EFFECTS OF FOREST FIRE AND LOGGING ON FOREST DEGREDATION IN MONGLIA

Yeong Dae Park, Don Koo Lee, Jamsran Tsogtbaatar, and John A. Stanturf[1]

Abstract—Forests in Mongolia have been severely degraded by forest fire and exploitive logging. This study investigated changes in vegetation and soil properties after forest fire or clearfelling. Microclimate conditions such as temperature and relative humidity (RH) changed drastically after forest fire or logging; temperature increased 1.6-1.7 °C on average, whereas RH decreased up to 15.7 percent after logging. Thus, burned and logged stands became drier and it mainly affected understory species composition such as the succession of steppe xerophytes from taiga and meadow mesophytes. Soil moisture significantly decreased after forest fire or logging, and the extent of decrease was more severe in the logged stand. The chemical properties of the organic layer were significantly changed, more so than the properties of the mineral soil horizons.

INTRODUCTION

Forest degradation is one of the main environmental concerns globally because degradation constrains environmental functions of forests (Daily and Ehrlich 1995, Burley 2002). Global attention to forest degradation in northeast Asia including the Russian Far East, China, Mongolia and the Democratic People's Republic of Korea (DPRK), has been greatly heightened by dramatic changes in climate in recent years (Lee and Park 2001). Forests in Mongolia have been severely degraded by wildfire and exploitive logging (World Bank 2002, Tsogtbaatar 2004), and this degradation has negatively affected the environment of neighboring countries including Korea. Between 1971 and 1997, approximately 2,700 large- and small-scale fires occurred and destroyed over 14 million ha of forests. Particularly in 1997, 2.7 million ha burned (FAO, 2001). During the last decade, Mongolia lost approximately 4 million ha of forests, averaging 40,000 ha annually but between 1990 and 2000, the rate of deforestation increased to 60,000 ha/year. As a result of this ongoing loss and degradation, 1.6 million ha of forest area has been completely lost between 1974 and 2000 due to fire, improper clearfelling, overgrazing, and mining activities (UNEP, 2002). The objectives of this study were (1) to investigate the changes in vegetation and soil properties after forest fire or clearfelling, and (2) to discuss the effects on forest degradation and future restoration work in Mongolia.

MATERIALS AND METHODS

The field study was conducted at southern area of Khenti in Mongolia, which lies between the southern fringe of the Siberian boreal forest and the Mid-Asia Steppe zone. This area is very sensitive and vulnerable to external disturbances such as forest fire and logging. A total of 17 study sites were selected: six for reference sites, seven for burned sites, and four for clearfelled sites. In each site, three 30 by 30 m square plots were randomly established to investigate the composition of overstory species. In each main plot, three 5 by 5 m square subplots were established to investigate natural regeneration and five 2 by 2 m square subplots were included to investigate the composition of understory vegetation. For all identified vegetation, we calculated importance value, species diversity, and similarity in order to examine the changes in vegetation after forest fire or logging. In each main plot, soils were sampled using a soil auger at three soil depths: the forest floor (O) and two mineral horizons (A and B), with four replications for each horizon. All samples were air-dried after collection and analyzed for physical and chemical properties such as moisture content, pH, soil texture, organic matter, nitrogen, phosphorous and cation exchange capacity (CEC). Three portable HOBO data loggers were launched in each stand to collect daily mean temperature and relative humidity at one-hour intervals. The differences in vegetation and soil properties among the study plots were determined by analysis of variance (ANOVA) using Tukey's Studentized Range to test separation of means (SAS 8.2). The significance for all analyses was set at α=0.05.

RESULTS AND DISCUSSION

Changes in Vegetation Composition after Forest Fire or Logging

Stand development and natural regeneration—The patterns of stand development after fire or clearfelling in *Larix sibirica* stands mainly progressed in four stages: (1) secondary *Larix sibirica* stand, (2) hardwood stand mainly composed of birch (*Betula* spp.) and willow (*Salix* spp.), (3) bush stand, and (4) grassland (steppe). Stand development strongly depended on the intensity of degradation and the potential for natural regeneration (Oliver and Larson 1996). The intensity of degradation in secondary larch and hardwood forests was slight after forest fire and these forests progressed easily into a natural regeneration stage with more than 5,000 seedlings/ha. The bush stand and steppe, however, were affected by severe degradation after clearfelling, and progressed slowly into, or did not reach the natural regeneration stage; there were less than 100 seedlings/ha. Natural regeneration usually occurs more readily on burned as opposed to logged sites as a result

[1]Visiting Scientist, Center for Forest Disturbance Science, U.S. Forest Service, Athens, GA; Professor, Dept. of Forest Sciences, Seoul National University, Seoul Republic of Korea; Director, Institute of Geoecology, Mongolian Academy of Sciences, Ulaanbaatar, Mongolia; Research Ecologist, Center for Forest Disturbance Science, U.S. Forest Service, Athens, GA, respectively.

Citation for proceedings: Stanturf, John A., ed. 2010. Proceedings of the 14th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-121. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 614 p.

of initial competition, with or without understory vegetation (White 1979). Thus, rehabilitation is needed more urgently after logging than after wildfire.

Changes in understory composition—The number of species was not significantly changed after logging but significantly increased after forest fire (fig. 1). Burned stands were significantly more even than the logged stands, although the other diversity indices were not significantly different between treatments (table 1). Changes in the composition of the plant community resulted from changes in microclimate after forest fire or logging, particularly from higher temperatures and lower humidity (RH). These effects were most noticeable for herbaceous species, including taiga and steppe mesophytes such as *Vaccinium vitis-idaea*, *Pyrola incarnata*, and *Linnea borealis*, which were succeeded by steppe xerophytes such as *Carex duriuscula, C. lanceolata*, *Poa sibirica* and *P. attenuate*. The contribution of the taiga community (number of species) after fire decreased, from 30.6 percent in the reference stand to 11.4 percent in the burned stand and the taiga species completely disappeared after logging. For both the burned and logged stands, the characteristic forest meadow and steppe species increased relative to their proportion of the reference stand (fig. 1). The similarity coefficient of species composition between natural (reference) and burned stands was higher than that between natural and logged stands (table 2). This result indicated that logging changed species composition more drastically than burning, which is in agreement with other studies (Everett and others 1990, Rees and Juday 2002). Therefore, clearfelling has a more adverse effect on species diversity and natural regeneration than forest fire.

Changes in Microclimate

Forest fire and clearfelling altered microclimate and affected species composition and stand development (Kimmins 1997). Microclimate variables such as temperature and RH sharply changed after forest fire or logging. Temperature increased by an average of 1.6 to 1.7 °C and RH decreased up to 15.7 percent after clearfelling (fig. 2). These results suggest that environmental conditions in both the burned and the logged stands became drier than in the reference stand.

Changes in Soil Properties

Physical properties—Soil moisture significantly decreased after forest fire or clearfelling, and the extent of decrease was more severe in the logged stand (table 3). These results indicate that changes in physical soil properties such as water content and bulk density were more affected by logging than forest fire. Reduced infiltration rates lead to increased overland flow and accelerated soil erosion in Mongolia (Gombosuren 1992).

Chemical properties—The chemical properties of the soil organic layer were significantly affected by forest fire or clearfelling but not the mineral soil (table 4). Forest fire stimulated an increase in pH while significantly decreasing organic matter (OM) content. The pH increase was probably

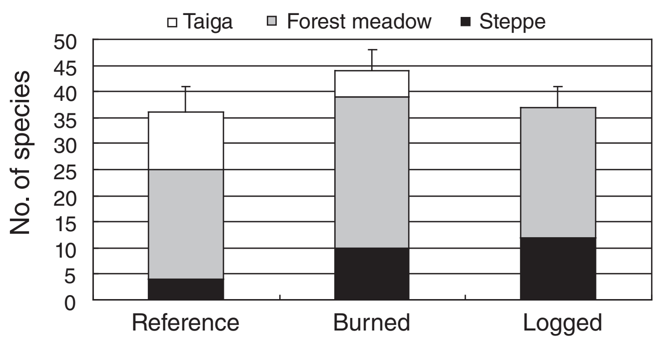

Figure 1—Changes in plant community after forest fire or logging.

Table 1—Species diversity indices of natural, burned and logged stands

Diversity indices	Natural stand	Burned stand	Logged stand
Evenness (*J*)	0.770[b *]	0.830[a]	0.751[b]
Shannon (*H'*)	2.317	2.388	2.175
Simpson (D)	0.8467	0.8647	0.8092

* Different letter indicate significant difference at 5%

Table 2—Similarity coefficient (%) among reference, burned and logged stands

Similarity coefficient (%)	Reference-Burned	Reference-Logged	Burned-Logged
Bray and Curtis (BC)	36.8	20.9	31.3
Sørensen (Ss)	33.1	24.3	29.0

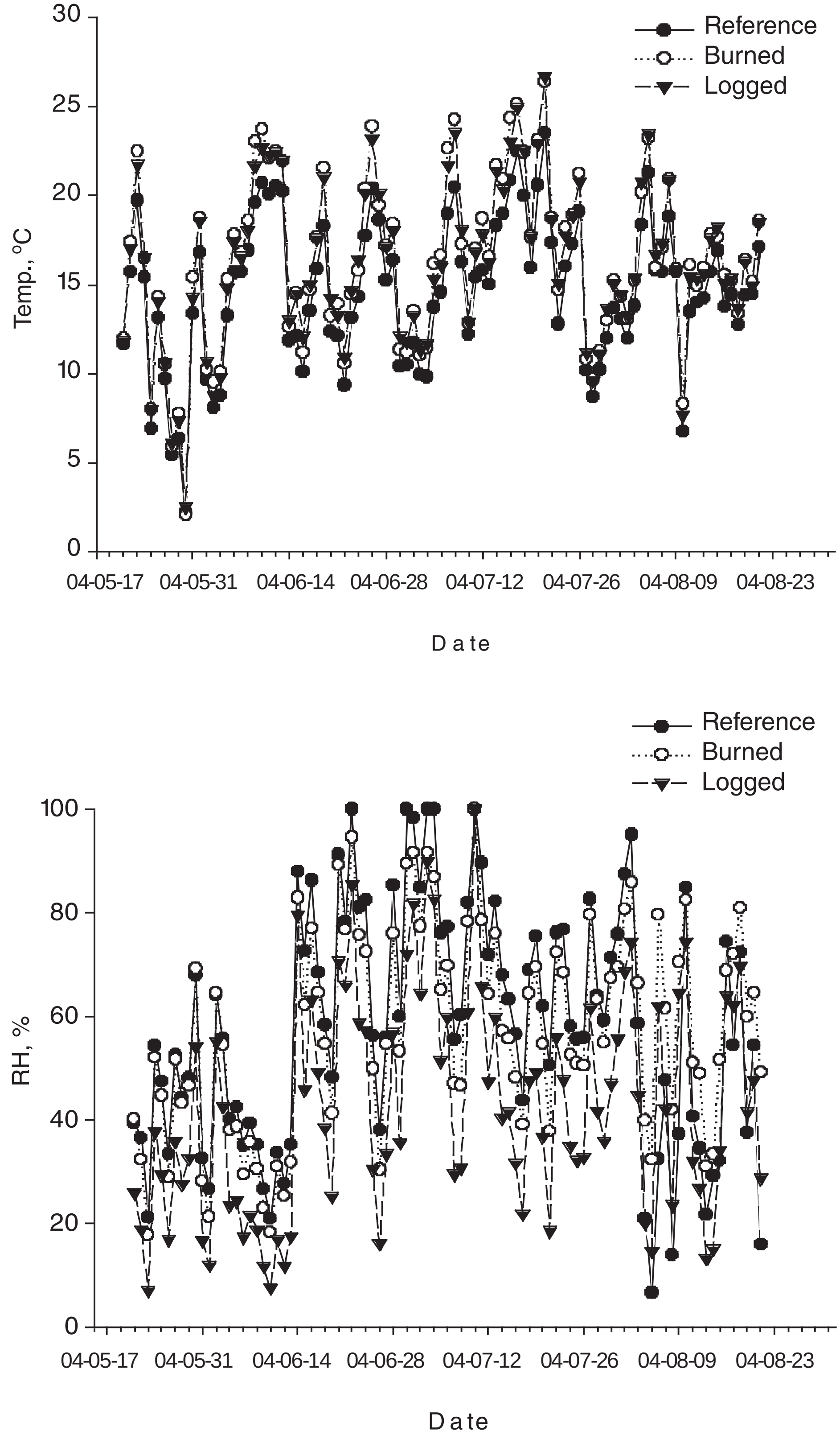

Figure 2—Daily mean temperature and RH at study sites.

Table 3—Changes in physical soil properties after forest fire or logging

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)
	Logged	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)
	Logged	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)
	Logged	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 4—Changes in pH, OM and nitrogen contents of forest soil after fire or logging

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]
	Logged	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]
	Logged	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]
	Logged	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 $p<0$

caused by ash deposition on the soil surface after fire (DeBano and others 1998, Fisher and Binkley 2000). Logging caused a significant decrease of inorganic N (NH_4^+-N, NO_3^--N) in the forest floor (O horizon) compared to the composition of the O horizon of the natural and burned stands. Available P in the mineral soil significantly increased after fire, although it decreased after logging. These results indicate that clearfelling caused more adverse changes in species composition and soil properties than were caused by forest fire. Loss of the forest floor and surface mineral soil by improper logging activity can be a serious obstacle to reforestation or rehabilitation (Giardina and Rhoades 2001) and soil and nutrient losses through erosion and leaching may lower site productivity.

CONCLUSIONS

Severe degradation led to bush and steppe stand conditions, where natural regeneration progressed slowly or did not occur for a long time. Thus, artificial regeneration (planting) is needed on these sites. Microclimate conditions such as temperature and RH drastically change after forest fire or clearfelling. The increased temperature and decreased RH mainly affected understory species composition. Forest fire and clearfelling significantly decreased soil moisture, which adversely affect seedling regeneration and growth by limiting water availability. The organic layer was more affected than mineral soil horizons. In the mineral soil, available P increased after fire and decreased after logging.

Exploitive logging and wildfires are the major causes of forest degradation in Mongolia. This research showed that logging activity more negatively affected vegetation and soil properties than fire. Thus, restoration of forest degraded by logging should have a higher priority for restoration than sites degraded by fire.

ACKNOWLEDGMENT

This research is a part of research project entitled, “Cooperative Research for Restoration of Degraded Ecosystems in Northeast Asian Regions” supported by the Korea Science and Engineering Foundation (KOSEF).

LITERATURE CITED

Burley, J. 2002. The role of genetics and physiology in forest restoration and reforestation. In: Proceedings of the 11th International Bio-Refor Workshop. Seoul National University, Seoul, Korea: 6-10.

Daily, G.C.; Ehrlich, P.R. 1995. Population extinction and the biodiversity crisis. In: Perrings, C.A. [and others] (eds.). Biodiversity Conservation. Kluwer Academic Publishers, New York: 45-55.

DeBano, L.F.; Neary, D.G.; Ffolliott, P.F. 1998. Fire's Effects on Ecosystems. John Wiley & Sons, Inc. New York: 333 p.

Everett, R.; Zabowski D.; McColley P. 1990. Vegetative restoration of western-montane forest soils. In: Proceedings of management and productivity of western montane forest soils. Boise, ID: 29-31.

Fisher, R.F.; Binkley, D. 2000. Ecology and Management of Forest Soils. John Wiley & Sons, New York: 489 p.

FAO. 2001. Global Forest Resources Assessment. Food and Agriculture Organization of the United Nations Rome, Italy: 479 pp.

Giardina, C.P.; Rhoades, C.C. 2001. Clear cutting and burning affect nitrogen supply, phosphorus fractions and seedling growth in soils from a Wyoming lodgepole pine forest. Forest Ecology and Management. 140: 19-28.

Gombosuren, N. 1992. The role of sub-taiga larch forest for water regulation and soil conservation at Eastern Khenti, Mongolia. Ph.D. dissertation. Mongolian Agricultural University, Ulaanbaatar, Mongolia.

Kimmins, J.P. 1997. Forest Ecology: A Foundation for Sustainable Management. Prentice-Hall, Inc. New York: 596 p.

Lee, D.K.; Park, Y.D. 2001. Degradation issues in the Southeast and Northeast Asia. Proceedings of Bio-Refor Tokyo Workshop. 7-11 October 2001, Tokyo, Japan: 5-9.

Oliver, C.D.; Larson, B.C. 1996. Forest Stand Dynamics. John Wiley & Sons, Inc. New York: 520 p.

Rees, D.C.; Juday, G.P. 2002. Plant species diversity on logged versus burned sites in central Alaska. Forest Ecology and Management. 155: 291-302.

Tsogtbaatar, J. 2004. Deforestation and reforestation needs in Mongolia. Forest Ecology and Management. 201: 57-63.

UNEP. 2002. Mongolia: State of the Environment. United Nations Environment Programme, Ulaanbaatar, Mongolia.

White, P.S. 1979. Pattern, process, and natural disturbance in vegetation. Botanical Review. 45: 229-299.

World Bank. 2002. Mongolia Environment Monitor. Ulaanbaatar, Mongolia. 38 p.