論　文

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Comparison of forest biomass before- and after- wild forest fires in the conifer forest in northern Mongolia

モンゴル北部針葉樹林における山火事前後のバイオマス比較

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Abstract: In Asia, large forest fires have devastated large areas of forests; however, recovery of forest vegetation after the fires has not been well reported, particularly in northern Mongolian conifer forests. This study investigates vegetation recovery, soil water contents, and satellite images to detect the exact year of forest fire, species composition and vegetation recovery of the burned forest, biomass changes, and carbon emission at the burned site. Satellite data showed that forest fires occurred in 1998 and 2009. Forest biomass was reduced to one-third (75–20 t/ha) after the fires. Tree species composition of the study sites primarily changed from mature conifer forests (*Larix* and *Pinus*) to young deciduous broadleaved forests (*Betula* and *Populus*). Soil water content was constantly low during the growing season (0.052–0.086 m3/m3). Carbon emission model Yasso07 showed that coarse woody debris of *Pinus* will continue to emit carbon after the forest fires for the next 200 years. This study suggests that a combination of satellite images, field survey, and model simulation is important to examine the impacts of forest fires on vegetation.

Key-word: semi-arid, satellite data, soil moisture, model simulation, steppe–taiga transition zone

要旨：アジアでは林野火災により広い面積が消失しているが，モンゴル国北部の針葉樹林では火災後の植生回復過程はあまり明らかにされていない。本研究では火災発生後の植生回復，土壌水分含量変化，衛星情報による火災発生年の特定，推定バイオマス量の変化，炭素放出量推定などを行った。衛星データにより火災の発生は1998年と2009年と特定できた。火災の前後で森林のバイオマスは約75 t/haから20 t/haに減少し，樹種はカラマツ属とマツ属の針葉樹林からカバノキ属とポプラ属へと変化した。成長期の土壌水分含量は常に低かった(0.052～0.086 m^3/m^3)。炭素分解モデルYasso07によれば，優占種であるマツ属の炭素分解は今後200年は継続する。衛星写真と現地調査，シミュレーションを統合した林野火災影響研究は重要である。

キーワード：半乾燥，衛星データ，土壌水分，モデルシュミレーション，ステップ - タイガ移行帯

Ⅰ　Introduction

Large-scale forest fires frequently occur in Asia and can destroy several different types of forests such as boreal, temperate, and tropical forests. The damage caused by a fire poses a major obstacle for maintaining and improving timber resources and forest environments. Some studies have focused

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on the recovery of vegetation after forest fires. In Indonesia, Hiratsuka *et al.* (*5*) examined the recovery of vegetation after forest fires in the tropical rain forests. In a semi-arid Asian region in Mongolia, Chu *et al.* (1) used satellite data to examine post-fire regeneration in a Siberian larch forest located in the transition zone between the steppes and boreal coniferous forests (taiga). However, to our knowledge, no studies have combined ground surveys with satellite data analysis for assessing the recovery of vegetation after forest fires. Thus, the actual situation of vegetation recovery after forest fires remains largely unknown.

Given the lack of post-fire recovery data, we conducted a survey of vegetation and soil water content after forest fires in the southernmost area of a taiga in northern Mongolia. We used satellite data to identify the initiation of forest fires, and additionally simulated carbon emission from coarse woody debris after the fires, to help clarify post-fire changes in the forest and the subsequent recovery processes.

Ⅱ Material and methods

A ground survey was conducted between June 29 and July 8, 2016, and August 4 and 11, 2017, in an area close to Khyalganat (49.6°N, 104.2°E) near the northern border of Mongolia with Russia (Fig. 1). The survey site lies in a semi-arid transition zone between the steppe and taiga (Fig. 1).

The average elevation of the study site was 1,119 m above the mean sea level. According to the WorldClim database (http://www.worldclim.org/), the study area had a mean annual rainfall of 387 mm, mean daily temperature of −20°C in January, mean daily minimum temperature of −26.5°C in January, and mean daily temperature of 16.8°C in July.

A vegetation survey was conducted at the selected forest fire site, which showed recent fire evidence, and at a reference site, which showed not much fire evidence, to clarify the changes in biomass quantity and vegetation composition in response to forest recovery after a wildfire. A series of eight survey plots (20 × 20 m in size) were established in two valleys at the forest fire site (plots 1–8), and four survey plots were established at the reference sites (9–12). In each plot, the following data were obtained for every tree: species identification, diameter at breast height (DBH), diameter at the base (0 m, i.e., D0), and tree height. Soil moisture was also measured in the plots 1, 2, and 3 at 10-cm depth and 40-cm depth in the soil between July and October 2016, respectively, using standard soil moisture sensors (UIZ-ECO10).

Each tree was identified as to whether it was dead or alive and was categorized into the following three groups: [1] those that died owing to the forest fire, [2] those that survived the forest fire, and [3] those that newly emerged after the forest fire. The DBH values of some of the dead trees which were either cut or burned to the ground were estimated from relationships between DBH and D0 measurements.

The change in the quantity of forest biomass in response to forest fires was estimated using our survey data. Biomass was estimated for each tree on the basis of DBH measurements relative to the allometry formulas assigned to the species (*3,7,10,11*). The year in which each fire occurred was determined using satellite images such as Landsat.

For *Pinus*-dominated forests (plots 3, 5, and 8), which are typical in this region, carbon emissions due to forest fires were estimated using a soil carbon model, Yasso07 (*6*), which can take into account decomposition processes of coarse woody debris. The Yasso07 model requires information on quantity and chemical components of carbon input from dead organic matter, air temperature, and precipitation. The quantity of carbon input was calculated as one-half of aboveground biomass of dead woods. Data on monthly temperature and precipitation were prepared from the WorldClim database. The chemical composition of *Pinus* wood was derived from Liski *et al.* (*6*). In the burned forests, the decomposition rate of litter may be relatively low compared to that in the unburned forests, because of the decrease in soil microbiota and fungi. However, the effects of forest fires on the decomposition rate are still unclear, and some studies have reported contradictory results (e.g., (*9*)). Therefore, for the decomposition parameter, we used default values in the Yasso07 model prepared for the unburned forests.

Ⅲ Results

The soil of the study site was composed of weathered granite. The soil moisture content at 10-cm depth was 0.052–0.065 m^3/m^3 on the upper and the middle slopes and 0.080–0.086 m^3/m^3 on the lower slope (Table 1). The results of satellite data analysis indicated that at least two fires had occurred in the surveyed area, with the first fire in 1998 and the second in 2009. The changes in canopy tree composition owing to the fires varied among the plots (Fig. 2). Although conifers (*Larix* and *Pinus*) with DBH of ≥20 cm were growing in plots 1, 2, 3, and 6 before the fires, only small broadleaved trees (*Betula* and *Populus*) with DBH of ≤20 cm grew after the fires. Plot 5 was completely destroyed by the fires, with no trees surviving and no new trees regenerating after the fires. Although several trees were burned in plot 7, there remained some trees that survived the fires and several new trees had emerged. There were no major changes in plot 8 owing to the forest fires.

The forest biomass dramatically changed by the forest fires (Fig. 3). Our plots supported *ca*. 75t/ha of biomass before the fires, with only *ca*. 20t/ha of biomass remaining after the fires. Only a small minority of the biomass recovery was attributable to new tree growth after the fires (Fig. 3, pale gray areas). Plots 7 and 8 retained a high quantity of biomass because of a high number of trees that survived in those plots (Fig. 3 white areas).

The cumulative quantities of carbon dioxide emissions for the first 50 years estimated by the Yasso07 model were 3.2, 22.7, and 5.1 tC/ha for the plots 3, 5, and 8, respectively. Carbon emission was estimated to continue over 100 years after the fires (Fig. 4).

IV　Discussion

Although eight years have passed since the 2009 forest fire, it is clear that newly emerging trees contributed very little to biomass recovery and that the trees that survived the fire were the primary contributors in some plots where the biomass quantity was relatively large even after the fires. The study results suggest that ascertaining qualitative changes in vegetation solely on the basis of satellite data is difficult; however, a combination of ground surveys and satellite data can help quantify how an ecosystem recovers after a forest fire.

On the basis of our data, it became apparent that forest fires can greatly reduce forest biomass and can even change the dominant tree species in a forest. This suggests that forest fires can cause qualitative and quantitative changes in biodiversity and ecosystem function and services.

The estimated quantities of carbon emission by the forest fires for 50 years in this study area were consistent with the estimations in other boreal forests, such as 2.3–22.5 tC/ha in Russia (*2*) and 9.4–30.0 tC/ha in Alaska (*4*). Decomposition of burned wood and recovery of woody biomass would be relatively slow in this region, probably due to low temperature and precipitations. Increasing forest fire events due to climate changes and human activities would cause changes in the forest carbon cycle in the boreal forests.

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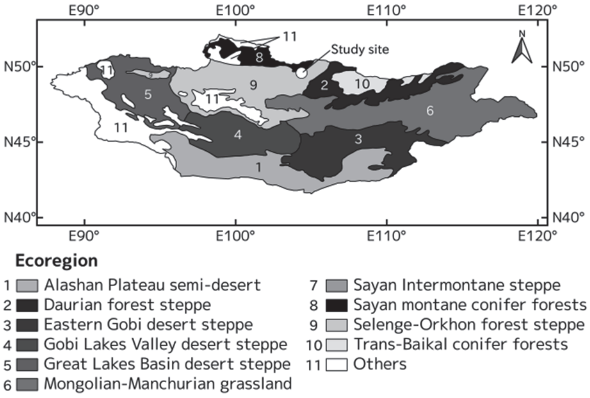

Fig. 1 Ecoregion in Mongolia and study plots (*8*)

Table 1 Monthly mean soil water content (m^3/m^3) of the study sites

	Upper slope (Plot 1)		Middle slope (Plot 2)		Lower slope (Plot 3)
	10cm	40cm	10cm	40cm	10cm
Jul.	0.064	0.068	0.052	0.057	0.083
Aug.	0.065	0.075	0.054	0.066	0.086
Sep.	0.061	0.071	0.055	0.064	0.080
Oct.	0.056	0.073	0.054	0.066	-

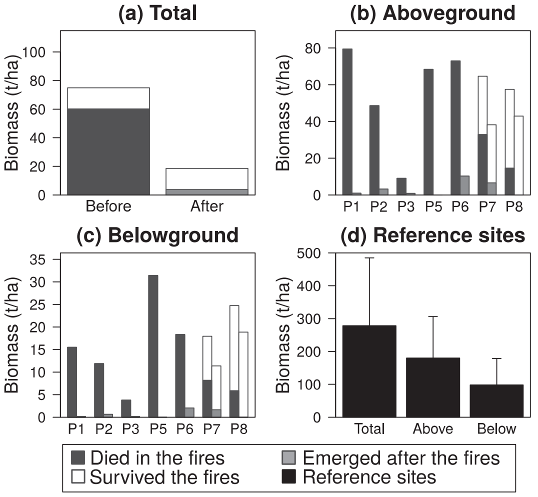

Fig. 3 Estimated biomass for (a) total, (b) aboveground, (c) belowground, and (d) reference sites. Left bars in (b) and (c) indicate before the fires, and right bars indicate after the fires

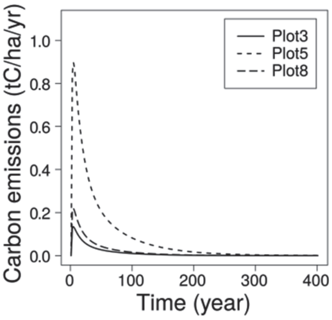

Fig. 4 Simulated annual carbon emission (tC/ha/yr) through time (years) as assessed by the Yasso07 model.

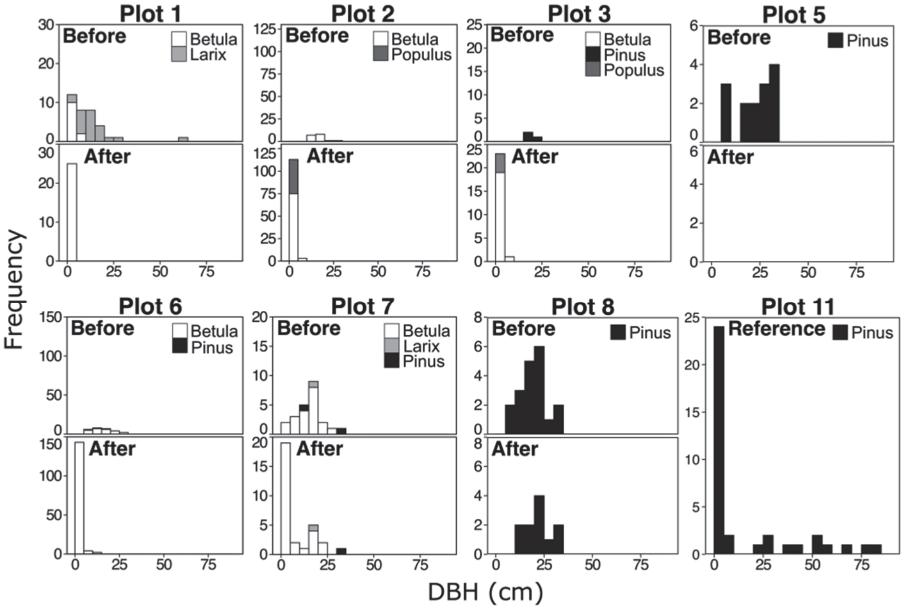

Fig. 2 The changes in size distribution and composition of canopy tree species in each plot. For plots 1–8, upper histograms indicate estimated size class frequency distribution of tree individuals before the forest fires, and bottom histograms indicate estimated size class frequency distribution after the forest fires. Plot 11 is the reference site that showed not much fire evidence