregate comparison results for each forest fire observation report as shown on Figure 3 to find an earliest hotspot corresponding to the forest fire report. As shown on Figure 3, some scene in time series has corresponding hotspots but in some scene the location of forest fire was not covered. If one scene of imagery has hotspots, we can find the forest fire using satellite imagery at least. Especially, if one scene of imagery earlier than the observation by firefighters or by JAL has hotspots, we can find the forest fire earlier than local agencies. Based on this point of view, we defined a term success of fire detection as a case that at least one corresponding hotspot is detected in compared satellite imagery. Here, a corresponding hotspot was defined as a hotspot found within 10 km around reported location during 11 days around forest fire observation date. We also defined success of early detection of forest fire as a case that at least one hotspot is detected on earlier satellite imagery than forest fire observation. The reason why we accept the location difference of ground truth and hotspot derived from satellite imagery for 10 km is that we utilized AVHRR imagery without geolocation collection because of technical reason. AVHRR imagery without geolocation collection has error for 10 km in maximum [Pergola and Tramutoli, 2003]. We also defined the forest fire detection rate as a rate of success of forest fire detection among all reports. Among success of forest fire detection, we counted the case of fire detected earlier than ground observation. We defined success of early detection as success to detect reported forest fire before ground observation date. We also define the rate of early detection as rate of success of early detection among all reported fires. This forest fire detection rate is shown on table 2.

<table>
<thead>
<tr>
<th>Fire observed by</th>
<th>Number of reports</th>
<th>Detected by satellite</th>
<th>Total detection rate</th>
<th>Detected before observation</th>
<th>Early detection rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Russia</td>
<td>214</td>
<td>87</td>
<td>41%</td>
<td>53</td>
<td>25%</td>
</tr>
<tr>
<td>JAL</td>
<td>19</td>
<td>18</td>
<td>95%</td>
<td>15</td>
<td>79%</td>
</tr>
<tr>
<td>Total</td>
<td>233</td>
<td>105</td>
<td>45%</td>
<td>68</td>
<td>29%</td>
</tr>
</tbody>
</table>

4. Conclusions

As shown on Table 2, the forest fire early detection rate of forest fires reported by firefighters was as low as 25% in spite of high fire detection rate as 79%. There are a couple of
possible technical reasons which affect the fire detection rate including; the number of available imagery was limited, many of pixels corresponding to the reported fires are too slant to detect forest fires for far place, and detection analysis was limited to NOAA-16. We checked these possible reasons to identify massive difference of observation by firefighter and by JAL passenger flight. This deference between detection rates for Russian agency and for JAL passenger flight would be caused by the deference of scale of fire, because the shorter observation distance by firefighter around a couple of 100 meters altitude enable to observe smaller forest fires less than 1 ha.

Pert II  Fire detection using MODIS satellite imagery

2 Methods and objectives

As a preparation of the early fire detection and fire expansion simulation, we performed fire detection using MODIS satellite imagery as a daily product. MODIS satellite imagery received on Fairbanks was stored on a data server in IJIS room. Hot spots were detected using these MODIS satellite imagery as a daily product using a fire detection algorithm by [Kaufman, 2003]. We developed a program to process from raw satellite imagery to hotspot image reprojected to UTM projection covering Alaska area automatically as a daily product.

3. Results and Conclusions

Hotspots are detected for MODIS satellite imagery, which are reprojected to UTM projection. Imagery on Figure 3 is an example series of hotspots plotted on MODIS true color imagery. This series of imagery shows a fire expansion of forest fire from July 22. to 25, and fire depression from July 29.

Figure 3: A series of imagery with detected hotspots of forest fires by MODIS. (Red plots correspond to hotspots, yellow line to highways. Imagery includes Fairbanks on the bottom, Coldfoot on the top and Circle on right side.)
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Preliminary report on 2005 and 2004 Alaska forest fires

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Abstract

In 2004 and 2005, many large-scale forest fires had occurred in Alaska. The burnt area in 2004 was 26,142 km² and it was 18,816 km² in 2005. They were respectively the first and the third historical record since 1956. The cause of these fires is now under investigating. This is a preliminary report on these fires.

In 2004, severe lightning in June and July had caused most fires. Not a few fires grew into large-scale fires with the help of severe drought and Chinook or foehn phenomena. As a result, the total burnt area reached about 26,000 km² and it is almost the same area of the Lake Erie.

One of the large-scale fires called “Boundary fire” occurred near Fairbanks was chosen to investigate fire growth process in detail. Boundary fire has been considered as a second largest fire in 2004. Fire growth of large-scale forest fire was clearly showed by some analytical results of the hot spot (fire), climate, and fire history data. “Boundary fire” and other fires became a large-scale fire for the following processes.

1. Sever lightning occurred in the beginning of June and ignited various places in the boreal forest in Alaska. One of these lightning ignited the forest in “Boundary fire” area on 13th June and first hot spot was detected on 18th June.
2. First hot spot peak appeared on 30th June due to the dry weather conditions that made by Chinook.
3. Most fires were self-extinguished or lost activeness due to the large massive smoke from severe fires.
4. Second hot spot peak was found on 13th July and made by drought from the beginning of June.
5. Most fires in the second peak were extinguished due to the rainfall of the end of July.
6. Third hot spot peak appeared on 11th August due to the drought from the beginning of August.

1. INTRODUCTION

The boreal forest or Taiga occupies one third of forest area in the world. From spring to fall, the risk of fire is high in this region due to low precipitation regime which amounts to less
than 300mm. Due to ongoing global climate change, fire incidence in high latitude may increase because of the observed decreasing trend of summer precipitation.

In 2002, many large-scale forest fires occurred near Yakutsk, the capital city of the Sakha Republic in Siberia. The total burnt area was estimated at more than 23,000 km², this burnt area is the largest reported in Sakha since 1955 and about ten times larger than mean burnt area (about 2,400 km²).

In 2003, forests near the Baykal lake in Siberia burned severely. The total burnt area in Russia (whole Siberia) was estimated at more than 234,000 km².

In 2004, many large-scale forest fires occurred in Alaska. The main cause was lightning. Many of them grew into large-scale fires due to severe drought conditions and the presence of Chinook or Foehn phenomenon. As a result, the total burnt area in 2004 was about 26,000 km², the largest historical record since 1956.

To protect the Taiga from severe forest fires due to global climate change, it is important to investigate the trends and characteristics of not only forest fire occurrences but also weather.

2.  FOREST FIRES IN ALASKA

2.1 History of Forest Fire and 2004 Fire

Alaska Forest fire history data from 1956 was obtained at the University of Alaska, Fairbanks (UAF) and at the Alaska Fire Service (AFS).

In Fig.1, bar graph indicates burnt area and line graph shows number of fires. Smaller bar and line indicate lightning caused forest fires. There is a big difference between the two lines but difference between the two bars is very small. This indicates that forest fires in Alaska are mainly caused by lightning and they account for much of the burnt area and for about 40% in the number of fires.

![Fig. 1  Forest Fire History in Alaska (1956—2005)](image-url)
In 2004, many fires occurred despite remarkable high precipitation in May for most of Alaska. Rainfall was observed in mid May through mid June due to strong convection. But a long drought period (about one month) in June-July and strong Foehn winds increase the activity of fires ignited by lightning. Thus, the total burnt area in 2004 became the largest since 1956.

2.2 Recent Tendency of Forest Fire and Lightning

Forest fire data from 1986 to 1999 and lightning data from 1989 to 1999 were processed to characterize average occurrence tendency of forest fire and lightning in Alaska (Hayasaka, H., 2003). Fig. 2 was drawn to show general trend of forest fire and lightning in Alaska. As explained below:
1. Almost all forest fires start or are ignited in June and July.
2. Forest fire occurrence peak appears in early July.
3. Occurrence date of the ten largest fires is shown in Fig.2 using numbers from 1 to ten. These numbers are next to the X-axis of Fig.2. Large fires mainly occur in June.
4. Lightning has two occurrence peaks, namely in early and mid July.
5. First lightning peak in early July corresponds with the forest fire occurrence peak.
6. Second lightning peak in mid July could not ignite forest as first peak did. This may be due to increasing rainfall.
7. Half of lightning occurs until the end of June while 80% occurs until mid July.

![Fig.2 Forest Fire and Lightning Tendencies in Alaska](image-url)
3. VARIOUS ASPECTS OF FOREST FIRES IN 2004

3.1 Forest Fire Activity Trend using Hot Spot

Number of daily hot spots detected by NASA using MODIS images was plotted in Fig.3. Hot spot (HS for short hereafter) is detected by infrared radiation sensor. Spatial resolution of HS is about 1.1x1.1 km. HS does not always mean fire but it is a useful tool to understand fire activities in a large area such as Alaska.

From Fig. 3, first HS or fire was found at day number 162 (DN for short hereafter). Fire started just after rainfall in early June. Three HS peaks exceeding 2500 are found in Fig.3. These fire peaks occurred on DN=181(6/29), 195(7/13) and 234(8/21).

![Fire Occurrence Tendency Using Hot Spot](image)

Fig.3  Fire Occurrence Tendency Using Hot Spot

3.2 Forest Fires Observed By Satellite

A Terra satellite image for DN=181(6/29) or most fire active day is shown in Fig.4. From this image, a few characteristics of 2004 fires are derived.

1. Many fires occurred at small limited area of Interior Alaska shown by a triangle with white line in Fig.4. This area is mostly surrounded by the Alaska and Dalton Highway and the Canadian border (vertical straight line in Fig.4). We may say that this area is the so-called large-scale fire free area found in the Alaska Fire History Map provided by AFS.
2. Many fires had straight long smoke tails. This means fire became active due to strong wind from east and northeast.
3. Massive smoke from fires was formed in the central of Yukon basin or in the west of Fairbanks. Smoke headed westward.
3.3 Forest Fires Distribution and Fire Expansion

Two fire maps near Fairbanks are shown in Fig. 5 to display fire location and size clearly. Left-hand and right-hand maps in Fig. 5 are for DN=180 (6/28) and DN=234 (8/21) respectively. Relatively large forest fires will be called by name such as “Boundary Fire” in Fig.5. In this paper, numbers from 1 to 24 were used to identify a fire like the one shown in Fig.5. For example, there is a big difference between shapes of fire affected area near figure 1. Thus, fire expansion will be easily grasped by comparison of two maps in Fig.5. “Boundary Fire” (figure 9) finally became one of the largest fires of Alaska in 2004.

3.4 Precipitation and Drought

Precipitation measured at Fairbanks is plotted in Fig.6. Integrated precipitation from DN=122 (5/1) is shown by a line. A drought period will be easily found on the line graph. The 39-days (DN=164~202) drought period started just after record precipitation in May. During this long drought period, two fire peaks appeared at DN=181 and 195 as shown in Fig.3. The second drought in August is responsible for the third fire peak at DN=234 shown in Fig.3.
4. THE BOUNDARY FIRE AND WEATHER

4.1 Outline of The Fire

The Boundary Fire, located about 32 km Northeast of Fairbanks, was ignited by lightning and detected on June 13 (DN=165). Rapid expansion of fire occurred due to Northeast wind and severe drought. Final burnt area reached 2,174 km$^2$. This value accounts for 8.4% of total burnt area in Alaska. Thus, the Boundary Fire was the second largest fire in 2004.

Two fire peaks were found on DN=181(6/29) and 199(7/17) in the fire trend of the Boundary Fire (Fig. 7). These two peaks correspond closely to the first two peaks in June and July in Fig. 3. In Fig. 7, there were two fire active periods from DN=179(6/28) to 184(7/2) and from DN=194(7/12) to 199(7/17). The Boundary Fire did not show a third peak in August. One of the reasons may be due to complete fire suppression done by the type I incident management team.

4.2 Fire Expansion Analysis Using Hot Spot Data

Hot spot data released from NASA contains information about location, acquisition date and time and so on. Hot spot distribution plotted above a map of the Boundary Fire is shown.
in Fig.8. Number of hot spots on June 28 was 208 and is shown by square symbols. Plot of hot spot was done with the help of CAD software.

![Map of the Boundary Fire and Hot Spot Distribution](image)

As many overlapping squares of hot spot are found in Fig.8, it is difficult to get clear information regarding burnt area. One of the authors is now developing a new and simple method with the help of CAD function to obtain burnt area from hot spot data. Obtained burnt area is expected to contain certain error originated mainly from the capability of infrared sensor in MODIS. But burnt area from hot spot data closely matches the value announced by the Alaska Fire Service. Both values are plotted in Fig.9. Final error was about 20%. This difference may arise from undetectable small fires and the simplified method still being under developed.

![Comparison of Burnt Area Values](image)

**4.3 Weather During The Boundary Fire**

Weather data was measured from DN=153 (6/1) to DN=213 (7/31) at the top of Carib Peak (peak height 773m) as shown in Fig.8. The Carib Peak is located at the west end of the
Boundary Fire. As fire came near the Carib Peak, a long and wide fire line developed on the ridge-way.

### 4.3.1 Relative Humidity and Air Temperature

Relative humidity and air temperature are shown in Fig. 10. Two rectangles show fire active days when number of hot spots exceeds 100. Two straight lines show the first hot spot detecting day and first hot spot free day except DN=210.

The Boundary Fire was ignited by lightning on DN=165(6/13) and the first hot spot was detected on DN=170(6/18). Just after this day (DN=170), temperature increased to nearly 28 degree C. On the other hand, relative humidity dropped to 20%. After that, temperature gradually decreased and humidity went up slowly. But temperature rose to 26 degree C and humidity dropped to around 30% again on DN=179 (6/27). From this day, fire became very active. Number hot spots exceeded 100 (Fig. 7).

From Fig.10, a certain level of daily maximum temperature and minimum relative humidity were found in two fire active periods. They are about 25 degree C (30 degree C at sea level) and roughly under 50 % (30-40% was found during the first fire active period) respectively. Fire will be active provided that both conditions are met.

![Relative Humidity and Air Temperature](image)

**Fig.10** Relative Humidity and Air Temperature

### 4.3.2 Wind Speed and Direction

Wind speed and direction are shown in Fig.11. Foehn winds called Chinook are easterly winds in summer according to the Alaska Fire Service. First Chinook wind blew on
DN=157(6/5) and continued for a few days. On DN=157, 2004 first hot spots or fire were detected (Fig.3).

In the Boundary Fire, Chinook played an important role in the first fire active period from DN=179(6/28) to 184(7/2). Almost constant wind direction (east-northeast) and strong wind (about 6.5 m/s on DN=180 to 184) were detected during the first fire active period (Fig.11). Crown fire could occur if wind speed exceeds 4.47 m/s (10 mph) according to AFS. Crown fire occurred and it explains the rapid fire expansion detected (Fig.9) and thick smoke accumulation found in the satellite images (Fig.4). About half size of the Boundary Fire burned during the first fire active period.

By the end of the first fire active period, wind began to blow from an opposite direction, namely west. Westerly wind with relatively high speed (6 m/s) continued to blow for about one week from DN=186 to 193. But fires did not become active because relative humidity was high (from 50 to 100%) and temperature was low (from 7 to 18 degree C, see Fig.10). Under these conditions, crown fire may hardly occur.

In the second fire active period from DN=194(7/12) to 199(7/17), wind direction was not stable but wind blew mainly from west and south with relatively low wind speed of about 3 m/s. Nevertheless fire become active because relative humidity was below 50 % and temperature became high (from 15 to 27 degree C, see Fig.10).

![Fig.11  Wind Velocity and Direction](image)

**4.3.3 Solar Radiation**

In the first fire active period from DN=179(6/28) to 184(7/2), rapid solar radiation decrease of about 60% was observed (Fig.12). It was from about 750 W/m² on DN=178(6/27) to 300 W/m² on DN=181(6/30). This significant solar radiation reduction was caused by
dense fire smoke. Dense fire smoke may shield sunlight to ground considerably. Under dense smoke, maximum temperature was gradually decreased to 15 degree C on DN=192(6/10). After this, temperature gradually recovered to 24 degree C on DN=194(6/12).

This temperature descent due to significant solar radiation reduction by dense fire smoke may affect local weather. Under low temperature and high humidity condition, fire could not be active. In other words, fire break was made by smoke from fire itself. We can conclude that there was a small-scale weather change due to fire smoke and a negative feedback called “self-extinguishment” occurred in the Boundary Fire.

5. CONCLUSIONS

First, forest fires in Alaska were discussed using fire history, recent fire and lightning tendencies. Forest fires in 2004 were visualized and analyzed with the help of NASA MODIS data. Hot spot data was used to display daily fire activity.

Second, one of the large-scale fires called “Boundary fire” that occurred near Fairbanks was chosen to investigate the relationship between fire expansion and weather condition in detail.

Conclusions are listed below.
1. In 2004, large fires occurred according to recent lightning and fire occurrence tendency. Namely, many fires ignited by lightning in June as usual but became very active at the end of June due to strong Chinook and long droughts.
2. According to weather data measured at the Carib Peak near the Boundary Fire area, Chinook occurred on DN=179(6/27) and lasted about six days. During Chinook, east-northeast wind speed was about 6 m/s, maximum temperature reached about 31 degree C (at sea level) and low relative humidity decreased to about 35%.
3. Thus, the first peak of hot spot (fire) on DN=181(6/29) occurred and it corresponded to the first lightning peak of normal year.
4. The second fire peak also appeared on about DN=195(7/13) and also followed the recent tendency of lightning.

5. Fire ceased after the first fire peak. Many fires may be self-extinguished or lost strength due to the dense and large massive smoke from severe fires.

6. The third hot spot peak appeared on DN=234(8/21).

This late summer or autumn fire may occur due to drought from the beginning of August. Autumn fires are responsible for about one third of total burnt area in 2004.

Autumn fires also occurred in the Taiga forest near Yakutsk (Far East Siberia) in September 2002 (Hayasaka, H., 2004). The cause of autumn fire may be due to climate change.

Forest fires in 2005 were also very active in Alaska. As a result, number of fires is almost the same as in 2004 and the total burnt area will reach about 60% of the previous year. It will be the third fire active year in the past 60 years.

Active fire occurrence of two consecutive years has seldom occurred. A four-year interval was reported by Kasischke, E.S., Williams, D. and Barry, D (2002). Relationship with El Nino episode was investigated by Hess, J.C. and et. al. (2001). Recent climate change on boreal forest fire activities in Alaska should be more thoroughly studied (Stevens, E. and Dallison, D, 2005). New strategies facing climate change conditions should be introduced to keep the Taiga saved from being permanently depleted by forest fires. The authors will continue to clear present fire situation in Alaska from various scientific points of view.

ACKNOWLEDGMENT

Many data used in this paper were obtained from various agencies and universities in the United States. The authors would like to express our appreciation to their assistance and cooperation. Fire history data was provided from University of Alaska Fairbanks (UAF) and Alaska Fire Service (AFS). Weather data was from UAF. Satellite image and hot spot data was courtesy of MODIS Rapid Response Project at NASA/GSFC. Fire maps were provided by the United States Department of Agriculture (USDA) Forest Service and AFS.

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Assessing the Severity of the 2004 Alaskan Fires through Satellite and Field Observations

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We are just beginning the second year of two NASA funded research projects whose focus is on developing approaches to estimate the amounts of carbon released during the burning of surface organic layers in black spruce forests and peatlands that are common throughout the North American boreal forest. The objectives of these studies are fourfold: (a) to quantify the variability in surface fuel consumption that occurs during boreal fires in North America; (b) to understand the factors that cause this variability; (c) to assess using information derived from satellite imagery to map variations in surface characteristics that can be related to surface and aboveground fire severity; and (d) to incorporate our improve understanding of factors resulting in variations in burn severity into the Terrestrial Ecosystem Model to examine how variations in the North American fire regime have influenced terrestrial carbon source-relationships in this region (see paper by Balshi et al.).

During the first year of our study, we focused on: (a) conducting field studies in the fires that took place in interior Alaska in 2004 and 2005 to collect data to measure the variability in surface fuel consumption in black spruce forests and to assess fire severity using different indices (such as the composite burn index); and (b) assessing the relationship between the composite burn index and the normalized burned ratio derived from Landsat imagery. Results from these studies will be presented, along with our plans for further field studies during 2006 will be presented.
Assessment of Remotely Sensed Index for Mapping Burn Severity in Interior Alaska’s Black Spruce Forests

Alaska experienced two large fire seasons in 2004 and 2005 with over 6.7 and 4.5 million acres burned, respectively. A large portion of these burns occurred in black spruce (Picea mariana) ecosystems of Interior Alaska.

Land managers and fire management officials are especially interested in the effects of burn severity on future stand trajectories in black spruce ecosystems because of issues related to wildlife habitat improvement and natural fuel breaks. However, the remoteness and scale of Alaskan fires prevent feasible ground or aerial truthing of burn severity.

Burn severity assessments in Alaska’s black spruce communities are potentially amenable to remote sensing. Based on research in Alaska and the lower-48, there is a strong linear relationship between a remotely sensed index, the Differenced Normalized Burn Ratio (dNBR) and a field-based metric, the Composite Burn Index (CBI). However, the strength of this relationship has not been specifically tested within the black spruce communities of Interior Alaska and our goal is to assess the correlation within this one vegetation type.

Our objectives are:

1. Determine the association between a remotely sensed burn severity index (dNBR) and a field-based burn severity metric (CBI) within black spruce communities.

2. Assess the sources of variation in the remotely sensed burn severity index including:
   a) Date of pre and post-fire imagery
   b) Canopy versus soil burn severity field estimates
Ground Surface Burn Severity Index based on Thermal Conductivity Measurements

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ABSTRACT
It is important to evaluate the burned severity related to the impacts of thermal regime of permafrost and ecosystems. At Poker Flat, the profiles of thermal conductivity in upper layers were obtained by means of in situ measurements. The residual organic layer depth is determined by the profiles of thermal conductivity measurements. The difference of thermal conductivity between unburnt and burnt sites is about one order magnitude. Therefore using thermal conductivity profile at each site, the severity of burn is clearly defined. At the most severely burnt site in Poker Flat, only a few centimeter of organic layer was detected. The following impact of loss of organic layer is deepening of active layer. Some estimation of active layer change is conducted.

1. INTRODUCTION
At the time of prescribe burn experiment “FROOSTFIRE”, some part if the area in Caribou Poker Creek, boreal forest was rather severely burned. (Hinzman et al 2003). Effects of burned impacted to the thermal regime of the permafrost and also loss of surface organic layer induced by burned may cause of deepening of active layers. Internal thawed layer termed as Talik formed after burned. The loss of top organic layer also caused the delay of recovery of vegetation in the area of severely burned in Delta Junction in 1999. Then the importance of categorizing degree of burn is pointed out in many aspects. The thickness of organic layer is one of the important factors as to control the active layer deepening after burn. The present author already surveyed the degree of burn after FROOSTFIRE experiment and severe burn in Delta Junction in 1999. Then he showed the one diagram of severity index as Fig.1. If there residual organic layer remains after fire, the thermal conductivity at the depth 3cm is measured. Then at the depths of 15cm another measurement in mineral soil layer is conducted. The ratio of two measured thermal conductivities obtained at the various burned sites in the central Alaska were drawn in Fig.1
Fig. 1  Fire Severity Index based on the Ratio between Thermal Conductivities of Surface Organic layer K3 and Lower Mineral Soil Layer K15

This is a preliminary result of the index of burned severity as to relate to the impacts to active layer deepening.

2 FIELD MEASUREMENTS

In August 2004 and 2005, intensive field measurements of thermal conductivity were conducted in Poker Flat Rocket Range, where severe forest fire occurred in 2004. Two measurements were conducted at the identical points as to compare the changes of one year difference.

Fig2. and Fig3. indicate the each location of sampling sites in Poker Flat.

Fig2.  Severe burned site in August 2004 at Poker Flat
These two sites are almost identical

Fig3.  Severe burned site in August 2005 at Poker Flat
The measurements at the site on different dates in August 2004 and 2005 are shown in Fig 4 and Fig.5. Both measurements were made at some sites where surface organic layers were not lost by burn. It assumes as control site indication unburned condition.

It is clearly shown that both profiles indicate unburned organic layer is about 30cm and the difference of thermal conductivities between organic layer and mineral soil layer is about 10 times. The profiles obtained in 2004 and 2005 are identical. Then the profiles of thermal conductivities at moderately and severely burned sites are shown Fig.6 and Fig.7.
In Fig. 7 the thermal conductivity value yields the same value of the lower mineral soil. It means at the severely burned site, no organic layer left after burn. In Fig. 6 the profile of thermal conductivity indicates the residual depth of top organic layer is about 10cm.

3 DISCUSSION AND CONCLUSION
Once one compares the carbon stock in boreal forest area both top organic layer and stand trees, he may find the amount of carbon in organic layer is larger by 4 times than stand trees. For the evaluation of fire impact to carbon cycle, it is important to estimate the degree of loss of top organic layer. For the estimation of carbon loss by burn, residual depth of top organic layer must be determined in quantitative manner. The difference of thermal conductivities both top organic layer and lower mineral soil layer is 10 times and it is easily determined by in-situ measurement. Based on the numerical analysis of the surface boundary heat condition, the deepening of active layer will be estimated. Brouchkov et al. (2004) already attempted the effect of burned loss of organic layer to the deepening of active layer. Iwahana et al. (2005) also estimated the deepening of active layer after loss of organic layer as annually 7% deepening of the active layer in eastern Siberia.

Impacts of severe fire are not only thermal regime and carbon cycle but also delay of vegetation recovery. In 1999 at Delta Junction there occurred the severe burned fire. At that site, top organic layer was completely lost. From that fire event, the recovery of vegetation delayed until 2005. In Fig. 8 recent condition of surface vegetation is shown. As to demonstrate the delay of recovery, vegetation recovery at the C4 in CPCRW where FORSTFIRE was conducted is shown in Fig 9. One can easily recognizes the delay of vegetation recovery in Delta Junction.

Fig8 Vegetation Recovery at Delta Junction in August 2004
Fig9. Vegetation Recovery at C4 CPCRW in August 2004

The profile of thermal conductivity at Delta Junction yields a similar tendency of the severely burned site at Poker Flat. It implies that the vegetation recovery at the severely burned site at Poker Flat may delay in a few years.

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Permafrost Degradation After the Tundra Fire in Seward Peninsula, Alaska - A perennial Study-

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ABSTRACT

Thermal, water and electrical conditions of permafrost after the tundra fire were observed in Seward Peninsula, southwest Alaska, in order to evaluate the effect of fire on permafrost conditions. Field observations were made in 2005 and four sites were established where the slope direction and surface disturbance condition are different; south- or north-facing, and burned or unburned. At each site ground temperature and water content were measured by pit survey, and the seasonal thawed depth measurements were also conducted by using the steel rod from the ground surface. Transient electromagnetic surveys were carried out along profiles with the length of 140-180m to compare the permafrost condition using a transmitter loop of 60 x 60m.

The temperatures of 20-40cm deep at the burned sites were 4-5 ºC higher than that at the unburned sites. The soil water contents at the burned sites showed the high condition. The measured thawed depths are significantly different between the burned and unburned sites, which were more than 20cm deeper in the burned sites than that in the unburned sites.

The obtained apparent resistivity curves and estimated resistivity models showed that a significant difference was observed between south- and north-facing slopes. At the north-facing sites, high resistivity layers were estimated near the ground surface with the thickness of 20-26m, which represents permafrost. The permafrost base could not be detected at the south-facing sites because the base is located in bedrock. There is no significant difference of the curves and models between burned and unburned sites. However, only at the burned south-facing site, stable data could be obtained by using the standard central induction configuration, which means that this site has a relative low resistivity condition near the ground surface. Thus, the burned south-facing site may have a different permafrost condition near the surface.
1. INTRODUCTION

Tundra fire, which burns shrubs, grasses and organic soils of the northern tundra terrain, may act as a strong accelerator on degradation of permafrost under the global warming. Increase of burned area by tundra fire is expected as much as twice due to the predicted warmer and dryer summer (Rupp et al., 2000), although current activity of the tundra fire is less frequent than the wildfires in boreal forest (Racine et al., 1985). Tundra fire disturbance and corresponding vegetation changes bring heat budget on ground surface, and these may yield degradation of permafrost (Racine et al., 2004).

Effect of tundra fire on the permafrost, however, has been rarely studied yet. In 2001 summer, large area of tussock-shrub tundra burned in interior Seward Peninsula, providing a proper field to examine the relationship between tundra fire and degradation of the permafrost. Main goal of our study is to assess the effect of tundra fire on permafrost conditions in the recently burned tundra terrain. As the first step of the study, we surveyed seasonal thaw layer conditions and permafrost thickness. Surveys were conducted in July and August, 2005.

2. STUDY AREA

The study sites are located in Kougarok region in the interior part of Seward Peninsula (Fig. 1), where 1997 tundra fire burned hill slopes covered with tussock-shrub tundra vegetation. Regional climate of interior Seward Peninsula is rather continental, highlighting large annual range of air temperature and dry summer. According to the meteorological station near the study sites (K2 meteorological station in Fig. 1), annual mean air temperature (MAAT) at 1m above ground is -3.6, -4.7, -3.8, and -1.3°C in the year of 2000, 2001, 2003, and 2004, respectively (Hinzman, 2005).

We select four sites to compare both the effects of slope direction (i.e. north or south-facing slope) and tundra fire disturbance on permafrost (Fig. 1). The burned and unburned sites are delimited by a gravel road which stopped further fire spreading (Fig. 1). It can be assumed that the burned and unburned sites had the same vegetation in the pre-fire stage. In the unburned sites (sites 1 and 3), tussock-shrub tundra are spreading on middle-lower part of the hill slope. Sphagnum sp. covers the depressions between the tussock mounds on unburned slopes.

On the other hand, the 1997 tundra fire caused a considerable change on vegetation pattern in the burned sites (Sites 2 and 4). Small mound of Sedge (tussocks), 30-50cm diameter, is predominant in the burned sites. Shrubs were mostly burned and not recovered yet, except some survived shrubs (mainly Ledum palustre and Betula Nana).
3. METHODS

3.1 Thawed soil properties

We measured ground temperature and soil water content by pit excavations. To avoid topographic irregularities of tussocks, we chose lower depression between tussocks for pit sites. Pits were excavated until frozen layer appeared. Volumetric soil water contents were measured with handy TDR with 12cm sensor probes.

3.2 Seasonal thaw depth

Seasonal thaw depth in permafrost terrain can be easily measured by probing with a steel rod, because thawed soil is much softer than the frozen soil. We made 60-80 measurements within a circular area of 20m diameter in every site. Obtained data were compared with statistics (Man-Whitney U test).

3.3 Permafrost thickness

We hired Transient Electromagnetic Method (TEM) for detecting permafrost thickness. A direct current is driven into a 60m loop of wire on the ground surface. Transient response of the secondary magnetic field is measured by a receiver coil after the quit of the direct current. The secondary magnetic field gradually collapses due to ohmic losses in the resistive earth. The collapse rate increases as the resistivity of the background increased. Frozen ground has higher resistivity than that of unfrozen sediments (Hoekstra et al., 1975), enabling the reorganization of permafrost thickness by the TEM method (Harada et al., 2000).

![Pit works of soil stratigraphy, soil temperature and volumetric water content. Note the water contents are un-calibrated data obtained by TDR in situ.](image-url)
4. RESULTS

4.1 Soil properties and thaw depth

Contextures of the thawed layers are characterized by upper dark organic soil and lower silty-clay mineral soil (Fig. 3). There is significant variation in thickness of the upper organic layer among all sites. Thick organic soil (>20cm) appears even in burned site (Pit No.1 in Site 2), indicating the depth of organic soil is site specific and very changeable due to the fire intensity and rough topography of the tussocks.

Soil temperatures and water contents are higher in the burned sites (sites 2, 4) and burned sites (sites 1 and 3). The high water contents can be attributed to the decrease of evapotranspiration resulting from the burn-out of shrubs. Correspondingly, ground temperatures in 20-40cm depth are 4-5°C higher in the burned sites than that in the unburned sites (Fig. 2).

Thaw depths are also significantly different between the burned and unburned sites (Fig. 3), and this difference is confirmed by the thaw depth proving with a steel rod. Table 1 shows the results of paired non-parametric test of the thaw depths. Seasonal thaw depths are apparently deeper (Mann-Whitney U-test, P<0.001) in the burned sites (avg. 63cm) than in the

![Table 1](image-url)

**Table 1.** Comparison of the thaw depth by Mann-Whitney U-test (data obtained between 30 July and 1 August, 2005)

![Figure 3](image-url)

**Fig. 3.** Histogram shows the distribution of Thaw depths detected by steel rod in each site.
unburned sites (avg. 40cm), indicating fire effects on seasonal thaw depth. On the other hand, there are no significant differences in the thaw depth between north- facing and south-facing slopes.

4.2 Permafrost thickness by TEM soundings

Fig. 4 shows the apparent resistivity curves obtained by the TEM surveys and the estimated resistivity models. Comparing the curves, a significant difference between south- and north-facing slopes was obtained. Estimated models of both slopes were also different.

At the north-facing slopes (Sites 3 and 4), the first layer had resistivity values of more than 500 ohm-m with thicknesses of 20-26 m, which represents permafrost confirmed by the pit work. The second layer was relatively conductive (less than 200 ohm-m) and was revealed to be unfrozen. The third resistive layer with resistivity values of more than 4000 ohm-m appeared bedrock.

The estimated resistivity structures at the south-facing slopes (Sites 1 and 2) show no intermediate conductive layer between permafrost and bedrock observed at the north-facing slopes. It may be because that the depth to bedrock at the south-facing slopes is thinner than that at the north-facing slopes and the permafrost base is located in bedrock at the south-facing slopes. Thus, the permafrost base could not be detected by TEM surveys.

Comparing the resistivity curves and estimated models, there is no significant difference between burned and unburned slopes. However, at the burned south-facing slope, stable data could be obtained by using the central induction configuration. This configuration was applied to the other three slopes, but no stable data was observed. In a high-resistivity environment like shallow bedrock, the quick responses of the secondary magnetic field create
difficulties in estimating the resistivity structure by the standard central induction measurements. Thus, the burned south-facing slope may have a different permafrost condition near surface.

5. DISCUSSION AND CONCLUSION

The large difference in seasonal thaw depths between burned and unburned sites (Fig. 3 and Table 1) indicates the degradation of upper layer of permafrost due to the tundra fire, because both burned and unburned sites can be assumed to have similar condition until the 1997 fire.

However, the effect of fire on permafrost may be restricted within some meters below the ground. Nearly same resistivity in the both sites in north-facing slope indicates that the permafrost characteristics are similar, even the seasonal thawing had deepened due to the tundra fire. On the other hand, the stable TEM data obtained in the burned south-facing slope (Site 2) indicates some effects of fire on shallower part of the permafrost.

We have started monitoring of ground temperature and soil water content by data loggers in all four sites. Further detailed discussion can be possible after the correction of monitoring data.

REFERENCES


Preliminary study on permafrost degradation by 2004 Boundary fire: Site description, active layer, and geomorphological control on the vegetation recovery

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ABSTRACT

2004 Alaskan wildfire occurred near Fairbanks (The “Boundary fire”) heavily burned surface organic matters and soils. Surficial soil loss may cause permafrost degradation, and it finally affects slope stability, water circulation regime, and vegetation recovery. Under the inter-discipline observation program, we attempt to clarify 1) Changes on permafrost distribution, 2) Changes on thermal regime of permafrost / active layer, 3) Topographical changes due to the soil loss and permafrost degradation. In the first summer, measurements of thermal regime in the melting layer and microtopography were carried out. Pit excavation in August revealed that the removal of organic layer was a major controlling factor for the melting depth. Melting depth was deepest (>1m) in the heavily-disturbed sites (H), while the shallowest depth (<0.5m) appeared in the less-disturbed sites (L). In the moderately-disturbed sites (M), melting depth drastically varied in short distance, due to the mosaic-like distribution of the remained organics and Sphagnum. Under the thick organic layers in M sites, melting depth was very shallow (<0.5m), appearing similar to the melting depth in the L sites. Photogrammetric measurements on 1m quadrats highlighted very rough micro-topography on the heavy burned site. Digital images were corrected by a consumer-level digital camera, and were analyzed with photogrammetry software and GIS. The final contour map and DEM have a resolution of less than 1mm. Small ridges and troughs exhibited on the burned surface. These small ridge and troughs seems to determine the distribution of seedling. 2D coordinates of seedlings on the quadrats, which were measured by Tsuyuzaki and Narita, agree well with the position of troughs. This suggests that the subsequent changes of micro-topography after the fire disturbance may control the distribution of seedlings.
1. INTRODUCTION

Alaskan permafrost has warmed over the past century, and it has continued into the 21st century in Alaska (e.g. Osterkamp, 2003, Romanovsky et al., 2003, Osterkamp, 2005). Meanwhile, the global circulation model shows an increase on air temperature in the arctic up to 5 °C in the next half century (Maxwell, 1992). The warming effect on permafrost is different in its portion. The warming effect on permafrost will be serious in discontinuous permafrost with temperature close to 0 °C (e.g. Hinzman et al., 2005).

Wild fire disturbances may accelerate the degradation of permafrost. Yoshikawa et al. (2003) summarized the impacts of wildfire on the permafrost in the boreal forest of Alaska, highlighting that the thickness of the remaining organic layer controls thermal regime of permafrost. Due to the high content of water, permafrost degradation induces subsequent morphological changes. Given the above conditions and predictions of current climatic models, it is important to monitor the thermal regime and corresponding landform changes on recently burned boreal forest on the discontinuous permafrost.

In the year 2004, an intensive wild fire (boundary fire) had burned the boreal forest in the vicinity of Fairbanks. This fire was one of the series of Alaskan fire which was the largest on record for Alaska (Pfister et al., 2005). This offers a valuable opportunity to monitor the permafrost and relating ecological changes after the intensive wildfire. Therefore, we have started a 3 year-round monitoring program sponsored by JAXA. Our goal of this study is (1) clarify permafrost and active layer changes initiated by intensive wildfire, (2) monitor the morphological changes associated with deepening of seasonal thaw layer, and (3) clarify the interactions between thermal, hydrological and morphological changes in the seasonal thaw layer and vegetation recovery after the fire disturbance.

2. STUDY AREA AND SITE DESIGN

The study area is located in northwest-facing slope in Poker Flat Research Range near Fairbanks (Fig. 1). 2004 Boundary fire burned northwest-facing slopes entirely, except eastern part and valley bottom. Black spruces (*Picea mariana*) were predominant before the fire disturbance. Peat moss and feather moss covered the forest floor, and some of them had survived the fire disturbance. Tussocks dominated in the lower most part of the northwestern slope. Although they were burned, tussock grass had already recovered when we visited on May, 2005. The burned northwest-facing slope was characterized by rather gentle slope and clast-rich sediments. According to the topographical map, slope angle is approximately 16°. Some large spruces were fallen down, unsealing the top soil layer. In such place, we could see the
sediments beneath it, and found the yellow-colored sediments contained many plate-like rectangular crusts with a mean diameter of 10-20cm.

Most measurement and monitoring were carried out in nearby area to the 10m by 10m quadrat sites of ecology group. According to the surficial conditions, they categorized them for three types: heavily-disturbed sites (H), moderately-disturbed sites (M), and less-disturbed sites (L). In addition, two sites were established on the top hill side (K1, K2) near the meteorological station by hydrology group, and the other two sites (S1, S2) were set up in the lower most part of the burned slope (Fig. 2). Field work was carried out in May and August 2005. In this report, we summarize preliminary field data. Detail analysis results and monitoring data will appear after the next field campaign planned in summer 2006.

3. METHODS

3.1 Thaw depth measurements

Thaw-depth detection by the steel rod was unsuccessful, due mainly to the crusts abundant within the subsurface. Consequently, we made a number of experimental pits by hand-digging. Ground temperature, soil water content, and thermal conductivity were measured in the pit walls. Volumetric soil water contents were measured with handy TDR with 12cm sensor probes by Campbell Science, Inc., and thermal conductivities were measured by a Thermal Properties Meter by Decagon, Inc. We dug the observational pits in plots L1, M1, M2, S1, and H4. In the S1 plot, where the microtopography of mound-like tussocks and troughs are significant, pit was dug in the trough between the tussocks. Surveys were carried out in the period in 11–15 August, 2005.

3.2 Microtopography measurements

Photogrammetry is a fundamental method used for geomorphological mapping. In recent years, advances in image processing techniques allow the use of digital images taken with consumer-grade digital cameras for DTM (Digital Terrain Model) generation. This technique has been used successfully in micro-topographical measurements in the resolution of less than 1 mm (e.g. Rieke-Zapp and Nearing, 2005). In this study, we attempt to measure the millimeter-scale measurements on the 1m by 1m vegetation plots with this method. The results were compared with the plot data of seedlings measured by the ecological group. Measurements were carried out in May and August. In May, we took photogrammetric data upon all 1m plots (total 96). In August, selected 13 plots were re-measured because we found significant seedlings on these plots. A 3D modeling software KURAVES-K (Kurashiki boseki Co., Ltd., Japan) was used to create DTM. Finally, DEM (Digital Mesh Map) of 1cm grid size was generated by GIS software ArcGIS (ESRI Inc., U.S.A.).
4. RESULTS

4.1 Surficial characteristics

As first, we summarized the surficial characteristics on each site type (H, M, L, and S). Heavily disturbed sites (H) were characterized by dry, charcoal rich surfaces (Fig. 3b). On the other hand, the moderately-disturbed sites (M) had complex mosaics of burned surface and survived moss carpet (Fig. 3c). Burned surface in M sites seems to have a nearly same condition as on the burned surface in H sites. Remnants of moss carpet may reduce geothermal heat transfer into the ground, because it may act as an insulator for the mineral soil surface against winter cooling and summer warming. Such insulation effect may significant in Less-disturbed sites (L), where the moss carpet covered most part of the surface (Fig. 3a). The surface characteristics on site S1 (lower most part of the slope) differed completely from the other sites. It was very wet, and tussocks distributed over the 10m quadrat (Fig. 3d). We account S1 for a variation of the Moderately-disturbed sites (M).

![Figure 3](image-url) Surficial characteristics on the study sites
Figure 4  Ground temperature, volumetric soil water content, and thermal conductivity measured in representative sites for the each plot type.
4.2 Soil properties and thaw depth

In this section, we use the thickness of melting mineral soil (TMMS) instead of the thaw depth from the surface, because the thaw depth was apparently associated with the thickness of moss mat (Fig. 4). In the heavily-disturbed site (H4; Fig. 4a), the TMMS reached to 118cm. Volumetric soil water content is quite low (<30%) in upper part, and it is even less than 50% near the frozen table. In Less-disturbed site (L1; Fig. 4b), all obtained values were totally different from the H site. The TMMS was very thin (25cm), and ground water content was higher (nearly 100%) above the frozen table. The TMMS and water contents of Moderately-disturbed sites (M1-1, M1-2, and M2; Fig. 4c, d, e) took roughly medium values between them of H and L sites. These values were also different between the two settings: with moss carpet (*Sphagnum* spp.) or not (Fig. 4c, d). In M1-1 pit with moss mat (Fig. 4c), TMMS and water content showed very similar values to them in the L1 site. On the other hand, TMMS in M1-2 (without moss mat) reached to 66cm, indicating the thaw depth is strongly thickened by the disappearance of moss layer (Fig. 4d). In M2 site (Fig. 4e), the TMMS was rather thicker (48cm) than in M1-2, even if it had a thick moss layer. In summary, TMMS was deepest in the heavily-disturbed site (H), while the shallowest depth appeared in the less-disturbed site (L). S1 site has an exceptionally high value on soil water content. Vertical layers in S1 were mainly composed of silty layer without crusts, indicating sedimentation is much faster than the other sites situating on slopes.

4.3 Microtopography on the heavily burned site and its relationship with seedlings

Although analyses are still in progress, an experimental results show a clear relationship between micrortopography and seedlings. Fig. 5 shows microtopography in the 1m plot S1-5, showing there are many step-like landforms prevailed on the burned surface (Fig. 5a). A DEM (Digital Elevation Map) was generated from the digital photogrammetric analysis (Fig. 5c), and X-Y coordinates of the seedlings (mainly fireweed; *Epilobium angustifolium*) were sampled *in situ* by Dr. Tsuyuzaki and Dr. Narita of ecological group (Fig. 5b). Integrated image (Fig. 5d) revealed that the seedlings tend to concentrate within small troughs and step edges on the burned ground surface.

Figure 5  Experimental results of microtopographic measurement by digital photogrammetry and its integration with seedling data
5. DISCUSSION

5-1. Intensity of fire disturbance and seasonal thaw layer regime

Among the all plots we surveyed by the pit work, the thickness of melting mineral soil (TMMS) apparently deepened in the burned sites. Heavily-disturbed sites (H) have dark, dry surface and thickest TMMS layer among the surveyed sites. In such darkened surface, albedo should be reduced significantly. It is likely that the reduced albedo causes an increase of incoming short-wave radiation, resulting higher ground surface temperature (Yoshikawa et al., 2002). Such increasing ground heat flux in melting season may cause the deepening of the melting layer as appeared in Fig. 4a. On the other hand, ground thermal regime may differ in short distance, if the removal of moss mats occurred sporadically. A large difference on TMMS between M1-1 (with moss mat) and M1-2 (without moss mat) supports this idea. The TMMS thickness in M1-2 is nearly same to that in Less-disturbed site (L1), even the moss mat around the M1-1 site had been disappeared. The moss mat removal by surficial fire may control the seasonal thaw depth in the study area.

5-2. Relationship between microtopography and seedlings

Seedlings were concentrated to the small troughs and step ridges on the burned surface (Fig. 5d), indicating that the scattered seeds tend to be caught by the depressions on rough surface of the burned ground in post-fire period. In this perennial study, we do not have any data to explain how such troughs and steps had formed on the ground surface. This theme should be included in the future work, because the microtopography seems to be a controlling factor for initial period of the vegetation recovery in heavily-burned area in boreal forest. Analyses for the other sites are currently in progress, and we will discuss more about the concentration phenomena on seedlings by the micro-topographical effects.

REFERENCES


‘Heavily’ means moss layer was perfectly burned, and ‘moderate’ means moss was almost died but the moss layer remained more than 10 to 20 cm thick or more. In the middle of May, when it was soon after the snowmelt season, frost table was located at 5 cm below from the top of mineral soil in every three sites, and it was not depending on the surface condition. In middle August, frost table was deepest in site H in which it was more than 150 cm, and site M was next which is judging from the soil temperature declining trend. However, the frost table in site C was nearly the same as that in middle May due to the significantly low thermal conductivity of the living moss layer. If the wildfire did not occur, frost table in heavily- and moderate-burned sites could be shallow same as the control site. Increase in thawing layer thickness leads to the increase in the soil water storage capacity, and to the slower rainfall-runoff response in the stream.

4. SUMMARY

In order to examine the impacts of wildfire on hydrological environment in the boreal forest of interior Alaska, an observation site was set up at the Poker Flat Research Range in the upper Chatanika river valley. Preliminary results were obtainable through the field works in middle May and middle August of 2005 as follows:

1) Summer precipitation was 276 mm from May 15 to October 1, and it was considerably higher than normal.

2) Rainfall-runoff response was reduced with the increase of the thickness of thawing layer.

3) At the moss burned sites, frost table was deepening to 1 to 1.5 m during the summer. However, it was kept nearly the same, 0.4 m in deep, at the control site.
Impacts of wildfire on the permafrost in the boreal forests and the tussock tundra

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The impact to the permafrost during and after wildfire was studied using multi year fire sites including two-controlled burns. Heat transfer by conduction to the permafrost was not significant during fire. Immediately following fire ground thermal conductivity may increase 10-fold depending upon the extent of burning of the surfical organic soil. The thickness of the remaining organic layer strongly affects permafrost degradation and aggradation. If the organic layer thickness was not reduced during the burn, then the active layer did not change after the burn, in spite of the surface albedo decrease. Any significant disturbance to the surface organic layer will increase heat flow through the active layer into the permafrost. Approximately three to five years after severe disturbance and depending upon site conditions, the active layer will increase to a thickness that does not completely refreeze the following winter. This results in formation of a talik. Model studies suggest that if an organic layer of more than 7-12 cm remains following a wildfire, then the thermal impact to the permafrost will be minimal in the boreal forests of Interior Alaska. Tussock tundra contains possibly different heat transfer system (non-conductive heat transfer) that may cause more cooling of the ground after the fire.
The Role of Fire on The Surface Energy Balance at a Sub-Arctic Tussock Tundra Site

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Niagara Creek (6.5km²), situated at central Seward Peninsula, Northwestern Alaska, was affected by a severe burn August 2002. Soil and meteorological observations were made before and after the fire at a fixed location, with vegetation consisting of Eriphorum tussocks, year 2000 to 2005.

During this time period, the annual averaged soil temperature increased 2.5±0.6°C throughout the 1 m deep profile as a positively correlated increase with time following the burn. Local noon energy flux ratios during the second and third summer following fire indicate an altered energy partitioning in comparison to prefire situations, whereas the radiation efficiency (net radiation normalized to incoming short wave radiation) stays relatively stable. Summer 2004 exhibits noon albedo values of 0.13±0.01 compared to prefire data of 0.17±0.01 and 0.16±0.01. Unstable atmospheric conditions are found more prone to occur after the burn, represented by the Richardson number. Near surface soil display enhanced post-fire soil moisture levels following spring melt, close to saturation, throughout the thawed season, a phenomenon still present summer 2005. Thermokarst formation and severe erosion occurred along Niagara Creek streambed after the fire, which resulted in a formation of a > 3500 m³ void, an estimation made fall 2005.

Hydrological postfire model simulations of Niagara Creek watershed do not exhibit a large difference from the calibrated hydrograph, with only slightly higher peak flows. Evapotranspiration is reduced during post-fire simulations, while no clear change in recession periods after rainstorm events was found.

Keywords: Permafrost, active layer, thermal regime, energy flux, modeling.
Impacts of wildfire on the hydrological environment in Interior Alaska

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Abstract

“Boundary Fire 2004” in the boreal forest of Interior Alaska was the largest wildfire in these 50 years, and it is predicted to affect strongly to the hydrology, permafrost degradation, and vegetation recovery in the watershed. We made hydrological observations to examine the impacts of the wildfire in May and August of 2005 at the north-facing slope in the Poker Flat Research Range (GI/UAF), 50 km northeast of Fairbanks, Alaska. In a heavily-burned headwater basin, rainfall-runoff response of the small stream was reduced from May to June. These changes could be caused by the increase of soil water storage volume with the increase of thawing layer thickness. At the moss burned site on the hillslope, frost table was deepening to 1-1.5 m during the summer. However, it was kept nearly the same, 0.4 m in deep, at the control site. This indicates the high insulation effect of the moss, and its burnout increases the active layer thickness significantly.

1. INTRODUCTION

2004 Alaskan wildfire was the largest in these 50 years. A fire named “Boundary Fire”, that took place near Fairbanks as shown in Fig.1, strongly burned surface soil and is predicted to influence on
water cycle, permafrost degradation, and vegetation recovery in the watershed. A research team was established to monitor the influences after the fire with four interrelated study theme, which is hydrology, permafrost, ecosystem, and fire detection/prediction, under the Japan-U.S.A. cooperation. This report shows the preliminary result made by the hydrology group in the 2005 spring and summer field works.

Severe wildfires burned not only standing trees but also the understory plants and soils. The changes of surface soil layer would be physical (soil property, water content and amount of organic material), chemical (amount of major/trace ions, nutrients, pH) and ecological (decomposition and respiration). Those changes in surface soil layer would result in the changes in hydrological (surface heat balance, permafrost condition, runoff of sediments and nutrients, erosion) and ecological (nitrogen and carbon balance etc.) environments in the forest. Especially in the north-facing slopes, remarkable changes in subsurface runoff process will be caused due to the increase in thawing layer thickness. Our objectives are firstly to detect such the changes, and secondly to monitor its interannual variation with the recoveries of plants and permafrost.

2. STUDY SITE AND METHOD

Study site were established in the Poker Flat Research Range, which is the scientific rocket launching facility operated by the University of Alaska’s Geophysical Institute and

Fig. 2. A map of the study site.
about 50 km northeast of Fairbanks at 65°07′N, 147°27′W (Fig.2). This area is located across the Chatanika River from the Caribou Poker Creeks Research Watershed (CPCRW) of the university, and the topography, climate, vegetation and permafrost condition are almost same as the CPCRW. Elevation is 240 m to 450 m, and vegetation is mainly birch forest on south-facing slopes, black spruce on north-facing slopes, and tussocks, willow bushes and moss on the forest floor. In the middle of May 2005, an experimental hillslope plot was set up at the north-facing slope to observe the changes in surface soil layer condition after the fire. A hydrological observation site (point W in Fig.2) was set up in the small valley about 500 m away from there, to measure the stream water level, water temperature, electric conductivity and turbidity of the stream water. A meteorological observation site (point M in Fig.2) was also set up at the ridges of the hillslope, to measure the precipitation, air temperature, relative humidity, wind speed and direction, incoming and outgoing shortwave radiation, net radiation, surface radiative temperature, soil temperature (3 points), soil water content (2 points). In middle August, up to 1.5 m soil pit observations were made at the heavily-burned, moderate-burned and control sites. Soil temperature, water content, thermal conductivity profiles were measured in the 5 cm interval from the surface to the bottom.

3. RESULT AND DISCUSSION

Fig. 3 shows the summer precipitation from May 15 to October 1, 2005. Remarkable storm events occurred 4 times in May 17, June 1, June 19 and July 8, and the last storm event was largest among them. Rainy day succeeded 8 days from July 6 to 13, and daily amount of
The precipitation (P) and water level (W) at the hydrological observation site are shown in Fig. 4. Shaded bar and thick solid line indicate the hourly precipitation (P) and water level (W), respectively.

Unfortunately, we could not get water level data for July 8 event because of the sensor trouble after the June 19 event. Water level increase was largest in the May 17 event due to the large total precipitation and the high intensity. In addition, shallow frost table could be contributed to make such the significant response. Rain water could not infiltrate easily into the soil layer due to the existence of shallow frost table, and the water flowed over near the ground surface to the stream as a quick flow component. In the next two events, water level increase was weakened and the lag time of peak-to-peak became larger. One possible reason caused these changes is that soil water storage increased with the increase of the thawing layer thickness.

Results of soil pit observation in May and August were shown in Figs. 5 and 6. Letters of H, M and C indicate the heavily-burned, moderate-burned and control sites, respectively.

**Fig. 5.** Soil layer log and soil temperature in the middle of May 2005. Thick solid line shows the temperature profile from 0 to 20 degree Celsius. ‘M’, ‘H’ and ‘C’ mean the moderate-burned, heavily-burned and control sites, respectively.

Maximum rainfall intensity became 23.2 mm/h from 21:00 to 22:00. Total summer precipitation (May to September) was 276 mm, and it was quit larger than normal value in Fairbanks (175 mm).

Fig. 4 shows the responses of stream water level to each storm event. The maximum rainfall intensity became 23.2 mm/h from 21:00 to 22:00. Total summer precipitation (May to September) was 276 mm, and it was quit larger than normal value in Fairbanks (175 mm).
‘Heavily’ means moss layer was perfectly burned, and ‘moderate’ means moss was almost died but the moss layer remained more than 10 to 20 cm thick or more. In the middle of May, when it was soon after the snowmelt season, frost table was located at 5 cm below from the top of mineral soil in every three sites, and it was not depending on the surface condition. In middle August, frost table was deepest in site H in which it was more than 150 cm, and site M was next which is judging from the soil temperature declining trend. However, the frost table in site C was nearly the same as that in middle May due to the significantly low thermal conductivity of the living moss layer. If the wildfire did not occur, frost table in heavily- and moderate-burned sites could be shallow same as the control site. Increase in thawing layer thickness leads to the increase in the soil water storage capacity, and to the slower rainfall-runoff response in the stream.

Fig. 6. Soil layer log and profiles of temperature (T) (thick solid line; degree Celsius), volumetric water content (mc) (black square and thin dotted line; %) and thermal conductivity (K) (open circle and thin solid line; x0.1 W/m$^2$). H, M, C and column pattern mean same as Fig.5, and dark grey and grey in the mineral soil column mean silt and silty sand, respectively.

4. SUMMARY

In order to examine the impacts of wildfire on hydrological environment in the boreal forest of interior Alaska, an observation site was set up at the Poker Flat Research Range in the upper Chatanika river valley. Preliminary results were obtainable through the field works in middle May and middle August of 2005 as follows:

1) Summer precipitation was 276 mm from May 15 to October 1, and it was considerably higher than normal.
2) Rainfall-runoff response was reduced with the increase of the thickness of thawing layer.
3) At the moss burned sites, frost table was deepening to 1 to 1.5 m during the summer. However, it was kept nearly the same, 0.4 m in deep, at the control site.
Initial watershed response to boreal forest fires in Interior Alaska

Horacio Toniolo

ABSTRACT

The summer of 2004 in Alaska was characterized by enormous and devastating boreal forest fires. Small streams draining water from areas affected by fires in different proportions (i.e., unburned, partially, and severally burned) were systematically sampled during the summer of 2005. All the streams were located in watersheds underlain by discontinuous permafrost. In order to collect daily water samples, autosamplers were deployed in the streams after spring breakup. Pressure transducers and dataloggers in conjunction with velocity measurements were used to estimate water discharge in the streams. Human influence is negligible in the study areas, with the exception of modifications caused by fire suppression activities. Thus, collected data from these areas can be considered as a natural system response to forest fires. Initial data will be presented in the meeting.
The role of fire disturbance in the response of historical carbon dynamics in the boreal forest from 1950-2002

M. S. Balshi & A. D. McGuire

In the boreal forest, wildfire is a common occurrence, and changes in the fire regime have consequences for carbon dynamics as well as water and energy feedbacks to the climate system. Changes in climate and atmospheric CO₂ concentrations may also affect carbon dynamics through their effects on ecosystem processes. However our ability to project future temporal and spatial changes in carbon dynamics is limited by our understanding of how the temporal and spatial aspects of fire influence historical carbon dynamics.

To evaluate the temporal and spatial changes of carbon dynamics in response to CO₂, climate, and fire disturbance, we developed a fire module for the Terrestrial Ecosystem Model (TEM) and simulated carbon dynamics for the pan-boreal region north of 45° N from 1950-2002. We conducted three simulations: CO₂ fertilization only, CO₂ and climate variability, and CO₂, climate, and fire disturbance.

For fire simulations, information on historical fire return interval (FRI) was used for backcasting fire disturbance prior to the start of the historical fire records. We used cokriging estimates based on data for the IGBP high latitude transects in Eurasia and estimated FRIs for North America based on spatially and temporally explicit fire records for the period 1950-2002.

Simulation results for the pan-boreal region north of 45° N indicate that C storage increased in response to CO₂, climate, and fire at a rate of 344 Tg C yr⁻¹ between 1950 and 2002. Partitioning the effects of CO₂, climate, and fire for North America indicates that from 1950-2002, atmospheric CO₂ was responsible for sequestering 37.52 Tg C yr⁻¹ (3.48 g C m⁻² yr⁻¹), climatic variation was responsible for sequestering 38.09 Tg C yr⁻¹ (3.54 g C m⁻² yr⁻¹), and fire was responsible for releasing 7.01 Tg C yr⁻¹ (0.62 g C m⁻² yr⁻¹). For Eurasia, atmospheric CO₂ was responsible for sequestering 126.31 Tg C yr⁻¹ (4.96 g C m⁻² yr⁻¹), climatic variation was responsible for sequestering 70.87 Tg C yr⁻¹ (2.78 g C m⁻² yr⁻¹), and fire was responsible for sequestering 78.64 Tg C yr⁻¹ (3.08 g C m⁻² yr⁻¹).

Our analysis suggests that CO₂, climate, and fire each play important roles in carbon dynamics across the pan-boreal region. It also shows that it is important to incorporate fire in a temporally and spatially explicit manner when estimating the effects of fire on carbon dynamics for the boreal forest region. Our next step in this study is to develop a fire model that can be coupled to TEM to evaluate carbon dynamics across the boreal forest for future scenarios of climate change.
Are decreases in snow cover moderated by increased carbon storage in fire-disturbed high-latitude terrestrial ecosystems?

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High-latitude terrestrial ecosystems play an important role in the earth’s climate system due to the broad expanse that is occupied by fire-disturbed vegetation and seasonally snow-covered ground. As snow retreats in response to increasing temperatures in these regions, less solar energy is reflected into space and more energy is absorbed and transferred to the atmosphere. This results in a positive snow/albedo feedback loop that reinforces warming. This warming may be moderated by the enhanced capacity of these terrestrial ecosystems to sequester carbon under changes in atmospheric CO₂ concentrations, climate, and fire regimes. We compared these responses retrospectively based on simulations with a large-scale terrestrial ecosystem model for the land area north of 50° N. Our analysis took into account two historical 30-year time periods, 1920-1940 and 1970-2000, where surface air temperatures generally increased and snow cover generally decreased. Decreases in snow cover duration from 1920-1940 were approximately 0.9 – 1.7 days decade⁻¹, and were primarily due later snowfall in the autumn. From 1970-2000, the trend in snow cover duration was greater, decreasing by 1.6-3.8 days decade⁻¹, generally caused by earlier snow melt in the spring. Across the entire study domain, our findings suggest that changes in energy due to changes in snow cover show a heating effect of +1.1 W m⁻² during 1920-1940 with this trend increasing to +1.9 W m⁻² between 1970-2000. In comparison, changes in energy due to changes in atmospheric CO₂ concentrations, climate, and fire regimes showed a cooling effect of -0.17 W m⁻² between 1920 – 1940 and -1.0 W m⁻² between 1970-2000. These results indicate that the effects of a longer snow-free season on atmospheric energy balances should considered in studies of climate change, particularly with respect to associated shifts in vegetation between forests, grasslands, and tundra.
Observation of CO$_2$ efflux at Poker Flat forest fire burned site in 2005

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Abstract

Forest fire gives tremendous changes to surface conditions. In order to clarify the difference in soil respiration and its response to weather and soil conditions between burned and unburned, measurement using chambers were carried out in the summer of 2005. Together with the respiration measurement, chamber and soil temperatures and soil moisture as well as the meteorological conditions were observed.

CO$_2$ efflux from ground surface showed a clear diurnal variation at both burned and unburned site. It was correlated well with soil temperature and the sum of net respiration in the observation period from May 13 to October 3 (143 days) became 143 gCm$^{-2}$ at burned site and 253 gCm$^{-2}$ at unburned site. The ratio of the two was 56%.

1. Introduction

Boreal forests account for about one-third of the carbon sequestered in terrestrial ecosystems. Northern boreal forests represent approximately 35% of the world’s forests and contain approximately 66% of the world’s forest soil carbon pools (Oechel and Voulitis, 1997). Since boreal forests absorb atmospheric carbon dioxide and slowly decompose the litter, fibric and humic substances, the ecosystems are known as carbon sinks (Schlesinger, 1997).

Forest fire is a major disturbance in boreal forests and, as boreal forests emit higher concentrations of carbon to the atmosphere immediately after the fire, forest fires in the northern stands are well known as carbon resources (Kasisheke and Stocks, 2000).

2004 Alaskan forest fire was the largest in the area burned in the last 50 years. A 50-year record of Alaska boreal fires shows an increase of fire occurrence and area burned (French et al., 2002). In the 1990s, the average area burned in Alaska was 4 x 102 km$^2$ (Murphy et al., 2000). As of summer 2004, the total area burned in Alaska is more than 6 x 102 km$^2$ (Alaska Fire Service, http://fire.ak.blm.gov), clearly an extreme record. A wildfire named “Boundary fire” took place near Fairbanks in 2004, strongly burned surface soil and is predicted to influence on water circulation, permafrost degradation and vegetation recovery in the watershed.

In order to monitor the influences after the wildfire, Japan Aerospace Exploration Agency and International Arctic Research Center, University of Alaska jointly formed a program entitled “Monitoring of influence of 2004 Alaskan large forest fire on terrestrial environment” for 3 years. It is mutually established the basis for middle to long term monitoring by relating atmosphere, land surface (vegetation), permafrost and water cycles and by setting observation sites and regions the utmost.
In order to clarify the difference in net respiration and its response to weather and soil conditions between burned and unburned, measurement using light and dark chambers were carried out in the summer of 2005. Measurements of albedo, surface temperature, soil moisture and heat conductivity were also carried out in order to characterize the seasonal and inter-annual changes in these surface conditions. In this study, the preliminary results of the measurement are reported.

2. Study site and method

2.1. Observation site

The study site is located at southwest end of the burned area of “Boundary Fire” in 2004 (Fig. 1). It is located in the Poker Flat Rocket Launch Range of University of Alaska, northeast of Fairbanks, Alaska. We chose a north-facing slope (Fig. 2) for the study site because this region is in discontinuous permafrost area and the north-facing slope is expected to underlain by permafrost.

Fig. 1. Location of Poker Flat Rocket Launch Range (after http://www.uaf.edu/water/projects/cpcrw/metadata/cpcrwmetsitemap.htm)

Fig. 2. Location of observation site. L1-4, M1-4, S1-2 and K1-2 are the locations of plots for ecological study.
We have chosen two burned sites and one unburned site for the measurement (Fig. 2). Burned1 site (Fig. 3a) locates on the slope. It was severely burned and any vegetation came back on the summer 2005. Burned2 site (Figs. 3a and 3b) is also severely burned site on the top of ridge, but the vegetation came back in August 2005 (Fig. 3c). Control site is located on the slope where sphagnum moss is dominant (Fig. 3d).

2.2. Method

In order to clarify the differences in net respiration and its response to weather and soil conditions between burned and unburned, a measurement using close/open chambers were carried out in the summer of 2005 (Fig. 3). Together with the respiration measurement, chamber and soil temperatures and soil moisture as well as the meteorological conditions (at AWS site (Fig. 2) were observed.

For respiration measurement, a set of opaque and transparent chambers was used. Each chamber automatically closes and opens the lid by two timers, and the CO₂ concentration inside the chamber was measured every two minutes by an infrared CO₂ analyser (GMD20, Vaisala), and
recorded to a voltage recorder (VR-71, T andD). The chamber is closed for 15 minutes and then opened for 15 minutes. The chamber and soil temperatures were also measured every 5 minutes.

The increase rate of CO\(_2\) concentration, \(dC/dt\) (ppm s\(^{-1}\)) inside the chamber while the chamber was closed was calculated by best-fitting, and then calculated the soil (opaque chamber) and net respiration (transparent chamber), \(R_s\) (\(\mu\)molm\(^{-2}\)s\(^{-1}\)) by the following formula.

\[
R_s = \frac{1000}{22.4} \cdot \frac{273}{(273+T_c)} \cdot dC/dt,
\]

where \(T_c\) is the temperature inside the chamber.

We analyzed temperature responses of daily mean soil respiration calculated from half-hourly measurements using the following well-known exponential equation:

\[
R_s = a \exp(bT),
\]

Where \(a\) and \(b\) are fitted constants and \(T\) is soil temperature (K).

Fig. 3. The results of chamber measurement of respiration, at burned1 (a), burned2 (b) and control (c) site. Upper figures are by opaque chamber and lower figures by transparent chamber.

Fig. 4. Time series of soil temperature and net respiration by opaque chambers (upper) and the relationship between net respiration and soil temperature (lower).
3. Results

3.1. Soil respiration and net respiration

Soil and net respirations were measured with an automated closed/open chamber system during summer, 2005 at two burned sites (burned1 and burned2) and unburned (control) site. Fig. 3 shows the results of respiration measurements by opaque chambers (upper figures) and transparent chambers (lower figures). No vegetation came back at Burned1 site but some vegetations grew inside the both chambers at Burned2 site. Therefore, soil respiration by opaque chamber at Burned2 site was small when compared with those at Burned1 site, and net respiration by transparent chamber at Burned1 site was never became negative due to no CO₂ assimilation. Since no moss was removed inside the opaque chamber at control site, the result of measurement by the opaque chamber at control site does not indicate respiration rate. However, the difference between the two chambers at Control site means the CO₂ assimilation rate (not shown).

3.2. Net respiration and soil temperature

Upper figures in Fig. 4 show the time series of soil temperature and net respiration by opaque chambers and lower figures in Fig. 4 show the relationship between net respiration and soil temperature calculated using Eq. 1. Soil temperature at Burned1 and Burned2 became asa high as 16 °C but at Control site soil temperature varied between 6 °C and 10 °C. However, net respiration at Burned1 and Burned2 was smaller when compared with those at Control site. It must be due to the difference in the difference in biomass between the burned and unburned sites.

The relationship between net respiration and soil temperature was obtained by using Eq. 2. As mentioned above, some plants were grown inside the opaque chamber at Burned2 site, the correlation coefficient of the two was not good, whereas the relationships at Burned1 and Cotrol site were good.

Figure 5 shows time series of net respiration calculated using the relationship between soil temperature and net respiration for burned1 (left) and control (right). The general trend of the seasonal variation of respiration is the same at the both site. However, the net respiration become the largest at the middle of July at Burned1 site and at the middles of June and August at Control site. The reason of these differences is not clear, but it is possibly due to the soil temperature and soil moisture difference.
The sum of net respiration in the observation period from May 13 to October 3 (143 days) becomes 143 gCm⁻² at Burned1 and 253 gCm⁻² at Control. The ratio of the net respiration at Burned1 to Control is 56%.

4. Conclusion

In order to clarify the differences in net respiration and its response to weather and soil conditions between burned and unburned, a measurement using close/open chambers were carried out in the summer of 2005.
1) CO₂ efflux from the surface was 143 gCm⁻² at burned1 and 253 gCm⁻² at control from May13 to October 3 (143 days).
2) CO₂ efflux at severely burned site was 56% of the unburned site.

5. Future problems

The further analysis is needed for the study of net respiration at burned and unburned site. They are as follows. 1) Better relationships between CO₂ efflux and soil temperature, 2) Consideration of effect of soil moisture to CO₂ efflux, 3) Consideration of effect of atmospheric conditions, such as air temperature and water vapor deficit, on CO₂ efflux, 4) Microbiological studies of soils, and 5) Effect of burned logs (fallen and standing) on CO₂ efflux.

References

Decomposition rate of woody debris in a burnt forest: Results of a preliminary study at Poker flat research range

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0. ABSTRACT
This study examined the decomposition respiration of woody debris (WD) occurred by forest fire in a black spruce forest at Poker flat research range, which was burned in June 2004. We measured decomposition respiration ($R_{WD}$) of standing and downed WD and temperature and water content of WD in August 2005. WD samples (diameter: 3-10cm) were obtained from standing dead wood (snag) and downed dead wood (log) of black spruce. Temperature of WD was high (about 25°C), nevertheless $R_{WD}$ was very low (snags: 0.21±0.18, logs: 0.40±0.26mgCO$_2$ kg$^{-1}$ h$^{-1}$). Decomposition rate of snags and logs was estimated to be 0.001 and 0.002 y$^{-1}$, and mean residence time was about 1000 and 500 years, respectively. The low decomposition rate may be mostly induced by the extremely low water content of WD (both snags and logs: 0.18g g$^{-1}$). The slope facing to the south, well-drained soil, the lack of the crown of living trees and little precipitation may cause soil drying in the experimental site in summer season. Similarly, WD water content became low resulting in low microbial activity. $R_{WD}$ was significantly different between snags and logs ($t$-test, $P$<0.05), however, water content and wood density were almost similar ($t$-test, $P$=0.53, $P$=0.49, respectively). This difference was induced by low $R_{WD}$ of snag samples located at the high position (more than 4m) and all of these samples did not expose CO$_2$. Thus, the height of the WD position affects microbial invasion resulting in low decomposition rate. The vertical position of WD may affect decomposition rate of WD due to both the differences in microbial invasion and water content of WD. Therefore, the vertical position of WD may be a significant factor to determine decomposition dynamics of WD.

1. INTRODUCTION
Woody debris (WD) is an important component of all forest ecosystems. WD influences carbon storage, nutrient and water cycles, maintaining biodiversity and serves as a habitat for forest organisms (e.g. Harmon et al. 1986, Krankina et al. 2002). Recent studies analyzed the amount, structure, and dynamics of WD in natural and managed forest (e.g. Siitonen et al. 2000; Busing 2005). WD dynamics affects long-term carbon cycle (Janisch and Harmon 2002). However, WD have generally not been quantified in the carbon budgets in forest ecosystems. WD is an important wildfire fuel and respiratory sources of carbon through decomposition process in boreal forest (Bond-Lamberty et al. 2003). Thus, more accurate estimate of the amount of WD and decomposition
rate will help to advance long-term boreal carbon cycle. Global climate change will cause an increase in the fire and disturbance frequency in boreal forest (Kasischke 1999).

In this study, we focused on WD postfire decomposition rate and examined control factors and characteristics of the decomposition processes.

2. FIELD SURVEY METHODS

This study examined the amount and decomposition respiration of woody debris (WD) in a burnt black spruce forest at Poker flat research range in August 2005. The forest was burnt in June 2004. We defined WD as aboveground dead wood. We established two plots and measured diameter at breast height (DBH) and height (H) and identified the state of WD (standing dead wood: snags and downed dead wood: logs). We selected each three WD for snags and logs for the estimate of stem biomass. We measured diameter and length from the base at three or four points of stem and stem volume was calculated as a cylinder. We also cut samples at these points for wood density estimate. WD biomass was estimated by multiplying WD volume and wood density. An allometric relationship between DBH²H and WD biomass was used to estimate WD biomass for plot basis. WD samples for respiration measurements were obtained from snags and logs of black spruce existing in the forest. WD samples ranged 3-10cm in diameter and 20-28cm in length. Snag and log samples were obtained from the position at 8-700cm and 3-50cm from the ground, respectively. The cut surfaces of WD samples were sealed with silicone sealant to eliminate the emission of CO₂. Sub-sample was cut from the same WD to estimate wood density. Diameter and length of sub-samples were measured to calculate the volume and dried at 95°C for 48 hours. Wood density was estimated by the dry weight divided by the volume of sub-samples. We measured decomposition respiration of WD (R_{WD}) using a closed dynamic chamber system with infrared gas analyzer (IRGA). The measurement system was composed of an IRGA meter (LI-800, LI-COR Inc., Lincoln, NE, USA), a chamber (made of acrylic resin W18×D18×H10cm), tubes, a pump (CM-15, Enomoto Micro Pump, Tokyo, Japan), filters, and a flow meter. Simultaneously, temperature of WD was measured by thermometer (TR-52, TandD Inc., Tokyo, Japan). The position which temperature measured was 3cm in depth from the bark or the center of WD in case of the diameter less than 6cm. Fresh weight of WD samples was weighed to estimate gravimetric water content.

3. RESULTS and DISCUSSION

We obtained the allometry relationship between DBH²H and WD biomass (WD mass = 0.0202 DBH²H^{0.9897}, R²=0.97). The relationship was not different between snags and logs. Outlines of the plots were shown in Table 1. There was no living wood in the plots. DBH and height of plot 1 was little smaller than those of plot 2. Thus, WD biomass of plot 1 was smaller than that of plot 2. The ratio of logs was different between plot 1 and 2 (4 and 67%, respectively).
Table 1. Outlines of the plots.

<table>
<thead>
<tr>
<th></th>
<th>Plot 1</th>
<th>Plot 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>area (m²)</td>
<td>256.5</td>
<td>256.5</td>
</tr>
<tr>
<td>slope (degree)</td>
<td>18.0</td>
<td>18.0</td>
</tr>
<tr>
<td>DBH (cm)</td>
<td>4.1</td>
<td>5.3</td>
</tr>
<tr>
<td>Height (m)</td>
<td>3.7</td>
<td>4.7</td>
</tr>
<tr>
<td>WD mass total (t ha⁻¹)</td>
<td>5.55</td>
<td>8.44</td>
</tr>
<tr>
<td>snag</td>
<td>5.32</td>
<td>2.80</td>
</tr>
<tr>
<td>log</td>
<td>0.22</td>
<td>5.64</td>
</tr>
</tbody>
</table>

*R*<sub>WD</sub> was very low (n=10, snags: 0.21±0.18, logs: 0.40±0.26 mg CO₂ kg⁻¹ h⁻¹). If the respiration rate continues year-round, decomposition rate constant of snags and logs was 0.001 and 0.002 y⁻¹, respectively and mean residence time of snags and logs was calculated about 1000 and 500 years. At the measurement time, temperature of WD was high of 25°C. Nevertheless *R*<sub>WD</sub> was very low for both snags and logs. The low decomposition rate may be mostly induced by the low water content of WD (snags and logs: 0.18±0.07, 0.18±0.05 g g⁻¹, respectively). Compared to water content of logs in a tropical rain forest (Chambers *et al*., 2001; ranged from 0.1 to 2.3 g g⁻¹), boreal forest (Bond-Lamberty *et al*., 2003; decay class 1: 0.44±0.04 g g⁻¹), temperate forest (Jomura, unpublished data; 0.65±0.59 g g⁻¹), in this area WD water content was extremely low. The slope facing to the south, well-drained soil, the lack of the crown of living trees by fire, high temperature and little precipitation in summer season may cause surficial soil drying resulting in the extremely low water content of snags and logs. In spring, snow melt and permafrost degradation due to temperature increase increases water content of soil (Richter *et al*. 1999). Increase in water content of WD will occur with the changes and stimulate microbial activity of WD. Thus, to determine decomposition dynamics of WD after forest fire in this area, seasonal changes in decomposition rate should be measured. Low water content limits the activity of organisms and below 0.3 g g⁻¹, water is generally not available to microbes (Griffin, 1977). In this study, respiration was observed blow this point indicating that microbes can decompose WD even under the extremely low water content condition. However, decomposition rate was fairly low. Because of only one year after the forest fire, microbes have not developed sufficiently in WD and this may be the initial stage of decomposition.

Table 2. Mean wood density, gravimetric water content, and *R*<sub>WD</sub> by state.

<table>
<thead>
<tr>
<th>state</th>
<th>density g cm⁻³</th>
<th>gravimetric water content g g⁻¹</th>
<th><em>R</em>&lt;sub&gt;WD&lt;/sub&gt; mg CO₂ kg⁻¹ h⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>snag</td>
<td>0.46 (0.06)</td>
<td>0.18 (0.07)</td>
<td>0.21 (0.18)</td>
</tr>
<tr>
<td>log</td>
<td>0.45 (0.03)</td>
<td>0.18 (0.05)</td>
<td>0.40 (0.26)</td>
</tr>
</tbody>
</table>
was significantly different between snags and logs ($t$-test, $P<0.05$), however, water content and wood density were almost similar ($t$-test, $P=0.53$, $P=0.49$, respectively, Table 2). This difference was mostly induced by the low $R_{WD}$ of snag samples located at the high position (more than 4m) and all of these samples did not expose CO$_2$ (Figure 1). Thus, the height of the WD position affects microbial invasion resulting in low decomposition rate. The vertical position of WD may affect decomposition rate of WD due to both the differences in microbial invasion and water content of WD. Therefore, the vertical position of WD may be a significant factor to determine decomposition dynamics of WD.

4. REFERENCES


Effects of fire on fine root biomass in a black spruce forest:  
A preliminary study at the Poker Flat Research Range.

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ABSTRACT: Fine root is a key component in nutrient cycling of forested ecosystems. In this study, fine root biomass (< 2 mm in diameter) were examined at a severely burned black spruce forest at the Poker Flat Research Range in August 2005, one year after severe wildfire in summer 2004. An unburned black spruce forest close to the burned site was also investigated as a control. Estimated fine root biomass, including live and dead fine roots, in surface moss + organic layer to the soil depth of 20 cm was ~1010 and ~1040 g m\(^{-2}\) in burned and unburned sites, respectively, 70% of which was concentrated to surface moss + organic layers in both sites. However, because of technical difficulties, we could not separate roots from root-organic matter complexes in part and they were 360 and 900 g m\(^{-2}\) in burned and unburned sites, respectively. Thickness of the surface moss + organic layer was smaller in the burned site (~22 cm) than in the unburned site (~38 cm), which resulted in larger fine root density at the surface layer in burned site (~4.4 kg m\(^{-3}\)) than in unburned site (~2.4 kg m\(^{-3}\)). Roughly estimated living proportion of fine roots was 1% and 65% in the burned and unburned plots, respectively. Although there are technical problems to be solved, the results of this study suggested that wildfire in 2004 substantially affected ground surface condition (decline in moss + organic layer) and killed most of fine roots at the severely burned black spruce forest, but the effects on total fine root biomass might not be remarkable.

1. INTRODUCTION

Boreal forest is believed to play an important role in carbon dynamics in terrestrial ecosystems. One of the reasons is that the amount of soil carbon contained in boreal forests was estimated to be twice as large as that of temperate and tropical forests combined, even though boreal forests cover only half the land area of the other two forest types. However, it is expected that boreal forests may shift to a net source of carbon from a net sink in the near future, due to events such as deforestation activities and fire disturbance (Kasischke 2000). Black spruce (Picea mariana) is a dominant tree species on poorly drained north facing slopes, which is usually underlain with permafrost. Black spruce forests are widespread in interior Alaska and they cover more than 40% of the Fairbanks area (Viereck et al. 1983). Although black spruce forests are known to have low aboveground productivity, some papers suggested that belowground processes are much more dynamic than expected. In particular, a recent paper by Ruess et al. (2003) showed an importance of fine root dynamics: fine root production and respiration in black spruce forests accounted for 56% of total stand production and 56% of soil CO\(_2\) efflux, respectively (Ruess et al. 2003). Fire is a dominant disturbance in boreal forests and affects carbon and nutrient cycling in those forests significantly. However, there is only limited information on fire effects on fine root biomass and its dynamics, which would be a key factor in carbon and nutrient dynamics in black spruce forests. Therefore, in this study, we examined fine root biomass in a black spruce forest that was severely burned by wildfire that occurred in summer 2004.

2. FIELD SURVEY METHODS AND OBJECTIVES

The objective of this study was to elucidate effects of the wild fire in summer 2004 on fine root biomass in a black spruce (Picea mariana) forest. In August 2005, a field survey was conducted at a black spruce forest at the Poker Flat Research Range (65° 07' N, 147° 28' W) of the University of Alaska, Fairbanks, which was severely burned by wildfire in summer 2004. An unburned black spruce forest close to the burned forest was also investigated as a control. Samples, including surface moss + organic (MO) layer and mineral soils to the depth of 20 cm, were taken at 6 sampling
places in each site using a knife and/or a soil corer (4.8 cm in inner diameter) (Split tube sampler, Eijkelkamp, Netherland). Distances between the sampling places were approximately 3.5 m. The samples were divided into MO layer and 0–10 and 10–20 cm mineral soil layers and were kept at cool temperature or in a freezer (-20 °C) until processed. Then the samples were washed with tap water on a 0.5-mm mesh sieve and fine roots (< 2 mm in diameter) were picked up using tweezers. The fine roots were further classified into live and dead roots with criteria: live roots were firm and resilient. The fine root samples were dried at 70 °C for more than 48 hours and were weighed using an electric balance.

3. RESULT

In the burned site, surface moss + organic (MO) layer was severely burned by the wildfire in summer 2004 and there was no permafrost (to 160 cm deep mineral soil, Matsuura 2005) at sampling places in this site. In contrast, in the unburned site, some of the sampling places were frozen at bottom of the MO layer and mineral soils. Therefore we were not able to reach the soil depth of 20 cm for 4 of 6 soil core samplings in the unburned site.

Fine root biomass, including live and dead roots was ~1010 and ~1040 g m⁻² in MO layer to the soil depth of 20 cm in burned and unburned sites, respectively (Fig 1). Most of the roots (~99%) appeared to be dead in the burned site, whereas 65% of the fine roots in the unburned site were classified as living roots (Fig 1). Fine roots were concentrated to surface MO layer in both burned and unburned sites. The fine root biomass in the MO layer was ~850 and ~950 g m⁻² in the burned and unburned sites, respectively, which was ~70% of the total fine root biomass in surface to 20 cm deep mineral soil (Fig 2). Fine root density in the MO layer was larger in the burned site than in the unburned site due probably to reduced thickness of the MO layer in the burned site. If we assume that carbon contents in the fine roots were ~50%, fine roots in the MO layers would contain ~425 and ~475 g C m⁻² in burned and unburned sites, respectively. These values corresponded to ~20% and ~10% of organic carbon in the MO layers of burned (2.2 kg C m⁻²) and unburned sites (4.4 kg C m⁻²), respectively (Matsuura unpublished).

Because of technical difficulties, we were not able to separate roots, in part, from root-organic matter complexes (RO in Fig 1). In addition, fine roots of < 0.5 mm in diameter was partly lost through 0.5-mm mesh sieve during the root separation process. Therefore, the fine root biomass might be underestimated in this study.

![Graph 1: Live and dead fine root biomass in surface MO layer to 20 cm deep mineral soil (d < 2 mm)](image1)

![Graph 2: Vertical distribution of fine root biomass (d < 2 mm)](image2)

4. CONCLUSION

In conclusion, this study suggested that wildfire in summer 2004 burned surface moss + organic (MO) layer of a black spruce forest severely and reduced their thickness. It is also suggested that the disturbance killed most of fine roots in the burned site, although the effects on the total fine root biomass might not be remarkable.
Further research would be needed especially to evaluate effects of fire on very fine roots (d < 0.5 mm) that were partly lost in this study. Increase in depth of active soil layer after fire may change patterns of vertical distribution of fine roots in the future. It would be fruitful to elucidate fine root production and/or decomposition rates using ingrowth cores, root-litter bags or minirhizotron techniques related to status of the MO layers and depth of active soil layers for our better understanding of fire effects on carbon and nutrient dynamics in black spruce forests.

5. REFERENCE
Matsuura 2005: Forest fire effects on soils at Poker Flat Research Range, Interior Alaska -A preliminary survey for monitoring study-. Proceeding of the 6th International Conference on Global Change: Connection to the Arctic (GCCA-6), 215-216
Examination of structural constraints in relation to site condition in black spruce chronosequence

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1. INTRODUCTION

Structural development of crowded plant populations has been suggested to consist of three different phases when viewed in terms of a relationship between aboveground biomass and stand density (Prentice & Leemans 1990; Fig. 1). Plants grow in size without little mortality at phase I. Subsequently (phase II), the stand follows the self-thinning line with a slope of \textit{ca.} -0.5. Finally (phase III), stand density continues to decline without much change in biomass around its nearly constant value. There have been numerous examples confirming validity of phase I and phase II (Yoda et al. 1963, Yoda 1971, Harper 1977, Osawa & Sugita 1989, Osawa et al. 2003). Existence of phase III is more debatable. Model simulations showed its presence (Prentice & Leemans 1990), and argued it to be characteristic of ecosystem maturity. However, observation of phase III in real populations has been few. Data showing phase III were discussed for managed hardwood forests (Harper 1977, White 1980). However, they were interpreted to be results of tree harvesting (Harper 1977). One experiment showed loss of density-dependence in
aboveground biomass for plants growing under dim light (Lonsdale & Watkinson 1982). Infertile soils may also cause plants to die with little change in total biomass (Morris 2002). We have indicated that Larix gmelinii forests of central Siberia show clear pattern of phase III when the trees grow over continuous permafrost (Osawa et al. 2003). We further argued that this is not only a phase of stand development, but also indicates an alternative self-thinning line for the species (Osawa et al., in preparation).

Objective of the present study is to examine if phase III of stand development be observed among black spruce forests of Alaska and its adjacent localities in northwestern Canada (Fig. 2). The populations growing on continuous permafrost will be examined in detail. We also plan to examine if the constant value of biomass (at phase III), if present, can vary depending on site condition. Site condition may differ depending on the depth of soil active layer and other causes. Patterns of development in aboveground biomass and its components, root biomass, plant mortality, and spatial pattern of leaf distribution will be described among stands representing chronosequence after stand-replacing forest fires.

2. METHODS

2.1 Stand selection and measurement

Pure or nearly-pure stands of black spruce of various stand ages will be located in Alaska, U.S.A., Yukon, and MacKenzie delta in Northwest Territories, Canada. The stands will be chosen so that populations of various active layer depths are included. Following variables will be measured in each stand to allow the intended comparison: stand density, stem diameter at breast height (dbh), stem diameter at 30 cm aboveground (D_{30}), stem diameter at lowest living branch (excluding branches of layerings) (D_{lb}), and height of all living trees. Trees for measurement will be chosen by following the Wandering Quarter Method (Catana 1963, Osawa & Allen 1993). Trees of all sizes will be included as potential individuals for measurement. However, apparent layerings will be excluded.

2.2 Biomass equations

Trees of various sizes will be harvested in small number of selected stands. Tree dimensions will be measured as above, and biomass of each component will be measured by separating and sampling different organs. Root system will be excavated by hand, and weighed. Samples will be dried in oven for calculation of fresh/dry mass ratios. Then, regression equations will be developed to calculate individual dry mass of stem, branches, leaves, roots, etc.

2.2 Site condition

Site condition will be estimated by two means. First, mean tree height of a stand is calculated, and is used as a measure of site condition. This is a common
method of assigning site index in Russian literature (Usoltsev 2002). Second, depth of soil active layer will be measured in late summer or early fall using a soil penetrator with 5 km head mass. Mean of several measurements will be used as the depth for each stand.

2.3 Accumulation of stand data

Data of aboveground biomass and stand density will be compiled for each site condition, so that they would allow discussion of phase II and phase III in black spruce. Our experience in Siberia suggests that a few hundred stands should be measured to allow meaningful statements. We have already measured about 30 stands of black spruce in MacKenzie delta. UAF group may provide us existing data of about 90 stands. Measurement of additional 100-200 stands may be required for discussion of development of a representative site.

2.4 Description of stand development

Obtained data will be organized to describe possible development of stand structure and stand characteristics for a given site condition. Patterns of partitioning in fixed organic matter among organs, growth and death of individuals, development patterns of leaf biomass and three-dimensional leaf distribution in canopy space will be described or inferred. Then mechanisms of structural stand development in black spruce will be discussed.

3. POSSIBLE RESULTS

We have recently summarized a possible pattern of forest development after major fires for stands growing over continuous permafrost. Data for discussion came mostly from Siberia and for larch forests. However, we consider that something very similar probably applies to black spruce forests of northern North America. Suggested patterns of development include the following. First, leaf biomass of a stand may reach a maximum at relatively young stand age. It was suggested to be about 30 years for Larix gmelinii, after which leaf biomass declines only to about a quarter of the maximum. Second, self-thinning relationship (phase II) is observed until about age 30 years. Presence of a constant maximum aboveground biomass (phase III) becomes predominant after that (Fig. 2). Change in depth of soil active layer (its recovery) at stand age ca. 30 years is probably related to the shift in the pattern of stand development. Either (or both) lowering soil surface temperature or (and) change in patterns of nutrient dynamics may be the cause (Osawa et al. 2005). We conjectured (Osawa et al. 2005) that leaf distribution in canopy, tree size at mortality, size inequality of living trees, and light condition on forest floor may also change before and after the shift in stand development. All these parameters are planned to be examined for black spruce populations in the proposed study.
4. REFERENCES

Measurements of root respiration and soil respiration before and after forest fire
– Evaluation of the role of root in soil respiration–

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0. ABSTRACT
Soil respiration ($R_S$) and Root respiration ($R_R$) were measured in a heavy burnt plot and an unburned plot at Poker Flat Research Range. $R_S$ was measured using automated chamber system by IRGA. $R_R$ was measured using the same system by root sampling, and the sample root size was classified to 0-2, 2-5, 5-20, 20-50, 50$<$ mm in diameter. Measurements were conducted in summer season of 2005. At heavy burned plot, water content of root was low and $R_R$ was very low (almost zero). At the unburned plot, the smaller root had the higher respiration rate per weight. $R_R$ per root surface area was 0.05-0.08 mgCO$_2$ m$^{-2}$ s$^{-1}$ and similar to $R_R$ measured in a temperate forest in Japan under the same temperature. $R_S$ at the heavy burned plot was 0.01-0.04 mgCO$_2$ m$^{-2}$ s$^{-1}$ and it was 30-60% of that of the unburned plot. But $R_S$ at unburned plot was lower than that of temperate forest. So, the ratio of $R_R$ to $R_S$ in boreal forest was higher than that of temperate forest at least in summer season.

1. INTRODUCTION
Belowground process plays an important role in carbon cycle of biosphere. $R_S$ is the main pathway for carbon moving from the ecosystem to the atmosphere (Ryan and Law, 2005) and can strongly influence net ecosystem production (NEP). Therefore, $R_S$ has been measured in many ecosystems (e.g. Crill, 1991; Lavigne et al., 1997).

To understand CO$_2$ budget of forest ecosystem, it is needed to evaluate CO$_2$ efflux from the soil accurately by separating autotrophic from heterotrophic respiration. Here, autotrophic respiration means root respiration. There were many reports dealing with separation of soil-surface CO$_2$ into autotrophic and heterotrophic respiration. Hanson et al. (2000) concluded in their review that the contribution of $R_R$ to $R_S$ might converge at approximately 48.5% in the forest ecosystem, but this ratio changed widely between 10 to 90% according to measurement methods, forest type, season, and place.

The ratio of NEP to total ecosystem respiration and the contribution of fine root respiration ($R_{FR}$) to total $R_S$ are both thought to increase with increasing latitude in forest ecosystems. Roger et al.(2003) showed these two observations were functionally coupled and estimated of $R_{FR}$ / $R_S$ was 0.57 in three black spruce stands located along the floodplain of the Tanana River in Alaska. In boreal forest, forest fire is a major disturbance and significantly decreased $R_S$ by at most 50% (Kim et al., 2003). So it is important to describe the effect of forest fire on $R_S$ and $R_R$ in boreal forest.

In this study, we measured $R_S$ and $R_R$ in after and before forest fire. It is preliminary study at the Poker Flat Research Site.

2. FIELD SURVEY METHODS AND OBJECTIVES
Measurements were conducted in Poker Flat Research Range. Two plots were established at heavy burned area, which burned in June 2004, and unburned area. Fine root biomass was measured by Dr. Noguch at burned plot and unburned plot. The amount of woody debris was measured by Dr. Jomura at burned plot. Measurements were conducted in 8$^{th}$ to 13$^{th}$ Aug. 2005. Air temperature was 5 to 35 degrees centigrade in this term.

One of our objectives is the development of portable automatic chamber system for measurement CO$_2$ efflux from soil, root, and woody debris. In Alaska, there is widespread variation in air temperature. Because CO$_2$ efflux can be strongly influenced by temperature, it is needed to measure CO$_2$ efflux at high frequency. The CO$_2$ measurement system consists of a chamber (W18×D18×
H11 cm), an IRGA (Li-800, Li-cor, USA) and a pump. A chamber is made by acrylic resin and opened and closed automatically by air cylinders. Air is supplied from an air tank and controlled by a timer. The bottom of the chamber is suitable to measure soil respiration and convertible to box type for measurement root respiration. It needs low electric power (for timer, logger, IRGA, and electromagnetic valve) because it uses air power for opening a chamber. So, it is convenient for field measurement.

Our second objective is to measure $R_S$ and $R_R$ after and before forest fire. $R_S$ is an important role in carbon cycling of boreal ecosystems due to the high proportion of biomass allocated belowground (Roger et al., 2003). $R_S$ consists of $R_R$ (autotrophic respiration) and decomposition respiration (heterotrophic respiration), and to evaluate root respiration separately is necessary to understand the carbon cycling. However there is not so many studies of measurement of total $R_R$. We measured $R_S$ at both plots. Soil temperature and soil moisture were measured at same time. And we measured $R_R$ at both plots. Root samples were collected at heavy burned plot and unburned plot for measurement of $R_R$. The sample root size was classified to 0-2, 2-5, 5-20, 20-50, 50<mm in diameter. The surface area and dry weight of root samples were measured.

In previous study, we measured $R_S$ and $R_R$ in temperate forest in Japan. So, we compared $R_S$ and $R_R$ between temperate and boreal forest.

At both plots, root samples were remained in the soil into mesh bag for measuring root decomposition rate.

3. RESULT

Fig.1 shows the result of measurement of $R_S$ and soil temperature. $R_S$ at heavy burned plot was 0.01-0.04 (mgCO$_2$ m$^{-2}$ s$^{-1}$) and it was 30-60% of that of control plot.

![Fig.1. $R_S$ and soil temperature measured in burned and unburned plot at Poker Flat Research Site.](image)

At heavy burned plot, water content of root was low and $R_R$ was very low (almost zero). In heavy burned plot, $R_R$ was CO$_2$ efflux from dead root. At unburned plot, the smaller root had the higher respiration rate per weight. Fine root (< 2 mm) had high value of $R_R$ per weight. $R_R$ per sample root surface area was 0.05-0.08 mgCO$_2$ m$^{-2}$ s$^{-1}$ (Fig.2). The value was similar to $R_R$ measured in temperate forest in Japan under the same temperature.
4. CONCLUSION

In comparison with temperate forest in Japan, $R_S$ was lower and $R_R$ was similar at unburned plot. So, the ratio of $R_R$ to $R_S$ was higher than temperate forest at least in summer season. So, the role of $R_R$ is important in Alaska. It is needed to measure root distribution for estimation of $R_R$ per area. In heavy burned plot, $R_R$ was hardly included in $R_S$. It is suspected that $R_S$ will be higher with production of root after forest fire. We will estimate $R_R$ per area and evaluate the role of $R_R$ including $R_S$ in the future work.

![Graph](image)

**Fig. 2.** $R_R$ per root weight and $R_R$ per root surface area according to root size.

5. REFERENCES


Carbon loss from forest floor/top soil by wildfire:  
- A case study of 2004 fires at Poker Flat Research Range -

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ABSTRACT
Carbon loss after one year of 2004 wildfire was estimated in Poker Flat Research Range (PFRR). By comparing organic C storage at burned site with those of unburned sites, C loss from forest floor/top soil was estimated at three different forest types. Three profiles were surveyed at Picea mariana (black spruce) stands, of which two profiles were located on the burned forest. Heavily burned site showed remarkable permafrost table subsidence below 160 cm of mineral soil horizon; on the other hand, permafrost table existed at the depth of 33 cm below mineral soil at the unburned black spruce stand. Forest floor thickness of unburned black spruce stand was 20 to 30 cm. Decline of forest floor thicknesses after wild fire in Betula papyrifera var. humilis (Alaskan paper birch) stands was distinct with slightly scorched top soil, whereas there was not so much decline of forest floor thickness in Populus tremuloides (quaking aspen) stands. Organic C loss from forest floor was estimated as follows; 2.0 – 2.2 kg C m⁻² in black spruce stands, 2.6 kg C m⁻² in Alaskan paper birch stands, 0.2 kg C m⁻² in quaking aspen stands. C loss form top soil (30 cm storage) was not so clear in birch and aspen stands. Further studies on dead root organs and CWD contribution to C storage and loss are needed.

1. INTRODUCTION
Wildfire is one of major disturbances in northern forest ecosystems. Wildfire disturbances release large amount of carbon dioxide during burning process, and also change the site from sink to source for carbon (Kasischke & Stocks 2000). Soil properties such as nutrient storage and other chemical constituents are also affected by burning severity and fire frequencies (Dyrness & Van Cleve 1989; Certini 2005; Smithwick et al. 2005). The year 2004, there were many wildfire occurrences in Interior Alaska and Yukon Territories. Those fire occurrences and total burnt area in Interior Alaska was the worst record in the past five decades (Prof. Fukuda, personal communication). Effects of this fire are great concerns for regional environment, especially for carbon sink/source balance.
Permafrost type in Interior Alaska is discontinuous, so that permafrost melting event and postfire regeneration/succession process may vary site to site. Based on general scientific information on post fire regeneration in Alaskan forests (Van Cleve et al. 1986), long-term monitoring research after wildfire is attempted with integrated interdisciplinary fields (Chapin et al. 2006).

The large wildfire occurred in 2004 may be an important event which provides us an opportunity to recognize ecosystem processes and functions. This paper reports preliminary results of 2004 wildfire effects on carbon storage decline at Poker Flat Research Range.

2. STUDY SITE AND METHODS
I selected soil survey area in Poker Flat Research Range (65°07’ N — 147°28’ W) burned in 2004 summer. Soil profile survey and soil sampling were conducted in August 2005. Seven profiles were surveyed; three in Picea mariana (black spruce), two in mixed Betula papyrifera var. humilis (Alaskan paper birch / black spruce), and two in Populus tremuloides (quaking aspen) stands. Those seven profiles were located on NNW to WNW facing slope. For Picea stands, profile description and soil sampling were conducted in heavily burned stand (PF-1), no fire damages stand (PF-2), and moderately burned stand (PF-3). For Betula and Populus stands, pair of no fire damages and burned stand was surveyed; no fire damages Betula (PF-5), burned Betula (PF-6), no fire damages Populus...
(PF-4), and burned *Populus* (PF-7). Forest floor condition and litter accumulation depth, regeneration species, and depth of permafrost table were recorded. Other features of soil profile were described according to FAO/ISRIC system (FAO 1990). Soil organic C and total N storage were analyzed by dry combustion method (NF-22F, SUMIGRAPH).

3. RESULTS AND DISCUSSION

Permafrost existed under *Picea* stands, except for heavily burned stand (PF-1). The shallowest depth of permafrost was 33 cm below mineral soil surface at no fire damage *Picea* stand (PF-2). Surface organic layer with moss and lichen accumulated with 20 to 26 cm thickness. Moderately burned *Picea* stand (PF-3) had permafrost table at deeper position (67 cm). Heavily burned stand (PF-1) had no permafrost table until 160 cm depth from surface soil. Permafrost table might subside more than 1.3 m in one year after fire disturbance. There was no permafrost tables under the both burned and no fire damages stands of *Betula* and *Populus* within 1.1 m depth. Permafrost tale might not be formed under these deciduous tree stands where more heat energy was supplied than in north facing black spruce stands.

Regeneration process in *Picea* stands started with patches of *Chamaenerion angustifolium* (fireweed), *Calamagrostis* spp., and *Polygonum* spp. Survived shrubs, such as *Ledum decumbens* and *Vaccinium uliginosum*, flushed new foliage. Another dense vegetation patch of *Equisetum* spp. and *Marchantia polymorpha* developed at mesic site in burned area of *Picea* stands.

Thickness of forest floor in *Betula* stands decreased much; 12 cm in no damage stand (PF-5) to 2 cm in burned stand (PF-6). *Populus* stands showed less decrease of organic layer; 7-10 cm in no damage stand (PF-4) and 4-7 cm in burnt stand (PF-7). Vigorous regeneration observed in both deciduous dominant stands (PF-5 and PF-7). Seedling germination and vegetative sprout observed in burned *Betula* stand. Vegetative sprout regeneration from survived root system was dominant in burned *Populus* stand.

Organic carbon storage in each stands was estimated (Fig. 1). Decline of carbon storage after wildfire was estimated, assuming that C storage in unburned stands in 2005 were same regime of C storage as burned stands before 2004 wildfire. Compare with unburned black spruce stand, 2.0 to 2.2 kg C m\(^{-2}\) was lost, which derived from surface moss + lichen layer and 1/3 of O horizon. Mixed Alaskan paper birch/black spruce stand showed large C storage decline in forest floor. Nearly 80% of O horizon, 2.6 kg C m\(^{-2}\) was lost. On the other hand, there was only 10% of forest floor C storage decline (0.2 kg C m\(^{-2}\)) in quaking aspen stand.

Although top mineral horizon of soil profile in burned stands showed lighter soil color (10YR 5/3), comparing with topsoil color in no damage stands (10YR 3/3), there were no clear C storage decline in top 30 cm mineral soil. The C/N ratio of top 30 cm slightly decreased in black spruce and mixed Alaskan paper birch/black spruce stands.

4. CONCLUSION

Wildfire disturbance in 2004 caused much C loss from forest floor (0.2 – 2.6 kg C m\(^{-2}\)). Heterogeneity of fire severity and litter flammability affected mosaic pattern in disturbed area. Mineral soil C storage showed no clear decline, however top 30 cm mineral soil C/N ratio slightly decreased at burned black spruce and Alaskan paper birch/black spruce stands. This estimation excluded coarse woody debris (CWD) contribution to C storage after fire. Further research on C storage is needed.
Fig. 1. Estimated organic C storage of seven stands at PFRR. Shapes of polygons indicate C storage in each component as shown at upper left part of the figure.

REFERENCES
Modeling Climate-Fire-Vegetation Dynamic

S. Rupp

The boreal forest version of ALFRESCO was developed to explore the interactions and feedbacks between fire, climate, and vegetation in interior Alaska. ALFRESCO is a state-and-transition model of successional dynamics that explicitly represents the spatial processes of fire and vegetation recruitment across the landscape. ALFRESCO does not model fire behavior, but rather models the empirical relationship between growing-season climate (e.g., average temperature and total precipitation) and total annual area burned (i.e., the footprint of fire on the landscape). ALFRESCO also models the changes in vegetation flammability that occurs during succession through a flammability coefficient that changes with vegetation type and stand age.

We will report on several research projects utilizing ALFRESCO to simulate current and future landscape dynamics including response to forecast climatic warming and the influence of fire frequency on caribou habitat.
Climate warming has had large, societally important effects on Alaska. Ecosystem services, which are the benefits that society derives from ecosystems, provide one way to evaluate these effects. I briefly discuss the effects of climate warming on ecosystem services in Alaska, with an emphasis on the effects associated with changes in wildfire. Warming has had particularly profound effects on factors that influence landscape interactions (climate regulation, disturbance spread, and disease regulation). Ecosystem goods, such as food (subsistence resources), water, and wood that receive most management attention are only indirectly affected by warming. The cultural services provided by ecosystems are also sensitive to warming and have led to some of the few institutional responses that address causes of climate warming.
Fire Effects on Plant-Soil System in Taiga Forests in Interior Alaska

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ABSTRACT

Nutrient availability is assumed to increase and stimulate ecosystem productivity by global warming in many terrestrial ecosystems. Northern forests contain significant global carbon pools, and fire is a common component in these forests. Thus, concerns have recently been directed to fire effects on carbon and nitrogen cycles in plant-soil system. Our objective of this study is to clarify fire effects on 1) surface soil properties, especially soil N transformations, 2) dissolved organic matter characteristics in soil, 3) plant N use and 4) openness of N cycle. In Aug. 2005, a preliminary research was carried out in the Poker Flat Research Range located in the heavily burned area by a large forest fire in 2004. Pool size of inorganic N, metals, and dissolved organic carbon, and net rates of N mineralization and nitrification were compared (1) between burned and unburned areas in three different vegetation stands (black spruce, black spruce/paper birch, and aspen) and (2) between inside and outside of unburned “moss island”. Soil inorganic N pool size was larger in the burned stands than in the unburned stands, while rate of net N mineralization (measured using laboratory incubation) was greater in the unburned stands than in the burned stands. Between inside and outside of “moss island”, no clear difference was found in both inorganic N pool and net N mineralization rate, despite lower temperature in “moss island”. Fire effects on the change of vegetation are partly due to the species physiological characteristics about nutrient use. For example, results of a fertilization experiment in a tundra ecosystem showed that the responses of plant to N fertilization were highly variable among species, and some species increased their biomass by N fertilization but not N concentration, and the other species tended to be the opposite. These results and future research plans are discussed using our results on plant N use and openness of N cycle studied in Central Siberia and Alaskan tundra.

Keywords; nitrogen dynamics, plant-soil system, mineralization, dissolved organic carbon
1. INTRODUCTION

The structure and functioning of arctic and boreal ecosystems are sensitive to subtle changes in climate. There has been a doubling of the area burned in North America (Chapin et al. 2000), while fire is a common component in the dynamics of taiga forest in interior Alaska, and many studies have been done to understand the effects of fire on the ecosystem (Van Cleve et al. 1983). Forest fire has large influences on the regeneration process of vegetation and nutrient cycling in forest ecosystems. In terms of nutrient cycling, forest fire burns aboveground biomass and surface litter, leading to change in biomass allocation and physical and chemical conditions of surface soil.

Strong influence of nutrient availability on growth and regeneration of forest ecosystem has been well understood (Shaver et al. 1992). In this study, we mainly focus on N dynamics in plant-soil system. Forest fire burns the forest floor and aboveground biomass, possibly resulting in the changes of nitrogen (N) availability and pools of labile organic matter and metals. It is also considered to influences on N use and nutritional status of plants, consequently on plant-soil system. Our primary objective of this study is to understand the fire effects on plant-soil system in taiga forests in interior Alaska. To achieve this objective, we try to clarify the fire effects on 1) surface soil properties, especially soil N transformations, 2) dissolved organic matter characteristics in soil, 3) plant N use and 4) openness of N cycle.

2. CASE STUDY

2.1 CASE STUDY-1. Soil N dynamics and pools of DOC and metals

The studies on soil chemical properties were conducted at the Poker Flat Research Range, where experienced a large-scale forest fire in 2004. We found three vegetation types in the study site: 1) black spruce (Picea mariana), 2) mixed black spruce/paper birch (Betula papyrifera), and 3) aspen (Populus tremuloides). We collected forest floor materials and surface mineral soils in three replications, and buried ion exchange resins at A₀-mineral interface in five replications at the burned and unburned stands of the three vegetation types in Aug. 2005. For the collected samples, we measured pool size of inorganic N and net N transformation rates using 28-days laboratory incubation at 25°C. The buried ion exchange resins will be collected in Aug. 2006.

We also focused on spatial heterogeneity of fire severity in a black spruce stand. In a postfire black spruce forest stand in the Poker Flat, thick forest floor and moss (Sphagnum) layer which had been covered mineral soil before fire were mostly removed by fire, but partly remained like rocks or islands even after fire. We selected a unburned "moss island" in the postfire black spruce stand, and collected samples of forest floor materials and surface mineral soils inside and outside of the island using two transects as shown in Fig. 1; one was
across the slope (Transect 1), and the other was along the slope (Transect 2). The transects started from the out of “moss island”. The A₀ material (including moss layer) and mineral soil were sampled with 30cm intervals, and thickness of forest floor material and soil temperature at A₀-mineral interface were measured at the samplings. The samples were shipped to Japan with ice and net N transformation rates (using 28-days-laboratory incubation at 25°C) and pool size of 2N KCl extractable DOC, Al, Fe, Ca and Mg.

The preliminary results are shown in Fig. 2, 3, and 4. In both A₀ layer and surface mineral soil, pool size of inorganic N (NH₄⁺-N + NO₃⁻-N) were larger in burned stands than in unburned stands for all the three vegetation types (Fig. 2a and 2b). On the other hand, net rate of N mineralization was higher in unburned stands than in burned stands, except for mixed black spruce/paper birch (Fig. 2c and 2d). Soil N availability was unlikely to increase by forest fire, or rather likely to decrease, in contrast to the earlier reports (Smithwick et al. 2005). Further researches using field incubation and controlling environmental factors are needed for understanding this trend.

Fig. 1. A schematic diagram of the unburnt "moss island" in the burnt black spruce stand.

Fig. 2. The sizes of total inorganic N pool in A₀ layer (a) and at a depth of 0-5 cm in the mineral soil (b), and the rates of net N mineralization by laboratory incubation of A₀ layer (c) and mineral soil (d). Bars show standard errors (n = 3). BS, Black spruce; PB, Paper birch; AS, Aspen.
Figure 3 shows the thickness of A₀ layer including moss layer, and soil temperature at A₀-mineral soil interface of the two transects established at the postfire "moss island". Soil temperature was lower under the "moss island" with thick A₀ layer. However, the net rates of N mineralization did not vary between inside and outside of the "moss island" (Fig. 4).

Pool size of extractable DOC was obviously greater at the outside of the “moss island” compared to the inside (Fig. 5). It indicates that burned areas had greater pools of accessible, small-size, organic matter than unburned areas. It may also suggest higher potential pools of decomposable organic matter. Calcium and magnesium pool sizes were marginally concurrent with this trend. In contrast, aluminum and iron concentration were higher at the inside. These trends in metals may be related to those in extractable DOC because close relationships has been well known between soil DOC and metals.
2.2 CASE STUDY-2. Relationships among species dominance, physiological characteristics, and soil N condition

In arctic ecosystems where inorganic N production is low because of cold temperature, plant species take up N in various ways (Nadelhoffer et al. 1996). Plants take up N in different form, or from different depth, or through mycorrhiza; the species differentiation of N use enables many species to coexist.

The coexistence of diverse species in arctic ecosystem is likely to be sensitive to changes of limiting resource: soil N. Influences of soil N condition were investigated in moist non-acidic tussock tundra, Toolik LTER site, Alaska (Koyama and others, unpublished). Effects of long term N fertilization (10 g/m²/yr ammonium nitrate, for about 15 years) were investigated to describe the relationship between change of biomass and change of plant N use (especially, nitrate use). Plant species composition and dominance (% cover) was surveyed; leaf NRA (nitrate reductase activity: an index of plant nitrate use) and N concentration of 14 species (Three sedges (monocots): Carex bigelowii, Eriophorum angustifolium ssp. Triste, E. vaginatum. One forb: Polygonum bistorta. Two deciduous shrubs: Salix arctica, S. reticulata. One evergreen shrub: Dryas integrifolia. Two ericaceous shrub (Deciduous): Arctostaphylos alpina, Vaccinium uliginosum. Four ericaceous shrubs (Evergreen): Cassiope tetragona, Ledum palustre, Rhododendron lapponicum, V. vitis-idaea. One pterido- phyte: Equisetum arvense) were measured in control plot and N fertilized plot.

![Fig. 5. Pool sizes of extractable DOC (A and C) and Al, Fe, Ca, and Mg (B and D).](image_url)
Nitrogen fertilization increased the % cover of *C. bigelowii* and *S. reticulata*, while it reduced the % cover of *C. tetragina*, *R. lapponicum* and *E. arvense* (Fig. 6). *Polygonum bistorta*, *S. reticulata* and *E. arvense* showed very high leaf NRA in comparison with other species, but leaf NRA was not influenced by N fertilization. Leaf N concentration was increased by N fertilization in most species except *C. bigelowii*, *E. angustifolium* ssp. *Triste*, *E. vaginatum* and *S. reticulata*.

The results indicated that N fertilization increased either plant biomass or plant N contents, but not both at once. Nitrate reductase is a substrate inducible enzyme, and very high NRA was detected in some species; therefore certainly nitrate was produced in tundra soil. However, it is unlikely that the nitrate availability was increased by N fertilization, since plant NRA was not changed by N fertilization.

3. FUTURE RESEARCH PLAN

From the results of the case studies, a few influences of forest fire on plant-soil systems in these forests can be suggested: 1) postfire nutrient status varies possibly with forest types, 2) postfire distribution of soil nutrients and labile components may be related strongly to that of burned patch areas.

The influence of forest fire on the soil is considered to lead to change in the plant-soil system. Plant shows the high variability of nutrient use, especially in N, shown in Case 2. To estimate the above-mentioned factors, comparisons between burned and unburned systems are required. So that, based on the following hypotheses, we will make investigations on soil and plant, and discuss the effects of forest fire on plant-soil systems in taiga forests in interior Alaska.

**HYPOTHESIS & QUESTIONS**
-Strong influence of soil chemical condition including DOC and metals on plant biomass, plant nutrition, and plant distribution.
-Changes in soil N condition (N availability, N form and their spatiotemporal change) are different according to the types of disturbance (fire or N fertilization).
-The type of change by N enrichment (in biomass or in N contents) depends on species, and the species characteristics regulate the species dominance / composition after disturbance.
-Forest fire lead to increase nutrient loss from forest ecosystem?

INVESTIGATION -Comparison between burned and unburned site-
-Postfire distribution of soil nutrients and labile components in small scales, and its relationship with plant nutrient use and root distributions
-Species dominance: species composition, biomass of each species
-Species physiological characteristics: N use (N contents, N source (nitrate use, organic N use)) of dominant species

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We appreciate Dr. Y. Matsuura and colleagues at the Poker Flat Research Range, Alaska and the Tura experimental station, central Siberia for their cooperation. We also thank Drs. K. Koba, S. E. Hobbie, L. McSherry, L. Gough, and G. Shaver for their help in the tundra case study on plant N use.

REFERENCES

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 *Sphagnum* 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, monospecific 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

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**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.
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.

<table>
<thead>
<tr>
<th>Tree Species</th>
<th>Pre-fire</th>
<th>Post-fire</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Picea mariana</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stem density (m)</td>
<td>24.3 ± 3.9</td>
<td>5.3 ± 2.7</td>
</tr>
<tr>
<td>Total cross-sectional area (cm²)</td>
<td>439 ± 74</td>
<td>112 ± 58</td>
</tr>
<tr>
<td>Total stem volume (m³)</td>
<td>9.2 ± 2.0</td>
<td>2.3 ± 1.4</td>
</tr>
<tr>
<td>Others</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stem density (m)</td>
<td>0.8 ± 0.6</td>
<td>0.2 ± 0.2</td>
</tr>
<tr>
<td>Total cross-sectional area (cm²)</td>
<td>7 ± 6</td>
<td>2 ± 3</td>
</tr>
<tr>
<td>Total stem volume (m³)</td>
<td>0.0 ± 0.1</td>
<td>0.1 ± 0.1</td>
</tr>
</tbody>
</table>

Fig. 2. Relationship between burned area and mean duff thickness in 80 m x 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 cm² (mean ± standard error) and 9.2 ± 2.0 m³, respectively. Three other tree species, *Alnus crispa*, *Betula papyrifera*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.
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.

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).

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.) Hultén.
Table 2. Numbers of seedlings recorded in burned and unburned areas. Density (/m²) is shown in parentheses. Significant differences in seedling densities between burned and unburned areas are examined by χ²-test for *Picea mariana* (*P* < 0.01). The significance test was not conducted for the other three species.

<table>
<thead>
<tr>
<th>Habitat</th>
<th>Unburned</th>
<th>Burned</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Picea mariana</em></td>
<td>353 (13.7)</td>
<td>105 (1.9)</td>
</tr>
<tr>
<td><em>Betula papyrifera</em></td>
<td>0</td>
<td>20 (0.4)</td>
</tr>
<tr>
<td><em>Populus tremuloides</em></td>
<td>0</td>
<td>96 (1.8)</td>
</tr>
<tr>
<td><em>Salix</em> sp.</td>
<td>0</td>
<td>1 (0.0)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>353 (13.7)</td>
<td>222 (4.1)</td>
</tr>
</tbody>
</table>

**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.](image-url)
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.

**Acknowledgements**

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**References**


