B-053 Study on the estimation of carbon storage and fixation in the boreal forest in Russia（Abstract of the Final Report）

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[Abstract] We attempted to estimate accurately carbon storage and C fixation rate in forest ecosystem of Russia, including permafrost and non-permafrost region. We used datasets of forest inventory and those we newly obtained. We observed phenomenon of canopy dieback that is considered to be related to presence of permafrost. We also estimated carbon storage, net primary production (NPP), and net ecosystem production (NEP). Biomass estimation was conducted for 26 study sites of birch and mixed with larch after forest fires along chronosequence in Amur region. Carbon storage in the stands at around 150 years after fires was estimated to be 50 Mg C ha^{-1} on average. The pattern of above- and below-ground biomass accumulation of major forest types were examined in the non-permafrost regions in Central Siberia and Europe-Russia using compiled datasets by Usoltsev (2001). We found that the average values of T/R differed among the four forest types. Forest floor and mineral soil are large components of C storage. We estimated that forests in non-permafrost region store about 70 % of total C in forest floor and mineral soil of whole Russian northern forests. We obtained the land classification from 30-m resolution Landsat ETM+ image data and used it for evaluating the area ratios of the land categories in each pixel by using 500-m and 1-km resolution images. The 30-m resolution classification image was effective for the evaluation since the classification was consistent with the interpretation of the two IKONOS images obtained prior to and following the fire. Various indices derived the combination of NDVI and LST showed effectively the global dynamics of surface conditions of the Russian northern forests. The results appear the regional characteristics of the forests and impacts of global change from the point of carbon fixation.

1. Introduction

Russian has large forested area, which is about 20% of the total forest in the world. Forests in Russia are also expected to be a big carbon sink; however, carbon storage capacity has not been accessed by scientific rationales. Forests in Russia show specific characteristics in each type. The larch forest on the permafrost soil is one of the characteristics in Middle and East Siberia. Many simulations on the impact of global warming give warnings to this region. Because the forested land contains carbon in the soil more than three times of that of in temperate forest, the global warming will cause the emission of CO_2 in large amount. Therefore, lack of scientific information about the forest ecosystem in Russia should be overcome. Remote sensing and advanced GIS system are useful tools for those studies

2. Research Objective

We had four parts of sub-levels in the project. Objectives in each sub-level are as follows:

(1) To obtain accurate estimates of carbon storage and rate of carbon sequestration in large areas of permafrost forest ecosystems in Russian Siberia, utilizing published data of forest inventory and newly gathered stand data of this study. Additional objective of the project is to estimate belowground carbon stock of forests at relatively high accuracy, because understanding of belowground carbon stock has been quite poor in forest ecosystems. It shall allow us to have better estimates and obtain reliable ranges on the values of carbon accumulation, NPP, and NEP.

(2) We evaluate the regeneration process and the forest biomass of stands in order to estimate carbon storage capacity on non-permafrost regions in Far East Russia, central Siberia, and Europe-Russia. To examine the pattern of above- and below-ground biomass of major forest types is also the target of the project.

(3) To estimate the accurate area of fire disturbed site in forests is important elements for scaling-up process. We selected test case in eastern Siberia for fire-affected C storage. To establish a revised analytical method for satellite images is a main task.

(4) To detect changes in phenology of ecosystem is one of the objectives. We investigated to get actual long-term digital data about seasonal changes of Russian forests by remote sensing data.

3. Materials and Methods

(1) We utilize the published data of forest inventory (Usoltsev 2001) and newly gathered stand data of this study. We estimated several sets of ecological parameters to estimate tree growth and NPP.

(2) We made research on 26 study sites to evaluate forest biomass in Amur, Far East Russia. We made allometry equations between biomass and the years after forest fire occurred. For the analysis, we mainly used a biomass dataset of Russian forests that was compiled by Usoltsev (2001). Other published data of forest biomass, mainly reported by Russian scientists, were also employed. From these sources, we selected some data which provided the estimates of both aboveground and root biomass. In all, we used the following data for the analysis by each forest type; Scots pine (290 stands), spruce (146 stand), birch (116 stands), and aspen (35 stands).

(3) The spectral mixture analysis (SMA) and multiple linear regression analysis (MLRA) were

used from the viewpoints of the area ratio estimation of each land category in one pixel and in the entire study area. As a result, the 500-m resolution image provided more congruent results than the 1-km resolution image in both the SMA and MLRA.

(4) The NOAA Pathfinder data from 1981 to 2001 were processed. On the NDVI data, the large fluctuations originated from noises have been removed by our LMF-KF method. As the land surface temperature (LST) data, we introduced the Channel 4 data of NOAA-AVHRR. After the LMF-KF processing to NOAA Pathfinder data for 20 years, we could get "clear" (cloud-free and noise-free) images with 10 day interval for both NDVI and LST. The combination of cloud-free NDVI (LMF-NDVI) and LST (LMF-LST) developed many possibilities to monitor environmental conditions in vegetated area. The maximum LMF-NDVI of each year, for example, is considered as a good indicator for annual changes of vegetation condition as each LMF-NDVI shows the seasonal condition of vegetation coverage.

4. Results

(1) The maximum amount of aboveground biomass is in the range of 80-100 Mg ha^{-1} in *Larix gmelinii* that grow on permafrost. This value is much smaller than the aboveground biomass of *Pinus sylvestris* that often reaches 300 Mg ha^{-1}. *L. gmelinii* biomass can be as large as 370 Mg ha^{-1} in the region without the permafrost. Therefore, the observed small biomass of *L. gmelini*i is mainly due to the presence of permafrost. Belowground biomass of *L. gmelinii* is also small after stand age of about 100 years, showing the values smaller than 20 Mg ha^{-1}. Biomass values of *L. cajanderi* are somewhat larger that those of *L. gmelinii*. Aboveground biomass of L. cajanderi in 150-200 year-old stands are about 120 Mg ha^{-1}. That of belowground biomass of *L. cajanderi* was about 40 Mg ha^{-1}. The ratio of aboveground to belowground biomass (or, T/R ratio) was 1-2 in *L. gmelinii* and 1-3 in *L. cajanderi*. There is a tendency that T/R reaches unity gradually as the stand ages. This tendency is clearer in *L. gmelinii*. The T/R value is generally in the range of 3-5 in *Pinus sylvestris* and *Picea* species in the region without the permafrost. This contrast is important to remember in estimating regional biomass. Analysis of published data and newly obtained measurements reached a conclusion that larch forest ecosystems on continuous permafrost of Siberia are the carbon sink. It was estimated that median of NEP values for the entire forests was 0.6 tC ha^{-1} yr^{-1}. The total amount of sequestrated carbon by the larch forests over permafrost is estimated to be 0.14 Gt C yr^{-1}. This value is equivalent to 11% of carbon sequestration by the entire boreal forest biome in the world (1.24 Gt C yr^{-1}; Apps et al. 1993).

(2) Carbon storage in the stands at around 150 years after fires in Amur was estimated to be on average 50 ton C ha^{-1}, and reached to be the maximum aboveground C storage of 125 ton C ha^{-1}. Soil organic carbon storage reached to 145 ton C ha^{-1}. We examined relationship between stand age and biomass for each forest type. For the two types of evergreen forest, aboveground biomass increased with stand age in both types, but its growth rate and pattern differed between the pine and spruce forests. For example, the pine forests attained larger potential larger carbon stock in aboveground parts (e.g., 300 Mg/ha at 100 yrs-old) than the spruce forests. For the two types of deciduous broadleaved forest, above- and below-ground biomass also increased with stand age, but

the potential carbon accumulation was slightly larger in the aspen forests than in the birch forests. As compared to the evergreen forests, carbon accumulation rates of the broadleaved forests were generally lower. Carbon allocation pattern between above- and below-ground parts was examined using the T/R ratio (i.e., aboveground total/root biomass ratio). We found that the average values of T/R differed among the four forest types. However, the difference was not associated with a form of leaf longevity. Namely, T/R ratio of Scots pine forests (averaged 4 - 5) was similar to that of birch forests (about 5), and T/R ratio of spruce forests (about 3) was closed to that of aspen forests (about 3.7). As for the Scots pine forests, T/R ratio also differed by regions, e.g., T/Rs of the stands located on higher-altitude sites around Ural Mountains were relatively small than those of the stands on low-altitude plains in Europe-Russia. These results suggested that carbon accumulation rate of forests differed by reflecting mainly the difference in the form of leaf longevity (i.e., evergreen versus deciduous broadleaved), but carbon allocation pattern between above- and below-ground parts largely depended on the dominant species rather than leaf longevity. The information should be taken into consideration when we evaluate precisely a large-scale forest carbon stock in the target area by classifying the forests into some types on the vegetation map (remote sensing images).

(3) The area ratios of the total burn and surface burn were estimated using the SMA with the 500-m resolution image with 6% and 3% errors, respectively. The total-burn area and surface-burn area in the study area were estimated to be 3.8 (%) and 28.6 (%), which was an underestimation of 3% and overestimation of 38%, respectively. Although the MLRA required a wide reference image, it yielded an improved estimate of the surface-burn area. The estimation was tested in a scene immediately following the fire; this scene barely revealed the burn scars caused several years ago. Further investigation is necessary for the mappings of the total burn/wither and surface burn areas in East Siberia.

(4) The trend of annual maximum LMF-LST for 20 years is considered the average temperature changes of the surface, which must be related to the effect of global warming and changes of ground coverage. The LMF-LST data itself is useful for understanding environmental condition of the forest area. One of such information, for example, is the warm index (the summation of temperature when it is higher than 5 degree C), which is useful for zoning the eco-region in global scale. The freezing index has close relations with the distribution of permafrost; the map of which was developed by the IIASA (2002). The LMF-KF processed images brought us the possibilities to develop further indices from the combination of NDVI and LST, which could be useful for monitoring phenological conditions of forest area. Actually, it was possible to create various kinds of indices from the combination of NDVI and LST. The onset day and offset day of vegetation growth of each pixel were defined from the maximum and minimum NDVI when the LST has greater than 1 degree C. The accumulation value of the NDVI between onset and offset is the NOOS index. The NOOS has the highest relation with the forest distribution map which was reported by IIASA (2002). The seasonal changes are well observed on the NDVI and LST individually. However, the combination of NDVI and LST shows much clear idea of the growing season and the trend of vegetation condition of each pixel. The annual changes are also observed

through the various indices. The difference of maximum NDVI between 1982 and 2000 show degraded areas. The changes are very much related to fire occurrence map in Far East. The NPP of the whole Russian forest are calculated each year using the LMF-NDVI and LMF-LST. The average NPP of Russia in recent years showed about 0.8 Gt.

5. Discussion

We have discovered that the Self-thinning rule, a general law in plant ecology, does not apply in older stands of *L. gmelinii* that grow on permafrost. Larch ecosystems on permafrost exist only in central and eastern Siberia in the world. Datasets and new findings on these ecosystems will be more important in the future to predict warming effects on the northern terrestrial region. We showed that initial good growth of trees after fire disturbance can lead to crown dieback, and even death of a tree, later in stand development: growing fast is not always good for a tree. It was clarified that larch forests over the permafrost are carbon sink. The amount of carbon sequestration by this biome is estimated to be about 11% of entire boreal forests in the world.

T/R ratios were not constant among the forest types. These values varied much in the same species. We should take into account to estimate C storage in belowground biomass. Through our processing datasets for Russian northern forests, well-distributed datasets were provided for whole circumpolar estimation of C dynamics.

Remote sensing study and satellite image analysis provided regional and continental scaling up tools. Long-term climatic condition data and phenological and ecological parameters will promote next steps for inter-disciplinal studies, such as forest economy and recourse management planning, and policy-making decisions.

References

Alexeyev VA, Birdsey RA (1998) Carbon storage in forests and peatlands of Russia. 137pp, USDA Forest Service, General Technical Report NE-244.

Apps, M. J. et al. (1993) Boreal forests and tundra. Water, Air, and Soil Pollution 70: 39-53.

Usoltsev VA (2001) Forest biomass of northern Eurasia: Databese and geography.(in Russia) 706 pp, Russian Academy of Sciences, Yekaterinburg.

Major Publications

1) Kajimoto, T., Y. Matsuura, A. Osawa, A.P. Abaimov, O.A. Zyryanova, A.P. Isaev, D.P. Yefremov, S. Mori, T. Koike: Size-mass allometry and biomass allocation of two larch species growing on the continuous permafrost region of Siberia. Forest Ecology and Management, 222, 314-325 (2006)

2) Makoto, K. and Koike, T.: Effects of nitrogen supply on photosynthetic and anatomical changes in current-year needles of *Pinus koraiensis* seedlings grown under two irradiances. Photosynthetica 45,99-104 (2007)

3) Kajimoto T, Osawa A, Matsuura Y, Abaimov AP, Zyryanova OA, Kondo K, Tokuchi N, Hirobe M: Individual-based measurement and analysis of root system development: case studies for *Larix gmelinii* trees growing on the permafrost region in Siberia. Journal of Forest Research 12, 103-112 (2007)

4) Kushida, K., Isaev, A.P., Maximov, T.C., Takao, G., & Fukuda, M.: Remote sensing of upper canopy leaf area index and forest floor vegetation cover as indicators of net primary productivity in a Siberian larch forest. Journal of Geophysical Research 112, G02003, doi:10.1029/2006JG000269 (2007)

5) Kushida, K., Isaev, A.P., Takao, G., Maximov, T.C., & Fukuda, M.: Remote sensing of total and surface burn ratios following a wildfire in East Siberia using 30 m - 1 km resolution images. Eurasian J. For. Res. 10(1), 105-114 (2007)

6) Koike, T., Kitaoka, S., Masyagina, O.V., Watanabe, Y., Ji, D.H., Maruyama, Y. and Sasa, K.: Nitrogen dynamics in leaves of deciduous broad-leaved tree seedlings grown in a unmanaged larch plantation in northern Japan. Eurasian Journal of Forest Research 10: 115-119. (2007)

7 Makoto, K., Nemilostiv, Y.P., Zyryanova, O.A., Kajimoto, T., Matsuura, Y., Yoshida, T., Satoh, F., Sasa, K. and Koike, T.: Regeneration after forest fires in mixed conifer broadleaved forests of the Amur region in Far Eastern Russia: the relationship between species specific traits against fire and recent fire regimes. Eurasian Journal of Forest Research 10: 51-58. (2007)

8) Zyryanova, O.A., Yabarov, V.T., Tchikhacheva, T.L., Koike, T., Makoto, K., Matsuura, Y., Satoh, F., and Zyryanova, V. I.: The structure and biodiversity after fire disturbance in *Larix gmelinii* (Rupr.) Rupr. forests, northeastern Asia. Eurasian Journal of Forest Research 10: 19-29. (2007)