# Tree Planting: How Fast Can It Accelerate Post-fire Forest Restoration? - A Case Study in Northern Da Hinggan Mountains, China

**Article** *in* Chinese Geographical Science · December 2010

DOI: 10.1007/s11769-010-0436-y



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Chin. Geogra. Sci. 2010 20(6) 481–490
DOI: 10.1007/s11769-010-0436-y

# Tree Planting: How Fast Can It Accelerate Post-fire Forest Restoration? — A Case Study in Northern Da Hinggan Mountains, China

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**Abstract:** In 1987, a catastrophic fire burned over 1 330 000 ha in the densely forested area of the Da Hinggan Mountains in the northeastern China. After the fire, intensive management including burned trunk harvesting and coniferous tree planting had been conducted to accelerate forest restoration. To study the long term effect of these activities on forest recovery, we used a simulation modeling approach to study long-term (300 years) forest dynamics under current planting and natural regeneration scenarios. Results indicate that under tree planting scenario in the severely burned area, the dominant species Dahurian larch (*Larix gmelinii*) can reach pre-fire level (60% of the area) within 20 years and the maximum abundance can reach nearly 90% within 100 years. While under natural regeneration scenario, it needs about 250 years to reach its pre-fire level. From the perspective of timber production, tree planting can bring twice as much timber volume as that under natural regeneration within 300 years, which is the average longevity of *L. gmelinii*. It needs about 70 years to reach the timber volume of pre-fire level under the planting scenario, whereas it requires at least 250 years to reach the timber volume of pre-fire level under natural regeneration scenario. Another dominant species Asian White birch (*Betula platyphylla*) responded negatively to the planting of coniferous species. In general, tree planting of coniferous species after fire can greatly accelerate forest restoration in terms of species abundance and target timber volume, with desirable ecological and economic returns.

**Keywords:** tree planting; natural regeneration; post-fire forest restoration; species abundance; timber volume; LANDIS model

## 1 Introduction

Ecological restoration with native tree species planting is an effective way to accelerate positive succession in harvested, burned or degraded areas, often with increased economic returns (Miyawaki and Golley, 1993). Due to the magnitude of man and machine powers as well as large spatial extent involved, the long-term economic benefit from reforestation is often concerned (Beach *et al*., 2005; Siregar *et al*., 2007). Many restoration efforts used a combination of engineering approaches and the natural regeneration approaches in the reconstruction of the degraded forest system (Golley, 1999).

Haeussler *et al.* (2004) studied the succession and resilience of mixed wood communities 15–16 years after stand initiation with consecutive gradient treatments in the northwestern Canada. Their results demonstrated strong resilience of the boreal mixed wood plant communities and suggested that silvicultural intervention can modify stand composition and diversity to some extent. Fries *et al*. (1997) proposed that natural biodiversity can be maintained if forest management mimics natural processes, structures, and compositions in the production forest. Felker and Guevara (2003) studied the economic return of *Prosopis* lumber production in Argentina and found that shortening the rotation from 24 years to 15 years with clones can double the internal rate of return (IRR).

Post-fire forest restoration is usually left to natural regeneration processes in most of the forested areas

Received date: 2010-03-15; accepted date: 2010-08-10
Foundation item: Under the auspices of National Natural Science Foundation of China (No. 30270225, 40871245, 40331008, 40671013)
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around the world. However, when the burned area is large and severe, natural regeneration through succession may take too long time due to the lack of seeding sources or propagules. This may render the disturbed system to great risk of soil erosion and environmental degradation. An effective approach for forest restoration is to plant trees of dominant species to restore basic forest structure that prompts the recovery of biodiversity (Lamb *et al*., 1997; Tucker and Murphy, 1997; Chen *et al*., 2003). Espelta *et al.* (2003) made an economic and ecological multi-criteria evaluation of reforestation methods to recover burned *Pinus nigra* forests in the northeastern Spain. They proposed that the most preferred method in reforestation was to plant in uncleared or lightly grazed areas with soil preparation through ripping.

The long-term effect of planting (usually monoculture of target coniferous species) is rarely evaluated regarding the species composition, age structure and productivity in comparison with those under fully natural regeneration. Wang *et al*. (2006a) simulated the long-term effect of different planting intensities (from 10% to 70% of the study area) of coniferous species on the local forest landscape in the northern Da Hinggan Mountains and concluded that dispersed planting of 30% of the severely burned area would be more effective for forest restoration than the aggregated planting of 50% of the area that is implemented in the current strategy.

Chen *et al*. (2003) evaluated the effect of tree planting on the succession of Korean Pine (*Pinus koraiensis*) forest in terms of tree species composition, density and stem productivity with a gap model, in the Changbai Mountains, northeastern China. Their results showed that the restoration of clear-cut Korean pine forests to climax forests can be accelerated by the introduction of proper tree species such as *Larix olgensis* and *Pinus koreansis*. González-Ochoa *et al*. (2004) evaluated the effect of post-fire forest management on tree growth and cone production in *Pinus halepensis* in Spain. They found that thinning in the good quality site, and thinning plus scrubbing in the worse quality one were the treatments that most improved pine growth. Therefore appropriate human management does help forest restoration as expected.

The catastrophic fire in the northern Da Hinggan Mountains in 1987 had attracted much world′s attention. An area of about 1 330 000 ha was burned out by this fire, with 213 people killed, much more people wounded, and $3.96\times10^7$ $m^3$ of timber volume consumed. However, unlike the pure natural regeneration in the Yellowstone National Park after the fire in 1988 (Turner *et al*., 1994; 1997; 1999), intensive salvage harvesting of standing dead logs and planting coniferous trees were conducted after the fire, in an effort to restore timber volume of coniferous species as much as possible, since lumbering was the main forest industry in this region. The harvesting deteriorated the situation of lack of seeding sources in the severely burned area, while tree planting compensated this problem to some extent.

According to the field investigation 15 years after this catastrophic fire in the northern Da Hinggan Mountains, vegetation cover has been restored in most of the areas and the landscape has become heterogeneous largely due to planting trees of different years, mortality of the planted trees, forest pests and diseases, as well as different levels of natural regeneration. However, the effect of human planting on species composition and productivity compared to the pure natural regeneration has never been evaluated. Furthermore, since the Da Hinggan Mountains is the largest timber production area in China, as well as an area frequently suffered from natural and human induced fire, the long term ecological and economic effect of post-fire activities on forest restoration are of great interest to both scientists and forest administrators.

In this paper, we investigated the overall effects of tree planting on landscape-scale forest restoration, by comparing simulated serial data with burned blank and planted young forest as initial successional stages, respectively. Specifically, we intend to study: 1) How fast can tree planting accelerate post-fire forest restoration? 2) What are the long-term effects of tree planting on dominant tree species abundance and timber volume, compared with natural regeneration? We assumed that tree planting would accelerate the restoration process of the forest to the climax structure and improve the productivity of the timber volume to a large extent compared to natural regeneration.

## 2 Study Area and Methods

### 2.1 Study area

Tuqiang Forest Bureau (52°15′55″–53°33′40″N, 122°18′05″–123°29′00″E) in the central part of the burned area of the northern Da Hinggan Mountains was selected as the study area (Fig. 1). The climate is cold temperate monsoon, with an average annual temperature of –5℃ and an average annual precipitation of 432 mm. Winter is dry and cold, while summer is moist and warm. Brown coniferous forest soil is the dominate soil type, with a thickness of 10–30 cm. The zonal vegetation is cold temperate coniferous forest dominated by Dahurian Larch (*Larix gmelinii*), Mongolian Scorch Pine (*Pinus sylvestris* var. *mongolica*), Asian white birch (*Betula platyphylla*) and several species of aspen (*Poplus* spp.) (Qian *et al*., 2003).

The total area of the forest bureau is about 4 000 km$^2$, of which 60% burned in 1987. The severely burned area (more than 70% of trees dead) was about 900 km$^2$, or 22.5% of the whole bureau. Tree planting was mainly carried out in the severely burned area. The main species planted was *L. gmelinii*, with small area of *P. sylvestris* var. *mongolica* and Korean Spruce (*Picea koraiensis*). By 1997, approximately 50% of the severely burned area had been reforested, mostly in the area with high accessibility and good site conditions. In the moderately burned area (30%–70% of trees dead), human promoted restoration was conducted with mechanical plough, whereas in the lightly burned area (less than 30% of trees dead), natural regeneration was left. In the unburned area, log harvesting was continued (Wang *et al*., 2006b)

### 2.2 Simulation method

LANDIS (Landscape Model of Succession, Disturbance and Management) is a spatially explicit model designed to simulate long-term forest dynamics under natural and anthropogenic disturbances (He and Mladenoff, 1999; Mladenoff and He, 1999; He *et al*., 2005). To evaluate the long-term ecological effects of tree planting on post-fire succession, LANDIS version 4.0 was employed to simulate the long term forest dynamics in the severely burned area, as well as in the unburned area for reference, using parameters of abundance and timber volume for dominant species, such as *Larix gmelinii* and *Betula platyphylla*. The dynamics of forest succession, seed dispersal, wind, fire, biological disturbance (insects and diseases), harvesting, fuel accumulation and decomposition, and fuel management can all be simulated at tree species level, and extrapolated to landscape scale via cells and land types. Therefore the model can be applied at large spatial-temporal scales and has been widely used in North America and Europe (Mladenoff, 2004). The hypothesis for this model is that most of the ecological parameters such as reestablishment ability, bio-disturbance, topographical condition and fire regime are the same within one land type unit. It has been calibrated and verified in the northern Da Hinggan Mountains by Xu *et al*. (2004; 2005). For detailed model input information, please also refer to Wang *et al*. (2006a; 2006b; 2007). LANDIS version 4.0 has a special ′planting module′ which can fulfill the need of this study.

Key parameters of the model are species′ vital attributes (Table 1), including longevity, maturity age, shade tolerance, fire tolerance, seeding distance and vegetative reproduction information for each species, which were derived from field investigation data and pertinent literatures (Zhou, 1991; Xu, 1998; Xu *et al*., 2004; 2005). Although 8 tree species were simulated, we only report the results for two of them (*L. gmelinii* and *B. platyphylla*), since they occupied over 90% of the forest area before the fire and are important timber species in the study area.

Table 1 Species′ vital attributes for the northern Da Hinggan Mountains

| Species | LONG | MTR | ST | FT | ED | MD | VP |
|---|---|---|---|---|---|---|---|
| *Larix gmelinii* | 300 | 20 | 3 | 3 | 150 | 300 | 0 |
| *Pinus sylvestris* var. *mongolica* | 250 | 40 | 1 | 1 | 100 | 200 | 0 |
| *Picea koraiensis* | 300 | 30 | 4 | 2 | 10 | 150 | 0 |
| *Betula platyphylla* | 150 | 15 | 1 | 3 | 200 | 4000 | 0.8 |
| *Populus davidiana* | 180 | 20 | 1 | 3 | –1 | –1 | 1.0 |
| *Betula davurica* | 150 | 15 | 1 | 4 | 200 | 1000 | 0.8 |
| *Populus suaveolens* | 150 | 25 | 1 | 4 | –1 | –1 | 0.9 |
| *Chosenia arbutifolia* | 200 | 30 | 2 | 2 | –1 | –1 | 0.9 |

Notes: LONG, longevity (yr); MTR, age of maturity (yr); ST, shade tolerance; FT, fire tolerance; ED, effective seeding distance (m); MD, maximum seeding distance (m); VP, vegetative reproduction probability. Higher values for ST and FT indicate higher tolerance. ′–1′ represents unlimited seeding range
Sources: Wang *et al*., 2006a; 2006b

Forest composition maps that contain individual species presence/absence and age classes on each cell at the initial stages of the fire and tree planting were derived from forest stand maps of 1987 and 2000, which were investigated and compiled by the Forest Investigation, Planning and Designing Institute of the Da Hinggan Mountains. The forest stand map of the burned area was investigated in 1987 immediately after fire. Forest stand map of 2000 of the same area was employed to represent the initial status of the area with intensive tree planting and promoted forest restoration. Tree planting stopped in 1997. Since we are studying the long-term effect of 300 years, tree growth differences caused by the 10-year discrepancy at the initial stage can be ignored.

A land type map was derived from TM image of the study area taken in September 2000, which divided the heterogeneous study area into relatively homogeneous units. Eight land types were delineated from the map: open water, built-up area, terrace, sunny slope, shaded slope, burned terrace, burned sunny slope, and burned shaded slope (Fig. 1). The establishment coefficients of each species and fire disturbance regimes for each land type are also presented on the land type map. To be consecutive, the same land types were used for the tree planting scenario. Each species was assigned a re-establishment coefficient on each land type, with the value varying between 0–1 (Table 2). Higher values indicate higher possibility of successful re-establishment.

The mean return interval of fire disturbance was set at 325 years according to the historical record of the northern Da Hinggan Mountains (Hu *et al*., 2004). However, this period is longer than that under natural condition because fire prevention and suppression measures have been strictly reinforced after the fire in 1987.

To study the long-term effect of tree planting, two simulation scenarios were designed and the simulation results were compared for the severely burned landscape. One scenario reflects natural regeneration that does not include any planting, using forest stand map of 1987 as the starting point of landscape succession. The initial abundance of species in the whole study area was 40.9%

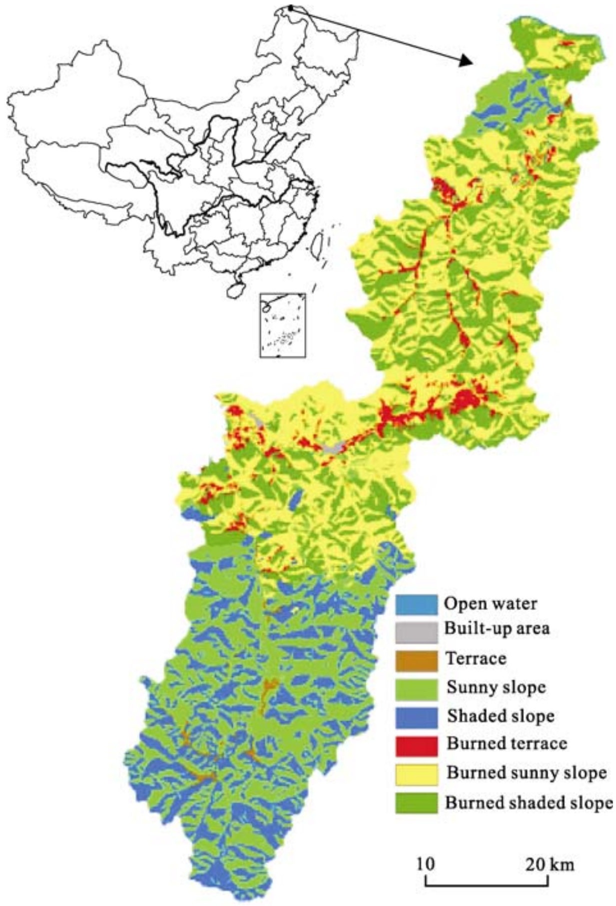


Fig. 1 Location and land types of study area

Table 2 Establishment coefficient for each species on each land type in northern Da Hinggan Mountains

| Land type | *Larix gmelinii* | *Pinus sylvestris* var. *mongolica* | *Picea koraiensis* | *Betula platyphylla* | *Populus davidiana* | *Betula davurica* | *Populus suaveolens* | *Chosenia arbutifolia* |
|---|---|---|---|---|---|---|---|---|
| Sunny slope | 0.300 | 0.250 | 0.030 | 0.300 | 0.010 | 0.100 | 0.000 | 0.000 |
| Shaded slope | 0.250 | 0.200 | 0.050 | 0.250 | 0.010 | 0.050 | 0.000 | 0.000 |
| Terrace | 0.002 | 0.000 | 0.000 | 0.004 | 0.001 | 0.000 | 0.010 | 0.050 |
| Burned sunny slope | 0.300 | 0.250 | 0.030 | 0.300 | 0.010 | 0.100 | 0.000 | 0.000 |
| Burned shaded slope | 0.250 | 0.200 | 0.050 | 0.250 | 0.010 | 0.050 | 0.000 | 0.000 |
| Burned terrace | 0.002 | 0.000 | 0.000 | 0.004 | 0.001 | 0.000 | 0.010 | 0.050 |
| Open water | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Built-up area | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

Sources: Wang *et al*., 2006a; 2006b

for *L. gmelinii* and 17.9% for *B. platyphylla*, immediately after the fire in 1987. These would be the seeding sources for the severely burned area under the natural regeneration scenario. About 22.5% of the study area was classified as severely burned area in 1987, which was considered as 'bare land' at initial stage under the natural regeneration scenario. We suppose that only natural fire, wind throw and diseases happened under this scenario, without any human disturbance. The other scenario reflects tree planting, which was based on the forest stand map of 2000, with data investigated after planting stopped in 1997. In total, 300 years (the average longevity of *L. gmelinii*) at 10 year steps were simulated with 5 replicates for each scenario.

Simulation was conducted for the whole study area, including the unburned, lightly burned, moderately and severely burned areas. Then species information was derived and compared for the severely burned area. This ensured the incorporation of seeding dispersal influence from outside of the severely burned area (especially under natural regeneration), while the effect of tree planting in the severely burned area can be isolated as well. The simulation results were illustrated with temporal changes of dominant tree species abundance and timber volume in the severely burned area. By comparing the two scenarios for the above mentioned trajectories, we could reveal the long-term effect of tree planting on target species restoration.

The species abundance was calculated as the area (in number of cells) percentage with this species in the study area. Since more than one species can occupy one cell (90 m × 90 m) in the output of LANDIS model, the sum of species abundance in the whole study area can be over 100%.

Timber volume is usually calculated according to field measurement of standard plots, based on diameter at breast height (DBH) and tree height. The output of LANDIS model only contains presence/absence of species and age cohort on each cell, at every 10 years. To estimate timber volume for different simulated years, we calculated the timber volume per hectare from different ages and the area of each species occupied. Since the timber volume can be different for the same species on different land types, we calibrated the timber volume data with forest stand maps derived from field investigation data in the unburned area in 1987 (Wang *et al.*, 2005). Statistical relationships between stand age and average timber volume were established via linear regression for each species on different land types, so that timber volume of dominant species based on simulation results can be calculated.

## 3 Results

### 3.1 Species abundance in severely burned area

Simulation results of severely burned area for the species abundance of *L. gmelinii* and *B. platyphylla* are compared under conditions of coniferous tree planting and natural regeneration (Fig. 2a and c), respectively.

Under tree planting, the area percentage of *Larix gmelinii* in the severely burned area is much higher than that under natural regeneration (Fig. 2a). According to our simulation, the area of *Larix gmelinii* can reach nearly 90% of the severely burned area within 100 years after tree planting. The area percentage remains high till the 250th year after the fire (Fig. 2a). Under natural regeneration, the area of *Larix gmelinii* can never reach the level of 2/3 of the severely burned area (Fig. 2a).

According to the pre-fire forest stand map, *L. gmelinii* occupied about 60% of the study area. Under natural regeneration, it needs at least 250 years to restore to the abundance of 60% in the severely burned area (Fig. 2a). While under tree planting, the relative percentage in the severely burned area was already over 45% in 1997, 10 years after fire. Within 20 years the abundance of *L. gmelinii* can reach its previous level in the severely burned area.

In contrast, the area percentage of *B. platyphylla* is relatively higher under natural regeneration than that under coniferous tree planting (Fig. 2c). *B. platyphylla* has high dispersal, sprouting and re-establishment ability. Under natural regeneration, the area of *B. platyphylla* thrived soon after fire, and can spread across the entire severely burned area (Fig. 2c). The area percentage of *B. platyphylla* will decrease to about 70% after 150–200 years, after coniferous species becomes dominant again. Under the tree planting of coniferous species, the area of *B. platyphylla* first increased quickly to above 50% within 30 years after fire (Fig. 2c), due to the high re-establishment ability of this species. But the maximum percentage is always lower than 55%. After 120 years, its area percentage will be lower than 50% in the severely burned area, since its maximum longevity in this region is 150 years. According to Fig. 2c, the planting of conifer-

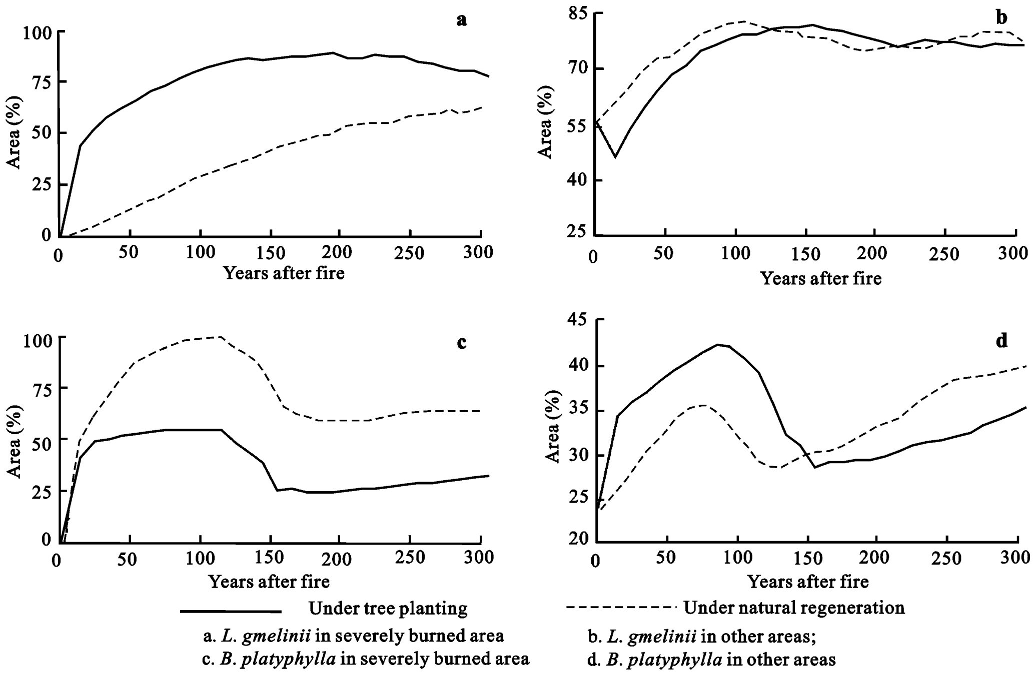


Fig. 2 Area percentages of *L. gmelinii* and *B. platyphylla* under different scenarios at different years after fire

ous species lowered the percentage of broad-leaved species for the entire simulated period (300 years).

### 3.2 Comparison of species abundance between severely burned area and other areas

Figure 2 also provides the simulation results for other areas (including moderately burned, lightly burned and unburned area, about 77.5% of the whole study area) except for the severely burned area for comparison. The two scenarios show no significant difference for *L. gmelinii* in the 300 years simulated (Fig. 2b). The sharp drop under the tree planting scenario (Fig. 2b) in the first 10 years was due to the harvesting of matured *L. gmelinii* in the unburned area. This harvesting also resulted in the relatively higher area percentage of *B. platyphylla* under tree planting than under natural regeneration within 150 years after fire (Fig. 2d).

Compared to the other areas, the severely burned area has a relatively higher area percentage of *L. gmelinii* during the simulation period due to planting of this species (Fig. 2a and b). But the area percentage of *B. platyphylla* is also higher in the severely burned area than that in the other areas, especially within the first 150 years (Fig. 2c and d). This is due to the 'over sprouting pulse' of broad-leaved species immediately after fire. The other areas except for severely burned area can be taken as a reference for successional process towards the climax situation.

### 3.3 Timber volume for target logging species in severely burned area

Figure 3 shows the increase of timber volume after fire for *L. gmelinii* and *B. platyphylla* in the severely burned area. Under natural regeneration, the timber volume for *L. gmelinii* increases gradually from almost zero to $6\times10^6$ m$^3$ within 300 years (Fig. 3a). Under tree planting, the timber volume increases quickly to over $8\times10^6$ m$^3$ within 100 years and maintains a high level till the 250th year after fire (Fig. 3a). Then the timber volume drops down because the average life span of *L. gmelinii* is about 300 years. Some of the trees begin to die out before reaching the average longevity. In average, with coniferous tree planting we can obtain almost twice as much timber volume as that under natural regeneration. The relatively high timber volume of *L. gmelinii* caused by tree planting can be maintained for the entire simulation period of 300 years, though the two curves tend to converge in the end.

The pre-fire timber volume of *L. gmelinii* was about $5.4\times10^6$ m$^3$ in the severely burned area. It needs at least 250 years to reach this volume level under natural regeneration, according to our simulation result (Fig. 3a). However, under tree planting, the timber volume of *L. gmelinii* can reach this amount within 70 years (Fig. 3a).

The timber volume of *B. platyphylla* increases quickly after fire in both scenarios (Fig. 3b). Then it begins to

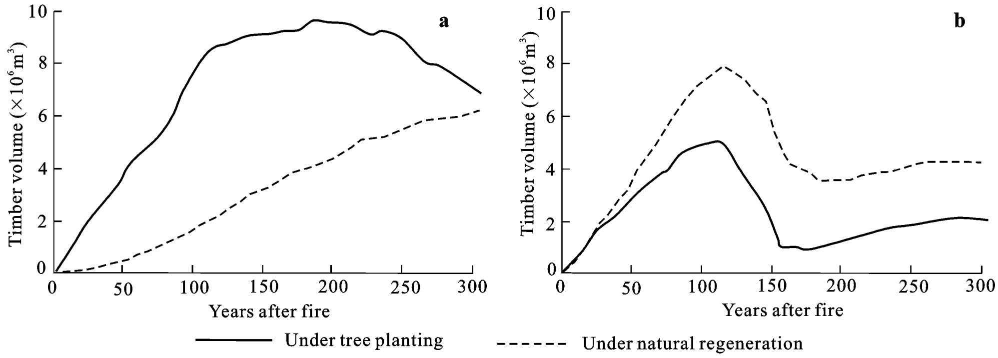


Fig. 3 Timber volume of *L. gmelinii* (a) and *B. platyphylla* (b) at different years after fire in severely burned area

decrease because of the increasing abundance of *L. gmelinii* as well as the decreasing abundance of *B. platyphylla* due to over maturity after about 100 years. Under natural regeneration, the maximum timber volume of *B. platyphylla* can reach $8\times10^6$ $m^3$ (Fig. 3b), while under tree planting, the maximum volume is only about $5\times10^6$ $m^3$ (Fig. 3b). The timber volume of *B. platyphylla* under tree planting is only half of that under natural regeneration, according to our simulation results. Therefore the timber volume of *L. gmelinii* is enhanced by coniferous tree planting, and that of *B. platyphylla* is hampered at the same time.

## 4 Discussion

Our results show that coniferous tree planting has greatly accelerated the restoration process in terms of species abundance and timber volume in the severely burned area of the northern Da Hinggan Mountains.

Under the tree planting scenario, the area percentage of *L. gmelinii* can restore to its pre-fire level within 20 years after fire, while the timber volume can restore to its pre-fire level within 70 years. Both species abundance and timber volume of *L. gmelinii* have shown much quicker restoration under tree planting compared to those under the natural regeneration scenario during the simulation period of 300 years. However, the curves of species abundance (Fig. 2a) and timber volume (Fig. 3a) of *L. gmelinii* under both scenarios tend to converge at the end of 300 years. This indicates that the benefit of coniferous tree planting is not likely to influence the next succession cycle. On the other hand, the curves of species abundance and timber volume for *B. platyphylla* does not converge (Fig. 2c, 3b), which suggests that the effects of fire and post-fire management on broadleaved trees will persist in the next succession cycle.

Although the simulation results for the specific period and timber volume gained through planting of coniferous trees might not be accurate due to the assumption and simplification of ecological processes, the general trend is obvious that post-fire planting of coniferous species does accelerate the restoration process, especially in the severely burned area. But the economic value of human input during tree planting and subsequent management was not calculated in this study. Therefore the net gain from planting needs further study. Other areas need to consider the economic input as well before taking actions of planting.

Natural regeneration simulated in this study was based on the condition that all the standing dead trees were harvested, and therefore no seed source in the severely burned area was available right after fire. In fact the extent of fire severity was not homogeneous even in the severely burned area. There were always some trees survived (< 30%) within severely burned area and they could serve as important seed sources for subsequent natural regeneration. However, the local people did not realize the ecological importance of these survived trees and clear-cut all the trees that were scorched within 1–2 years after the catastrophic fire. This further reduced the seed sources. As a result, 'natural regeneration' simulated in this study was under the hypothesis that all potential seeding sources had been wiped out. The lack of seed source condition in the severely burned area was over-estimated in 1987, but became true after the clear cutting. Therefore our comparison is valid in terms of its long term effect based on the two real initial situations.

In the tree planting scenario, natural death of trees before mature, diseases, and selected harvesting (or thinning, more birch than larch) were not taken into consideration due to lack of data. Diseases and pests mainly affect the young stands in the planted area with mono-species. After the mature of larch, these factors affect the fuel accumulation and fire possibility only (Hessburg *et al*., 2008). This may have reduced the realism of the simulation, especially for the first several decades, but have limited effect in the long term after natural process takes its way (Miyawaki and Golley, 1993).

Our study involves a large area (4 000 $km^2$) and long time span (300 years), so it is unfeasible to perform real field validation for such a study. Xu *et al.* (2004) studied the applicability and accuracy of LANDIS model in the northern Da Hinggan Mountains, China, and considered that with the current input parameters given, the simulation results are qualitatively consistent with the real situation in terms of species distribution, species composition, and fire disturbance. Cell level uncertainty of initial input data does not affect the overall accuracy at landscape level, especially at later stages of the simulation. The model was empirically validated with field data from the Huzhong Natural Forest Reserve (Xu *et al*., 2004; 2005). We also compared the trend of species area composition curves under natural succession between Huzhong (Xu *et al.*, 2004) and Tuqiang (Wang *et al.*, 2007). They showed comparable succession trends at later stages (after 150 years) of simulation. Our field observation from 2002 to 2008 also confirmed the simulation results in the Tuqiang Forest Bureau, especially that of the human planting scenario. At forest stands planted early after fire, *L. gemelinii* has already started reproduction, since it needs only 20 years to become mature. For a more convincing validation of the simulation results, we need to use future forest stand maps based on detailed field investigation.

One more point to be addressed is that the benefit gained from tree planting is far more than the factors simulated and analyzed in this study. For example, the accelerated vegetation recover may contribute to the soil and water conservation in the severely burned area by restoring the destroyed ground cover. But broad-leaved forest and bushes may contribute more to that at the early succession stage after fire. The evaluation for this aspect is still yet to be done. The habitat for wild animals is also restoring gradually in terms of quality and quantity of suitable area (Li *et al*., 2006; Xie *et al*., 2006). More importantly, since larch, frozen soil and wetlands in the study area are quite closely interrelated with each other (Zhou *et al*., 2003), the restored coniferous forest can impede the unfreezing process of permanent frozen soil layer caused by global warming and devastating fire, and thus contribute to the adaptation of local ecosystem to the elevated winter temperature. The long-term ecological effect of tree planting in this large burned area needs to be further monitored and assessed in future studies.

## 5 Conclusions

This paper simulated the long term effect of coniferous tree planting after the catastrophic fire in the northern Da Hinggan Mountains in 1987, with a spatially explicit model LANDIS4.0 under natural regeneration and tree planting scenarios. It can be concluded that under tree planting of local dominant coniferous species (*Larix gmelinii*), the area percentage can reach its pre-fire level of 60% within 20 years, while the timber volume of this species can reach its pre-fire level within 70 years. Under natural regeneration, the restoration of *L. gmelinii* is much hampered by the quick regeneration of *B. platyphylla*. Tree planting can shorten the restoration time of target species substantially. Therefore it is beneficial to the local ecosystem if the financial input is not considered.

This study involves a large area and long time span, so it is unfeasible to perform real field validation for such a study. For a more convincing validation of the simulation results, we need to use future forest stand maps based on detailed field investigation. Moreover, the benefit gained from tree planting is far more than the factors simulated and analyzed in this study. The long-term ecological effect of tree planting in this large burned area needs to be further monitored and assessed in future studies.

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