Regeneration in burned larch forests of Hovsgol region, northern Mongolia

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Abstract

Evaluating regeneration in the burned forest is one of the most important problems to predict the distribution of boreal forest under the climate change. Especially, in the thirsty area like Mongolia located in the southern fringe of the east Siberia Light Tiga zone, regeneration is highly susceptible to the change. In Darhad Valley, northernmost Mongolia where forests are dominated by larch (*Larix sibirica*), field survey at 14 sampling spots in two burned forest with different severity was conducted to clarify the condition of regeneration. As a result, in the moderate severity fire plots where the tree density of remaining adult trees was 42-271 trees ha^{-1}, regeneration was more active evaluating by growth density of sapling. The maximum density of sapling reached 2.68×10^4 trees ha^{-1} when the number of remaining adult trees was 50 trees ha^{-1}. In the high severity fire spots with less remaining adult trees, the number of sapling was significantly less. In the low severity fire plots, regeneration hardly occurred due to low light availability even though germination was abundant due to much amount of disseminated seeds. Thus, it was revealed that regeneration is controlled by light availability and the amount of seeds.

Keywords: *Larix sibirica*; Forest fire; Fire severity; Regeneration; Mongolia

1. Introduction

Evaluating regeneration in the burned forest is one of the most important problems to predict the distribution of boreal forest under the global climate change. Especially, in the thirsty area like Mongolia located in the southern fringe of the east Siberia Light Tiga zone, regeneration is highly susceptible to the change. Further, in such an area, forest fire frequently occurs with various fire severities. Therefore, it becomes difficult to evaluate the regeneration for the prediction of forest.

Forested areas in Mongolia have recently decreased due to occurrences of frequent wildfire (FAO 2000, Tsogtbaatar 2004). Fire severity significantly influences the dynamics of forest ecosystems (Van Wagner 1983; Johnson 1998; Abaimov et al. 2002b; Zyryanova et al. 2010; Tsvetkov 2004) and is an important factor for evaluating the influence of fire on post-fire regeneration (Abaimov et al. 2002b; Ehle and Baker 2003; Boyden et al. 2005; Jayen et al. 2006; Baker et al. 2007; Klenner et al. 2008). Severity is defined based on different parameters, among them: by the fire scar height on the tree (Brown and DeByle 1987), the basal area mortality (Christopher and Agee

1996), the mortality percentage of trees (Jayen et al. 2006) and occurrences of crown and surface fire (Ehle and Baker 2003; Baker et al. 2007). Variation in fire severity in forests appears to mainly influence post-fire stand structure. Seedling establishment occurs in pulses from a few years to 1-2 decades after fire (Christopher and Agee 1996). In the process of forest regeneration, the condition of burned material as determined by fire severity influences the dissemination and germination of seeds (Jayen et al. 2006). In Darhad Valley, the differences in fire severity have created a mosaic of forest regeneration patterns with some plots showing very poor to other very rich regeneration sites.

Thus, under the principle that post-fire conditions following a given fire intensity somehow determine the regeneration pattern, our objectives are (1) to evaluate the factors that control regeneration and (2) to determine the annual biomass increase at different regeneration sites.

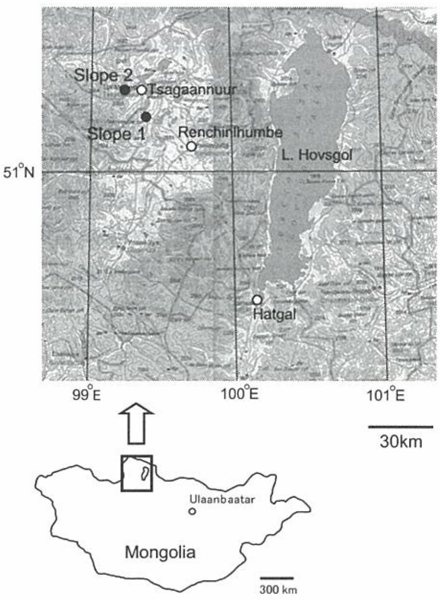

Figure 1 Location of the study site in Darhad valley

2. Study site and methods

The field survey was conducted on two burned hills, Slope 1 (51°13.7'N and 99°23.8'E) and Slope 2 (51°23.5'N and 99°17.6'E), about 20 km away from each other in the northwest of the Darhad valley. The north-facing Slope 1 has a gradient of 16.5° and was burned in June 1991 (Fig.2 a). On this Slope, 10 plots were selected based on the different fire severities, hereafter, P1-P10, covering a distance of 590 m from foot to top (altitude 1538-1705 m). The north-facing Slope 2 has a gentle gradient of 2° and was burned in May 1996 (Fig.2 b). On this slope, 4 plots (P11-P14) were set over a distance of 3500 m stretching from the lower end of burned forest to the top (altitude 1652-1761 m).

Fire severity can be classified into 3 types; low severity fires, which are mainly ground fires that kills few canopy trees, high severity fires that kill canopy trees, and moderate (or

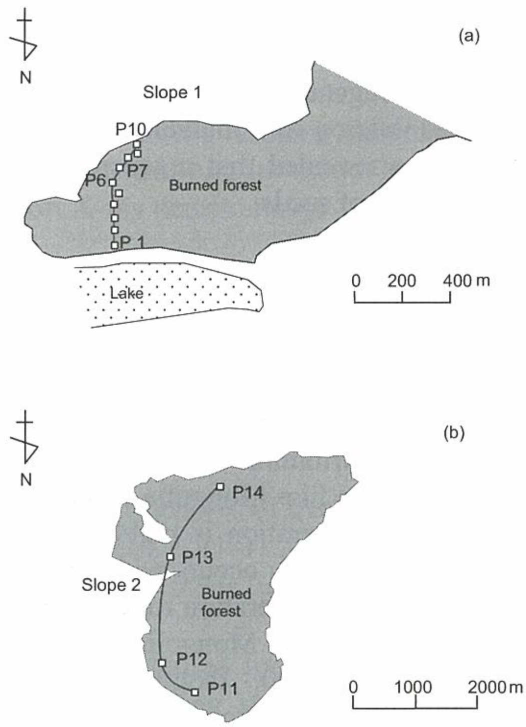

Figure 2 (a) Schematic drawing of Plots P1-P10 at Slope 1 and (b) P11-P14 at Slope 2 in the burned forest on the north-facing slope.

mixed) severity fires which is the combination of low and high severities (Baker et al. 2007). In this study, to quantify the severity and the regeneration, the number of remaining adult trees was counted in a 50×50 m quadrate which is established at each plot on Slope 1 (Fig.3). In each quadrate, 4 sub-quadrates of 5×5 m were used to count saplings for the survey of regenerated larch: 30 cm tall saplings or more in height and seedlings less than 30 cm. Furthermore, in each sub-plot, a quadrate of 1×1 m was set in a random position to quantify the amount of seeds. On the other hand, since the number of remaining adult trees in Slope 2 was small, a 100×100 m quadrate to evaluate the remaining adult trees was used at the 4 plots.

In the tree survey, the number, the height and DBH (diameter at breast height) of remaining adult trees (seed trees that grow before the fire and supply seeds) were measured. Adult trees were defined as to be at least 5 m in height and 5 cm in DBH. To determine tree age, cores were sampled from several adult trees by an increment borer (diameter of 10 mm: Mattson Inc., Sweden) in the quadrate of each plot. Additionally, in order to obtain the profile for saplings and seedlings in the sub-quadrate, the number, height, and basal diameter and DBH of high saplings were surveyed. From the 30 saplings chosen at random in each plot, the annual stem growing length between branches was measured for recent years. To clarify the germination year and the annual width by tree ring analysis, stem disks were cut at the base of 10 saplings in and around the quadrate at each plot. The amount of fallen seeds on the forest floor at each plot was counted in 4 quadrates of 1×1 m and taken an average. These investigations were conducted at Slope 1 in 2009 and at Slope 2 in 2007-2009. Light quantum at the forest floor at P1, P5 and P7 was measured from August 16 to September 14 in 2009 by a photosynthetically active radiation sensor (S-LIA-M003: Onset computer corp.) at 10 minutes intervals.

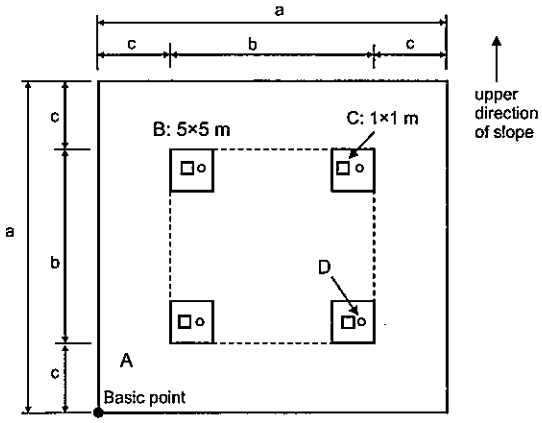

Figure 3 Design of the field sampling strategy.

P1 - P10 : a=50 m, b=30 m, c=10 m

P11 - P14 : a=100 m, b=50 m, c=25 m

A: Number of adult trees with diameter ≧5 cm DBH

B: Number of seedlings (height<30 cm) and saplings (height≧30 cm)

C: Seeds counting, Measurement of coverage, dry weight and height of grass in each quadrate B

D: Measurements of soil moisture, of surface soil layer (0-20 cm) composition

3. Results

3.1 Remaining adult trees and the environment

Remaining adult trees were fewer than in Slope 1 except for P12. At P14 only one tree remained in one hectare, representing the severity of the fire event. On this slope, adult tree density ranged from 1-77 trees ha^{-1}. The forest floor was covered by fire weed (*Chamaenerion angustifolium*) and by sufficient exposure to sunlight.

Plots P1-P5 distributed on the lower Slope 1 where adult trees remain sparse and stumps are found sporadically, as presented in Fig.4. Tree survey indicated that tree density was 42-271 trees ha^{-1}. Except for the tree density, adult trees were not different from those on the upper slope. The forest floor was well exposed to sunlight in some plots while being limited in others. In this forest, most of the adult trees were exposed to crown fires and died, with some of them surviving. Therefore, the fire is assumed to have been moderate severity.

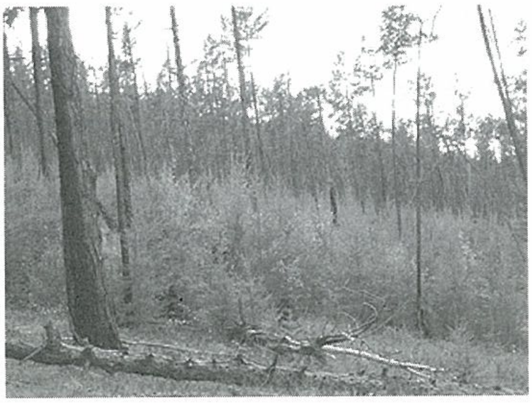

Figure 4 The remaining adult trees grow sparsely and the sapling density is high at Plot 3.

Plots P6-P10 distributed on the upper Slope 1 where adult trees grow densely and the number of stumps is low. However, many adult trees have had their bark burned following surface fires on the forest floor. Tree density was between 371-718 trees ha^{-1}. On this slope, exposition to direct sunlight on the forest floor was limited in time and space. Judging from the burned state, fire was a surface fire and not crown fire, so that fire severity is assumed to have been low.

In each plot, the mean height, mean DBH and tree age of remaining adult trees are shown as well as the tree density in Table 1.

3.2 Seeds and germination

After fire, one of the most important factors for regeneration is seed supply. To confirm the distribution of disseminated seeds, the number of seeds is shown against the density of adult trees in Fig.5. The number of seeds increased almost linearly with tree density. By tree ring analysis of saplings, it was revealed that the maximum emergence of saplings after fire was 6 years at all three sites, as given in Fig.6.

After the fire event, natural germination comes from the seeds of the surviving seedlings that grow up to be saplings. The distribution of densities for both seedlings and saplings at each plot are shown against adult trees in Fig.7. Since most of these seedlings in the higher range are 1 year old, it is estimated that the germination ratio is 4%, obtained from seedlings data and seed number. For less than 371 adult trees ha^{-1}, the density of seedlings is smaller than that of saplings. However, in the area with more adult trees, seedlings are more abundant and there are hardly any saplings. Seedlings did not grow to become saplings under the higher density of adult trees, while it did in the

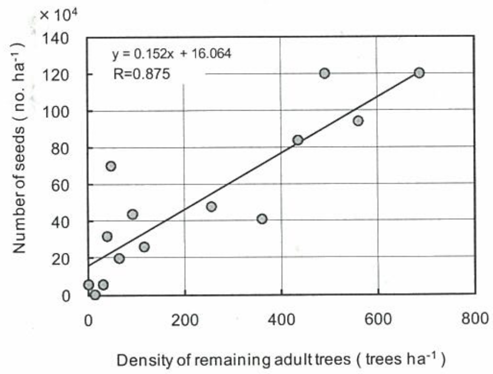

Figure 5 Distribution of dispersed seeds in the density of remaining adult trees.

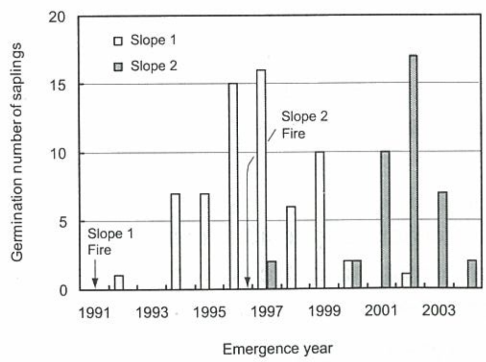

Figure 6 Emergence of saplings at Slope 1 and Slope 2 after the fire.

lower density.

3.3 Density of sapling in regeneration

Maximum sapling density (2.68×10^4 trees ha^{-1}) was found at an adult tree density of 50 trees ha^{-1}, which appears to be the most suitable condition for regeneration, as shown in Fig.8, although saplings can grow actively in the range of adult tree density of 42-271 trees ha^{-1} (Table 1). Considering the survey results, regeneration hardly occurred in burned sites with more than 371 trees ha^{-1}, the regeneration occurs in the range of 1-371 trees ha^{-1}.

3.4 Light availability

The results of the photosynthetically active radiation (PAR) having wavelength 400-700 nm as light quantum obtained in 2009 at P1, P5 and P7 are considered representative of different light availability. Shown in Fig.8, the values obtained were 2.3-8.1 MJ m^{-2} d^{-1} (4.8 MJ m^{-2} d^{-1} in daily average), 1.5-6.0 (3.1) and 1.1-3.5 (2.0), respectively, which corresponds to 65%, 42% and 27% of the daily average against the value of 7.3 MJ m^{-2} d^{-1} observed during the same term in 2010 at the nearest station site in Tsagaan nuur village (Hoshi 2011). As expected, PAR decreased as the density of adult trees increased.

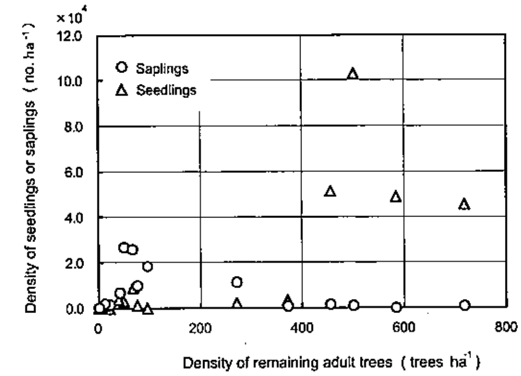

Figure 7 Distribution of seedlings or saplings density against density of the remaining adult trees.

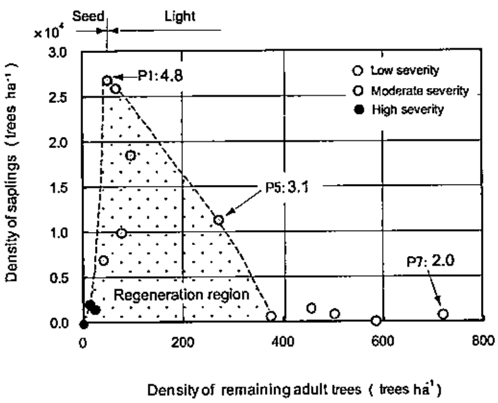

Figure 8 Regeneration region at various fire severities. Daily avg. PAR ($MJm^{-2}d^{-1}$) was measured at Plot P1, P5 and P7 during Aug.16-Sep. 14.

4. Discussion

4.1 Condition of remaining adult trees for regeneration after fire

The most important factors that control regeneration in this region appear to be the number of disseminated seeds and light availability. From the survey, it was verified that the number of disseminated seeds increased and light quantum decreased with increase of the number of remaining adult trees. Then, it can be deduced that sapling density is more influenced by the number of disseminated seeds below the adult tree density (50 trees ha^{-1}) at the point of maximum sapling density. Above this point sapling density decreases along with the light quantum.

When fire severity in burned forests is evaluated considering remaining adult trees and saplings, it can be divided into 3 groups; low, moderate and high severity (Table 1). High severity fire leaves roughly less than 42 trees ha^{-1} or less, while the moderate leaves from 42 trees ha^{-1} to 271 trees ha^{-1} and the low severity leaves more than 271 trees ha^{-1}. Therefore, regeneration is limited in the high and low severities burned forest but it is very active in the moderate one.

4.2 Increases of stem volume by regeneration after fire

When regeneration after forest fires starts, biomass is expected to increase. However, it is not clear how much the increase varies under different fire severity. Sapling stem volume at P1 to P5 in the moderate fire severity increased several folds 18 years after the fire event, while at P6 to P10 after low severity fire the increase in volume was negligible, shown in Fig.9. In the same way, the volume in the high severity fire plots was also very small in Slope 2, 11 years after the fire event, except for P12 in the moderate severity plot.

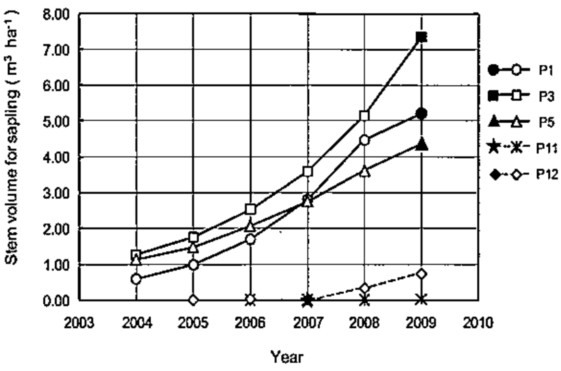

Figure 9 Estimated annual changes of stem volume of saplings. Measured value (black symbols) and calculated value (white symbols).

From the annual growing length of sapling stem and annual tree ring width, stem volume before and after the sapling survey was calculated using the mean estimated height and diameter. Among the plots selected, the estimated stem volume in the moderate increased remarkably while in the high severity fire plots, the stem volume hardly increased, as shown in Fig.9. The difference in stem volume growth in the high and the moderate severity fire plots has a 6 years lag after the fire event. If the stem volume at Plot 12 in 2009 is shifted to 2003, the difference among the moderately burned plots disappears in Slope 1 in 2004. Therefore, stem volume at P12 is expected to increase remarkably following the trends observed in the moderately burned plots in Slope 1.

Table 1 Characteristics of trees after the fire.

			Tall forest				Seed	Seedling	Sapling			
Site	Plot No.	Fire severity	Density	Height	DBH	Tree age		Density	Density	Height	Basal diameter	Stem volume
			trees ha⁻¹	m	cm	years	×10⁴ no. ha⁻¹	×10⁴ no. ha⁻¹	×10⁴ no. ha⁻¹	m	cm	m³ ha⁻¹
	P1	M	50	12.8	22.6		70	0.33	2.68	1.54	1.9	5.21
	P2	M	67	9.1	13.2		20	0.82	2.59	1.35	1.9	5.05
	P3	M	96	13.4	23.9	36-162	44	0.08	1.85	2.02	2.2	7.35
	P4	M	42	15.6	28.8		32	0.39	0.69	2.17	3.1	5.24
	P5	M	271	12.0	18.5		48	0.24	1.13	1.70	2.0	4.36
Slope 1	P6	L	371	10.5	16.5		41	0.42	0.07	0.54	1.1	0.009
	P7	L	718	10.7	17.2		120	4.56	0.07	0.48	1.0	0.007
	P8	L	501	11.7	18.4	95-150	120	10.29	0.08	0.60	1.0	0.010
	P9	L	455	13.2	20.4		84	4.14	0.15	0.48	0.8	0.011
	P10	L	584	10.5	15.6		94	4.90	0.00	0.00	0.0	0.000
	P11	H	23	9.1	13.6		6	0.02	0.08	0.65	1.4	0.025
	P12	M	77	11.2	16.5		26	0.18	0.62	0.57	1.0	0.179
Slope 2	P13	H	13	18.2	26.9	23-212	0	0.03	0.11	0.38	0.7	0.004
	P14	H	1	22.0	27.0		6	0.00	0.00	0.00	0.0	0.000

L: Low fie severity, M: Moderate fire severity, H: High fire severity, DBH: Diameter at breath height, Investigation at P11,P12 and P14 was conducted in 2007, that at P13 was in 2008, and the other was in 2009.

5. Conclusion

(1) After fire, germination did not occur immediately with the highest germination taking place 6 years after fire in both slopes.
(2) The density of remaining adult trees was a more appropriate factor to evaluate regeneration and a good indicator of fire severity which was useful to characterize fire severity as high, moderate and low.
(3) Regeneration occurred in the range of 42-271 trees ha^{-1} remaining adult trees ha^{-1}, with the most suitable conditions at a density of 50 trees ha^{-1}.
(4) Seed supply and light quantum are the most important controlling factors for regeneration.
(5) Stem volume of saplings increased most actively in the moderate severity fire area, while regeneration was retarded in the high and low severity fire areas due to lack of seed supply and light for saplings to grow, respectively.
Based on these results, regeneration in burned areas can be classified by the density of the remaining adult trees, and this approach can contribute to forest management practices such as conducting clear-cutting after fire.

Acknowledgements
This study was supported by UGAS Dean fund in Iwate University and scientific research fund and JSPS KAKENHI (Grant Number 22405022). Also, we greatly appreciate much support by Dr. C. Mizota, Dr. S. Ishida, Dr. S. Taki, Dr. M. Byambasuren and Dr. B. Banzragch.

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