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Ecological Indicators of Forest Degradation after Forest Fire and Clear-cutting in the Siberian Larch (*Larix sibirica*) Stand of Mongolia

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Abstract : This study was conducted to investigate ecological indicators of forest degradation after forest fire and clear-cutting in the Siberian larch (*Larix sibirica* Ledeb.) stand of Mongolia. The species abundance and biodiversity indices were higher in burned and clear-cut stands than those of reference stand, but boreal understory species, such as *Vaccinium vitis-idaea*, *Pyrola incarnata*, *Linnea borealis* and *Maianthemum bifolium*, completely disappeared and was replaced by sedge species, such as *Carex duriuscula, C. lanceolata, C. pediformis, Poa attenuata* and *P. pratensis*. During the research period, temperature increased by an average of 1.6°C in burned stand and 1.7°C in clear-cut stand compared to reference stand, but RH sharply decreased up to 15.7% in clear-cut stand. This result indicates that *Larix sibirica* stand became warmer and drier after forest fire and clear-cutting, and contributed to the abundance of sedge and grass species in the understory. Moreover, intense occupation of tall sedge grass after forest fire and clear-cutting had a vital role as obstacle on natural regeneration of *Larix sibirica*. The similarity of species composition between reference and burned stands was higher (73.6%) than between reference and clear-cut stands (63.8%). Soil moisture significantly decreased after forest fire and clear-cutting, and the extent of decrease was more severe in the clear-cut stand. The chemical properties at soil organic layer were significantly affected by forest fire and clear-cutting but not the mineral horizons. Inorganic nitrogen of the forest floor significantly decreased in the clear-cut stand (1.1±0.4 $mg \cdot kg^{-1}$) than that of the burned (4.5±2.3 $mg \cdot kg^{-1}$) and reference stands (5.0±2.3 $mg \cdot kg^{-1}$). Available P of the forest floor significantly increased after fire, whereas it decreased after clear-cutting. These results indicate that existence of boreal understory vegetation, and changes in soil moisture and available P are distinct attributes applicable as ecological indicators for identifying forest degradation in Mongolia.

Key words **:** *clear-cutting, ecological indicators, forest fire, forest degradation, Siberian larch, soil properties, understory vegetation*

Introduction

Ecological restoration is an activity that initiates and/or accelerates the recovery of an ecosystem that has been degraded, damaged, or destroyed (Society of Ecological Restoration International: SERI, 2004). The primary goal of ecological restoration is to re-establish self-sustaining ecosystem (Clewell and Aronson, 2006), which is a similar concept for sustainable forest management. Meeting this goal requires analysis of ecological factors that determine limits to the ecological composition, structure, and function of an ecosystem (Wyant *et al*., 1995).

Ecological indicators are analytical and interpretive tools of ecological dynamics and can be applied to monitor forest degradation after disturbance and restoration management in the future (Venturelli and Galli, 2006). To be effective indicators they should be adequately common and understood, and sensitive to underlying changes in the biophysical environment (Angelstam, 1998). Various studies have shown that understory vegetation and forest soil properties are used as effective indicators in identifying changes in forest ecosystem

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(Ohlson *et al*., 1997; McLachlan and Bazely, 2001; Krzic *et al*., 2003). A review of basic concepts of soil and vegetation development indicates that they are mutually associated with each other, both being the product of the same environmental variables.

Forests in Mongolia have been severely degraded by forest fire and clear-cutting (Tsogtbaatar, 2004). During the last decade, Mongolia lost approximately four million ha of forests, averaging to 40,000 ha annually but between 1990 and 2000, the rate of deforestation increased up to 60,000 ha per year. As a result of this ongoing loss and degradation, 1.6 million ha of forest area have been completely lost between 1974 and 2000 due to forest fire, improper cutting and clear-cutting, overgrazing, mining activities and among others (United Nations Environment Programme: UNEP, 2002).

Most forests in Mongolia are composed of *Larix sibirica* covering about 59% of the closed forest area (Ministry of Nature and Environment of Mongolia, 2002). The pattern of stand development after forest fire and clear-cutting at the *Larix sibirica* stands of Mongolia mainly progressed into four stages: 1) secondary *L. sibrica* stand, 2) replaced hardwood stand mainly composed of birch and willow species, 3) bush stand, and 4) grassland (steppe), which strongly depends on the intensity of disturbance and potential of natural regeneration (Thomas and Agee, 1986). Forest fire and clear-cutting can directly influence plant diversity and sustainability of forest production through soil or forest floor disturbance, altered habitat structure, removal of nutrients, or altered micro-climate condition in boreal forest ecosystem (Reich *et al*., 2001). Thus, it is very important to understand ecological changes in understory vegetation and soil properties after forest disturbance to investigate forest degradation as ecological indicators in Mongolia. The objectives of this study were: 1) to investigate ecological changes in understory vegetation and soil properties after forest fire and clear-cutting in Siberian larch stand, and 2) to discuss ecological indicators of forest degradation in Mongolia.

Materials and Methods

1. Selection of the study sites

The field study was conducted at the southern area of Khenti in Mongolia (Figure 1). This area lies between the southern fringe of the Siberian boreal forest and mid-Asia steppe zone, and it is about 80 km from the northeast of Ulaanbaatar. It is very sensitive and vulnerable to external disturbances due to its geographical characteristics and also had been continuously disturbed by people in the vicinity of Ulaanbaatar, capital of Mongolia. The most dominant species is *Larix sibirica*, which is distributed between 1,500 m and 1,700 m, and it only exist in the northern aspect due to harsh climate condition (average annual temperature ranges from -1.9 to -3.8°C and annual precipitation ranges from 240 to 320 mm). Hardwood species such as *Betula platyphylla*, *Salix* spp. and *Populus* spp. were invaded and occupied rapidly after forest fire and clear-cutting as pioneer species in this area.

Burned and clear-cut *L. sibirica* stands (having more than one ha disturbed), and reference *L. sibirica* stand as a control (which is undisturbed and adjacently located

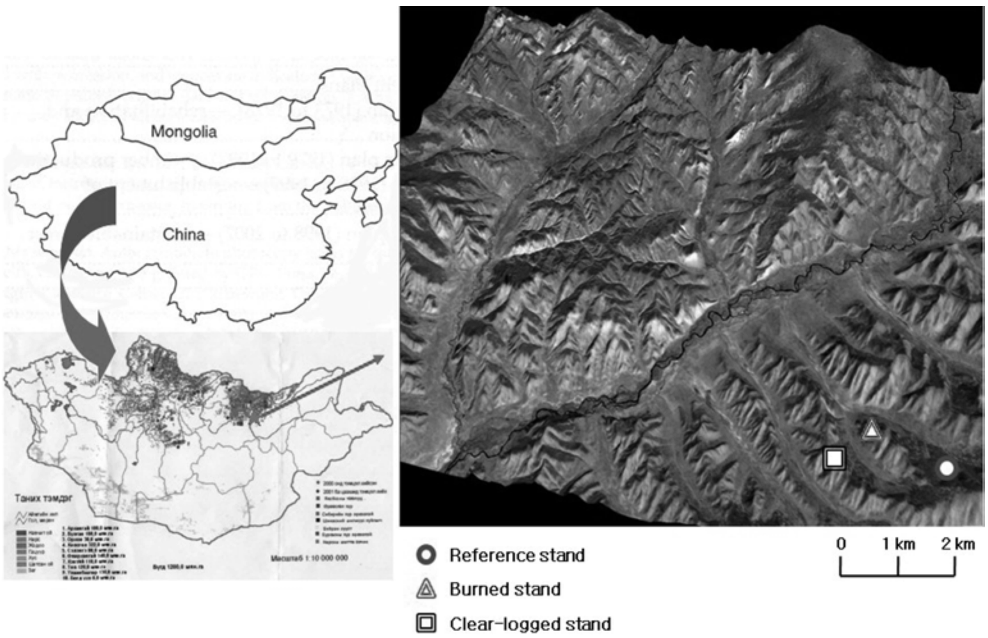


Figure 1. Location of the study sites.

Table 1. Characteristics of the study sites.

Study sites	Location	Elevation (m)	Dominant species in overstory	Age (yr.)	Overstory coverage	Seedling density of *L. sibirica* (no./ha)
Reference stand	48°03´N, 107°88´E	1,601	*Larix sibirica*	40-120	70%	1,520
Burned stand	48°03´N, 107°88´E	1,564	*L. sibirica,Betula platyphylla*	20-40	40%	320
Clear-cut stand	48°03´N, 107°88´E	1,550	*B. platyphylla*	10-30	10%	80

with each other) were chosen in this study (Table 1). It is estimated that forest fire and clear-cutting in this area occurred in the similar period, between 1965 and 1966, according to local record (written in Mongolian) and interview with the local people. In each study site, three 30 m×30 m square plots, a total of nine plots were randomly established to investigate stand characteristics including overstory coverage and density of *L. sibirica* seedlings (Table 1), and to set subplots for understory survey and soil sampling.

2. Identification of understory vegetation

A total of 15 square subplots (2 m×2 m) in each study site were set to investigate the composition of understory vegetation. Identification of understory species according to nomenclature of Grubov (1982) was conducted jointly with researchers from the Institute of Botany, Mongolian Academy of Sciences. The importance value, species diversity (richness, evenness, Shannon's index and Simpson's index) and similarity of all identified vegetation were calculated using the following formula (Ludwig and Reynolds, 1988; Kent and Coker, 1994).

3. Micro-climate data collection

Portable HOBO data loggers were launched in each stand with three replications to measure air temperature and relative humidity during the research period. All data were automatically collected with one-hour interval and the daily mean temperature and relative humidity were calculated (BoxCar Pro 4.0, Onset Computer Corporation, USA).

4. Soil sampling and statistical analysis

In each study stand, soil samples were collected using soil auger at three soil depths: the forest floor (O) and mineral horizons (A and B) with five replications. The soil samples were air-dried after collection and transported to Korea for analysis with consent from the Ministry of Nature and Environment of Mongolia and the National Plant Quarantine Service in Korea. The physical and chemical properties of all soil samples were analyzed, such as moisture content, pH, soil texture, organic matter, nitrogen and phosphorous (Bigham, 1986; Klute, 1986). The differences in soil properties among the study plots were determined by analysis of variance (ANOVA) and Tukey's Studentized Range test (SAS 8.2). The significance for all analyses was determined at α=0.05.

Results and Discussion

1. Changes in understory vegetation after forest fire and clear-cutting

Composition of understory vegetation in *Larix sibirica* stands in Mongolia drastically changed after forest fire and clear-cutting (Table 2).

$IV(\%) = \frac{FR+RC(\%)}{2}$	where *IV* is the importance value, *RF* is the relative frequency and *RC* is the relative coverage.
$R = \frac{S-1}{\ln(n)}$	where *R* is the species richness, *S* is the number of species observed in the sample and *n* is the total number of plots sampled.
$E = \frac{H'}{H'_{\max}}$	where *E* is the species evenness, *H'* is the number derived from the Shannon diversity index and *H'* max is the maximum value of *H'*.
$H' = \sum_{i=1}^{s}\left[\left(\frac{n_i}{n}\right)\ln\left(\frac{n_i}{n}\right)\right]$	where *H'* is the Shannon's index of diversity, *s* is the number of species observed in the sample, n_i is the number of individuals belonging to the *i*th of s species in the sample, and *n* is the total number of individuals in the sample.
$D = \sum_{i=1}^{s}\left[\frac{n_i(n_i-1)}{n(n-1)}\right]$	where *D* is the Simpson's index of diversity, *s* is the number of species observed in the sample, n_i is the number of individuals belonging to the *i*th of s species in the sample, and *n* is the total number of individuals in the sample.
$Ss = \frac{2z}{x+y}\times 100$	where *Ss* is the Sørensen's coefficient of similarity, *x* is the number of species at site *A*, *y* is the number of species at site *B*, and *z* is the number of common species at both sites.

Table 2. Changes in Importance value (IV) of understory vegetation at reference, burned and clear-cut stands.

No.	Species	Reference stand			Burned stand			Clear-cut stand		
		RF(%)	RC(%)	IV(%)	RF(%)	RC(%)	IV(%)	RF(%)	RC(%)	IV(%)
1	*Vaccinium vitis-idaea*	3.2	17.2	10.2						
2	*Carex amgunensis*	4.0	13.6	8.8	4.0	9.2	6.5	4.0	5.6	4.8
3	*Bromus inermis*	2.9	7.8	5.3	3.8	9.5	6.6	2.6	1.7	2.1
4	*Calamagrostis obtusata*	3.2	6.6	4.9	1.9	2.1	2.0			
5	*Fragaria orientalis*	3.5	4.6	4.0	3.2	7.9	5.5	3.4	4.5	4.0
6	*Linnea borealis*	2.9	4.8	3.9						
7	*Elymus sibiricus*	3.7	3.0	3.4	0.8	0.3	0.6	4.3	3.2	3.8
8	*Equisetum pratense*	3.2	2.7	3.0	1.1	0.5	0.8			
9	*Vicia baicalensis*	3.2	2.9	3.0	0.3	0.1	0.2			
10	*Aegopodium alpestre*	4.0	1.6	2.8	3.0	1.5	2.2			
11	*Poa sibirica*	3.6	1.9	2.7	1.6	0.9	1.3	2.3	1.8	2.0
12	*Artemisia sericea*	2.0	3.1	2.6	1.9	4.0	3.0	2.9	2.3	2.6
13	*Galium boreale*	3.2	1.8	2.5	2.2	2.4	2.3	2.9	1.2	2.1
14	*Geranium pseudosibiricum*	2.9	2.1	2.5	1.6	0.7	1.1	2.6	1.3	2.0
15	*Festuca ovina*	2.3	2.5	2.4	4.0	10.3	7.2	3.7	16.1	9.9
16	*Lathyrus humilis*	2.6	2.1	2.4	1.6	1.3	1.5	2.0	1.1	1.5
17	*Artemisia tanacetifolia*	2.6	2.1	2.3	3.5	3.3	3.4	2.9	3.6	3.3
18	*Vicia cracca*	2.6	1.9	2.2	3.8	2.6	3.2	2.9	2.2	2.5
19	*Campanula Truczaninovii*	2.9	1.1	2.0	2.7	1.6	2.1			
20	*Chrysanthemum zawadskii*	2.9	1.1	2.0	3.5	1.4	2.4	3.7	2.4	3.1
21	*Valeriana officinalis*	2.6	1.3	2.0	1.9	0.7	1.3	2.0	1.0	1.5
22	*Anemone crinita*	2.6	1.1	1.8	1.1	0.5	0.8	2.6	1.8	2.2
23	*Potentilla strigosa*	2.3	1.1	1.7	2.7	1.8	2.3	1.1	0.3	0.7
24	*Galium verum*	2.0	1.1	1.6	2.2	1.4	1.8	2.0	1.4	1.7
25	*Achillea asiatica*	2.3	0.7	1.5	0.8	0.2	0.5	1.1	0.5	0.8
26	*Carex lanceolata*	1.7	1.0	1.4	3.5	5.3	4.4	0.6	0.1	0.3
27	*Rubus arcticus*	2.0	0.9	1.4						
28	*Aconitum barbatum*	2.0	0.5	1.3	1.6	0.8	1.2	2.0	0.8	1.4
29	*Pulsatilla flavescens*	1.7	0.9	1.3	2.7	1.8	2.3	3.2	6.0	4.6
30	*Artemisia integrifolia*	1.4	0.6	1.0				3.2	2.8	3.0
31	*Hedysarum hedysaroides*	1.2	0.8	1.0	0.5	0.2	0.4	1.1	0.4	0.8
32	*Polygonum alopecuroides*	1.4	0.7	1.0	0.3	0.1	0.2	2.6	2.2	2.4
33	*Sanguisorba officinalis*	1.3	0.6	1.0	3.2	2.0	2.6	2.0	0.8	1.4
34	*Trientalis europaea*	1.4	0.5	1.0						
35	*Myosotis sylvatica*	1.4	0.4	0.9	3.5	1.6	2.5	3.4	1.2	2.3
36	*Ranunculus japonicus*	1.4	0.3	0.9	1.3	0.5	0.9	0.3	0.1	0.2
37	*Trollius asiaticus*	1.2	0.7	0.9	0.8	0.3	0.6			
38	*Thalictrum minus*	1.2	0.4	0.8	0.5	0.3	0.4	1.1	0.3	0.7
39	*Cimicifuga foetida*	1.2	0.2	0.7						
40	*Polemonium racemosum*	0.9	0.2	0.6	1.1	0.7	0.9	2.6	1.5	2.0
41	*Scorzonera radiata*	0.9	0.3	0.6	1.9	0.8	1.4			
42	*Silene sibirica*	0.9	0.2	0.6	0.5	0.2	0.4	2.6	1.0	1.8
43	*Viola biflora*	0.9	0.2	0.5	2.1	1.5	1.8			
44	*Dianthus superbus*	0.6	0.2	0.4						
45	*Vicia venosa*	0.6	0.3	0.4	0.8	0.2	0.5			
46	*Maianthemum bifolium*	0.6	0.1	0.3						
47	*Pyrola incarnata*	0.6	0.1	0.3						
48	*Polygonum viviparum*	0.3	0.1	0.2	0.3	0.2	0.2			
49	*Aconitum czekanovskii*				0.3	0.2	0.2			
50	*Agrostis mongolica*							3.4	9.7	6.6

Table 2. Continued.

No.	Species	Reference stand			Burned stand			Clear-cut stand		
		RF(%)	RC(%)	IV(%)	RF(%)	RC(%)	IV(%)	RF(%)	RC(%)	IV(%)
51	*Allium senescens*				0.3	0.1	0.2			
52	*Androsace septentrionalis*				0.5	0.2	0.4			
53	*Artemisia lacianata*							1.1	0.7	0.9
54	*Aster alpinus*				0.5	0.3	0.4			
55	*Bromus pumpelliana*							2.3	1.7	2.0
56	*Carex caespitosa*							2.9	1.5	2.2
57	*Carex duriuscula*				1.9	0.7	1.3			
58	*Carex pediformis*							1.7	1.1	1.4
59	*Cerastium ceratoides*				0.3	0.1	0.2	0.9	0.5	0.7
60	*Chamaenerion angustifolium*				4.0	8.4	6.2	3.2	7.3	5.2
61	*Draba nemosa*							0.3	0.1	0.2
62	*Dracocephalum grandiflorum*				1.3	2.8	2.1			
63	*Halenia corniculata*							0.6	0.1	0.3
64	*Helictotrichon schellianum*				1.6	0.7	1.1			
65	*Moerhingia laterifolia*				0.5	0.1	0.3			
66	*Pedicularis resupinata*							0.3	0.2	0.2
67	*Poa attenuata*							0.9	3.1	2.0
68	*Poa pratensis*				0.3	0.1	0.2			
69	*Potentilla nivea*				3.0	1.0	2.0	3.4	1.9	2.7
70	*Primula farinosa*				0.3	0.1	0.2			
71	*Rodiola rosea*				0.5	0.3	0.4			
72	*Sedum aizoon*				1.3	0.5	0.9			
73	*Stellaria graminea*				0.3	0.1	0.2	2.0	1.0	1.5
74	*Taraxacum officinale*							2.3	1.2	1.8
75	*Trifolium lupinaster*				1.3	0.6	0.9	0.7	0.3	0.5
76	*Trisetum sibiricum*				1.3	0.7	1.0			
77	*Vicia amoena*				2.7	2.3	2.5	0.3	0.4	0.3
	Sum	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

*The blank indicates no species exist.

Table 3. Species diversity indices of reference, burned and clear-cut stands.

Diversity indices	Reference stand	Burned stand	Clear-cut stand
Richness (*R*)	22.9 (3.7)	24.9 (2.9)	23.2 (4.4)
Evenness (*E*)	0.824 (0.064)	0.865 (0.038)	0.842 (0.034)
Shannon (*H'*)	2.577 (0.291)	2.779 (0.203)	2.635 (0.224)
Simpson (*D*)	0.8795 (0.0423)	0.9072 (0.0267)	0.8874 (0.026)

*Values in parenthesis indicate standard deviation.

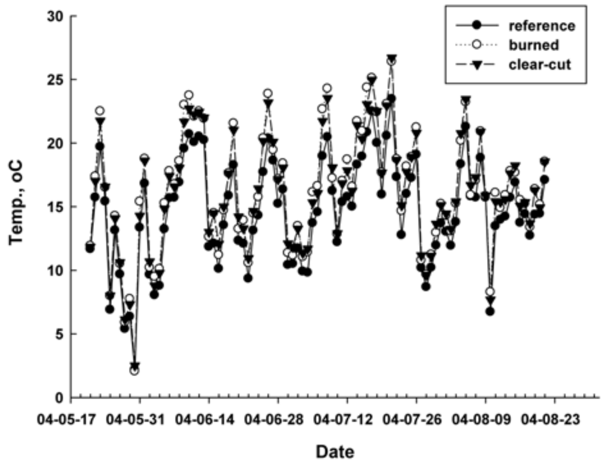
Vaccinium vitis-idaea, *Carex amgunensis* and *Bromus inermis* were most abundant understory species in the reference stand. However, *Festuca ovina* and *Chamaenerion angustifolium* were the dominant species in burned and clear-cut stands. *Chamaenerion angustifolium* (fireweed) was reported in the previous studies (Li *et al*., 2005; Pugachev *et al*., 2005) as very well-known good post-fire indicator in Khenti area, Mongolia and Russian Far East. The species abundance and biodiversity indices were higher in the burned and clear-cut stands than reference stand (Table 3). It was the result of increased forest gap due to elimination of upper layer trees by forest fire and clear-cutting. This provided better light environment for the invasion and development of understory vegetation (Messier *et al*., 1998; de Römer *et al*., 2007). There was positive result after forest disturbance on quantitative changes in species diversity but species composition changed negatively, such as the boreal understory species was replaced by sedge and steppe species. *Vaccinium vitis-idaea*, *Pyrola incarnata*, *Linnea borealis* and *Maianthemum bifolium* are boreal understory species which are distributed in humid and closed forest at high altitude with strong shade-tolerance under dense conifers but they are very vulnerable to anthropogenic disturbances, such as forest fire and clear-cutting in Mongolia (Zoyo, 2000).

In this study, they completely disappeared after forest fire and clear-cutting whereas sedge and steppe species, such as *Carex duriuscula, C. lanceolata, C. pediformis, Poa attenuata* and *P. pratensis,* newly invaded the area or increased their abundance. This result implied significantly that forest degradation has seriously progressed in *Larix sibirica* stand in Mongolia after forest fire and clear-cutting due to loss of habitat and decline of species diversity on boreal understory vegetation. Moreover, intense occupation of tall sedge grass after forest fire and clear-cutting has a vital role as obstacle on natural regeneration of *Larix sibirica*, which possibly accelerated forest degradation process. Thus, boreal understory vegetation has important ecological implication, which can serve as an indicator of forest degradation as well as useful in monitoring restoration process in Mongolia.

The Sørensen similarity index of understory vegetation among the reference, burned and clear-cut stands was determined. The similarity coefficient of species composition between reference and burned stands (73.6%) was higher than between reference and clear-cut stands (63.8%). This result indicates that clear-cutting activity changed species composition more differently compared to forest fire, which is supported by other studies (Everett *et al*., 1990; Rees and Juday, 2002). Therefore, clear-cutting activities have more adverse effects on species composition and diversity of understory vegetation than forest fire in Mongolia.

2. Changes in microclimatic variables after forest fire or clear-cutting

Forest fire and clear-cutting activities sharply alter microclimatic conditions and mainly affect species composition and stand development (Reich *et al*., 2001).



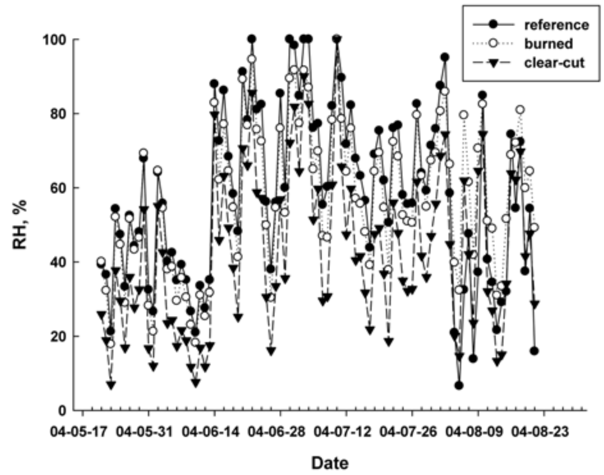


Figure 2. Daily mean temperature and RH in the study plots.

Microclimate variables, such as temperature and relative humidity (RH), in study plots were measured.

During the research period, temperature increased by an average of 1.6°C in burned stand and 1.7°C in clear-cut stand compared to reference stand, but RH sharply decreased up to 15.7% in clear-cut stand (Figure 2). This

Table 4. Changes in physical soil properties after forest fire or clear-cutting.

Soil horizon	Study sites	Soil texture				Water content (%)	Bulk density (g cm^{-3})
		Sand (%)	Silt (%)	Clay (%)	Texture		
O	Reference	29.6 (2.7)	49.2 (2.3)	21.2 (0.5)	loam	14.3 (2.2)^a	0.9 (0.1)
	Burned	27.5 (2.8)	46.9 (3.2)	25.6 (5.5)	loam	9.2 (1.2)^b	0.9 (0.2)
	Clear-cut	38.1 (4.2)	44.0 (4.5)	17.9 (0.9)	loam	6.5 (1.0)^c	1.1 (0.1)
A	Reference	27.9 (1.4)	43.2 (3.2)	28.9 (2.9)	clay loam	13.1 (3.5)^a	1.2 (0.1)
	Burned	20.2 (4.0)	47.3 (6.6)	32.5 (3.3)	clay loam	8.2 (0.6)^b	1.4 (0.1)
	Clear-cut	18.0 (2.5)	53.9 (0.6)	28.1 (3.1)	clay loam	5.9 (1.0)^c	1.6 (0.1)
B	Reference	24.2 (5.7)	48.0 (11.7)	27.8 (7.2)	loam	5.8 (0.8)^a	1.7 (0.1)
	Burned	18.9 (4.9)	49.5 (6.3)	31.6 (2.4)	clay loam	4.9 (0.4)^b	1.6 (0.0)
	Clear-cut	26.5 (1.6)	48.5 (5.7)	25.0 (5.1)	loam	3.9 (0.3)^c	1.7 (0.0)

*Values in parenthesis indicate standard error. Different letter indicate significant difference at $p<0.05$

Table 5. Changes in pH, OM and nitrogen contents of forest soil after fire or clear-cutting.

Soil horizon	Study sites	pH	OM (%)	TN (%)	Inorganic-N (mg kg^{-1})	TP (mg kg^{-1})	Available-P (mg kg^{-1})
O	Reference	5.4 (0.3)^b	13.2 (0.9)^a	0.71 (0.04)	5.0 (2.3)^a	450.5	8.1 (1.3)^b
	Burned	5.8 (0.2)^a	9.3 (0.6)^b	0.69 (0.16)	4.5 (2.3)^a	532.4	37.5 (2.7)^a
	Clear-cut	5.4 (0.2)^b	12.0 (0.5)^a	0.74 (0.11)	1.1 (0.4)^b	413.7	2.3 (0.5)^c
A	Reference	5.4 (0.5)^b	7.5 (0.9)	0.25 (0.08)	2.0 (0.6)	181.5	2.9 (1.5)^b
	Burned	6.2 (0.1)^a	6.1 (0.5)	0.23 (0.06)	0.9 (1.3)	307.7	4.5 (1.6)^a
	Clear-cut	5.6 (0.2)^b	7.1 (0.2)	0.22 (0.03)	0.2 (0.0)	301.0	1.4 (0.2)^c
B	Reference	6.0 (0.2)	4.6 (0.7)	0.09 (0.08)	0.2 (0.2)	137.9	1.3 (0.5)^b
	Burned	6.4 (0.4)	3.7 (1.0)	0.08 (0.02)	0.1 (0.1)	176.8	2.2 (1.4)^a
	Clear-cut	6.1 (0.4)	4.3 (0.5)	0.04 (0.01)	0.0 (0.0)	91.7	1.2 (0.1)^b

*Values in parenthesis indicate standard error. Different letters indicate significant difference at $p<0.05$

result indicates that microclimatic condition of *Larix sibirica* stand became warmer and drier after forest fire and clear-cutting, and affected the species composition of understory vegetation. For instance, more sedge and grass species became abundant in burned and clear-cut stands compared to reference stand.

3. Changes in soil properties after forest fire or clear-cutting

Soil moisture significantly decreased after forest fire or clear-cutting, and the extent of decrease was more severe in the clear-cut stand (Table 4). This result indicate that changes in physical soil properties, such as water content and bulk density, were more negatively affected by clear-cutting activity than by forest fire. The loss of soil moisture resulted in the compaction of soil which accelerated soil erosion and harmfully affected to plant root growth (Gombosuren, 1992).

The chemical properties at soil organic layer were significantly affected by forest fire and clear-cutting but not the mineral horizons (Table 5). Forest fire stimulated the increase of pH while organic matter (OM) content significantly decreased. This was caused by ash deposition on surface soil and nutrient losses through leaching (DeBano *et al*., 1998; Fisher and Binkley, 2000). Clear-cutting activities stimulated the decrease of inorganic N (NH_4^+-N, NO_3^--N). Inorganic nitrogen of the forest floor (O horizon) significantly decreased in the clear-cut stand compared to the burned and reference stands. Decreased nutrient and water uptake by vegetation, increased amounts of dead organic matter and changed soil hydraulic properties all promote N leaching after clear cutting but degree of leaching depends largely on the types of operation and its intensity (Piirainen *et al*., 2007). Available P of soil significantly increased after fire, whereas it decreased after clear-cutting. Therefore, the results indicate that clear-cutting activity rather than forest fire changed the soil properties more negatively. Loss of forest floor and surface mineral soil by improper clear-cutting activity can be a serious obstacle to the restoration or rehabilitation (Giardina and Rhoades, 2001).

4. Ecological indicators

Numerous studies have been attempted to develop ecological indicators for understanding ecological changes after forest disturbance and to monitor the ecological restoration process (Keddy and Drummond, 1996; Harris, 2003; Dodson *et al*., 2007; Nichols and Grant, 2007) at diverse forest ecosystems. SERI has produced a "Primer on Ecological Restoration (2004)" with nine ecological attributes, but some of them are conceptual and not realistic. Ruiz-Jaen and Aide (2005) simply categorized the use of three attributes, such as vegetation structure, biodiversity and ecological processes, to achieve realistic goals. The development of ecological indicators is needed to understand ecological changes brought by forest disturbance, to decide restoration techniques, and to monitor and value its achievement.

In this study, forest degradation process was identified by the composition of understory vegetation and forest soil properties in the *Larix sibirica* stand of Mongolia. The existence of boreal understory species, such as *Vaccinium vitis-idaea*, *Pyrola incarnata*, *Linnea borealis* and *Maianthemum bifolium,* was a very important indicator to define forest degradation in boreal forest, Mongolia, whereas soil moisture and available P among soil physical and chemical properties were distinct indicators to detect changes in forest soil after forest fire or clear-cutting. It is expected that the result of this study can be applied to decide on restoration treatments and to practically monitor restoration process in the *Larix sibirica* stand of Mongolia.

Conclusions

Forest fire and clear-cutting activity significantly affected understory vegetation and soil properties in the *Larix sibirica* stands of Mongolia. The boreal understory species replaced into sedge and steppe species after forest disturbance and the similarity coefficient of species composition between reference and burned stands was higher than between reference and clear-cut stands. The physical and chemical soil properties were significantly changed after forest disturbance, and it was more negatively in the clear-cut stand. Therefore, clear-cutting activity affected more negatively the understory composition and soil properties compared to forest fire. The existence of boreal understory species was an important indicator to define forest degradation in boreal forest of Mongolia while soil moisture and available P among soil physical and chemical properties were distinct indicators to detect changes in forest soil after forest fire and clear-cutting. Therefore, the results of this study could be useful in identifying ecological indicators of forest degradation, making decision on restoration treatments and monitoring restoration process in Mongolia.

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