Post-fire forest regeneration under different restoration treatments in the Greater Hinggan Mountain area of China

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Abstract

Forest fire is one of the dominant disturbance factors in boreal forests. Post-fire forest regeneration is crucial to both ecological research and forest management. Three different restoration treatments, namely natural regeneration, artificial regeneration, and artificial promotion, were adopted in the Greater Hinggan Mountain area of China after a serious forest fire occurred on May 6, 1987. Natural regeneration means recovering naturally without any intervention, artificial regeneration comprises salvage logging followed by complete planting, while artificial promotion refers to regeneration by removing dead trees, weeding, and digging some pits to promote seed germination.

The objectives of this study were to evaluate and compare the effects of the three restoration treatments and determine which approach is the most suitable for local forest recovery. A field survey was conducted to collect the attribute data, specifically species composition, structural parameters, and Leaf Area Index (LAI), which were analyzed through the analysis of variance and a post-hoc test. The broad-leaved species occupied the main component of the forest under natural regeneration while the coniferous species dominated those under the other two treatments. Tree height and Diameter at Breast Height (DBH) were significantly highest for the forest under artificial regeneration, but an insignificant difference was found for crown widths among the three treatments. Significantly highest LAI was observed in forest under natural regeneration. The results suggest artificial regeneration to be adopted in post-fire recovery if the goal is timber production, while natural regeneration to be utilized when focusing on canopy vertical density and species richness. The artificial promotion treatment showed no advantage. This study demonstrated the advantages of limited strategies that can be helpful for local post-fire forest management.

Keywords

Forest regeneration; Post-fire restoration; Restoration treatments; Leaf Area Index; The Greater Hinggan Mountain area.

1. Introduction

Forests are integrated, multi-functional, and multi-value terrestrial ecosystems with widely distributed coverage areas and complex composition, as well as high species diversity (David et al., 2008; Chen et al., 2010). Forest disturbance and recovery have been regarded as a primary mechanism for transferring carbon between the land surface and atmosphere, thus further play a crucial role in both regional and global carbon cycles as well as in forest monitoring and management (Healey et al., 2005; Soja et al., 2007; Masek et al., 2008; Cao et al., 2011; Dainou et al., 2011; Huang et al., 2012; Camac et al., 2013). Forest fire is one of the main disturbances involved in carbon transfer, especially in boreal forests (Asselin et al., 2001; Gromtsev, 2002; Forkel et al., 2012). Fires are the primary processes which organize the physical and biological attributes of the boreal biome over most of its range and influence the energy flow and biogeochemical cycles (Díaz-Delgado and Pons, 2001; Shorohova et al., 2009; Wotton et al., 2010; Chen et al., 2011). Consequently it is necessary to investigate the effects of fire on forest ecosystems and monitor the patterns of post-fire forest regeneration as it pertains to both post-fire ecological research and forest management (Bonan, 1989; Schulze et al., 2005; Stueve et al., 2009; Marzano et al., 2013; Otoda et al., 2013).

Although there are already a large number of studies about forest fires and post-fire forest recovery (Bergeron, 2000; Schulze et al., 2005; Shorohova et al., 2009), most of them focus on species composition and forest succession (Uemura et al., 1997; Schulze et al., 2005; Gauthier et al., 2010; Otoda et al., 2013), as well as on the structural parameters and plant cover/tree density (Pausas et al., 1999; Johnstone et al., 2004; Moreira et al., 2009, 2013; Ascoli et al., 2013a; Senici et al., 2013). However few studies have considered the forest ecosystem as a whole one, including all life forms (such as arbor species, shrubs, and grasses) (David et al., 2008), especially using quantitative indicators (Healey et al., 2005). Here, we introduce a three-dimensional scaling parameter, Leaf Area Index (LAI), which has been widely developed and validated in the interdisciplinary field of forest remote sensing combining forestry with remote sensing (McMichael et al., 2004; Boer et al., 2008; Chen et al., 2010).

The leaf forms the main surface for matter and energy exchange between the plant canopy and atmosphere, and LAI, defined as half the total leaf area per unit horizontal ground surface area, is proposed as a key variable in the research about terrestrial ecosystems and their development (Chen and Black, 1992; Arias et al., 2007; Schleppi et al., 2011). LAI can be used to characterize the canopy-atmosphere interface of an ecosystem, and is related to precipitation, atmospheric nutrient deposition and interception, canopy microclimate, radiation extinction, as well as water, carbon, and energy exchanges with the atmosphere (Chen et al., 2010). It can be retrieved from remote sensing data, and measured using advanced canopy analyzer devices (Arias et al., 2007).

The Greater Hinggan Mountains area, located in the northeast of China, is one of the most important forestry bases with dense virgin forests. This region is rich in forest resources, but also suffers a high incidence of forest fires that are highly determined by fire suppression (Chang et al., 2007; Chen et al., 2011). Among all the fires occurred in this area, that broke out on May 6th, 1987 (abbreviated as “5.6 Fire” hereafter) has become the most noteworthy one, as it was the most serious forest fire since the founding of the People’s Republic of China. It resulted in a burned area of 1.7×10^6 ha and a burned forest area of 1.01×10^6 ha (Zhao et al., 1994). After this fire, the local forest bureaus have taken a series of measures to recover the forests; many favorable conditions have been created for speeding up recovery and for ecological forest construction. During the restoration process, three different restoration treatments were adopted for the regeneration of the forests in the burned area. The dynamics of forest regeneration were different depending on the treatment determined for regeneration.

In this study, taking the “5.6 Fire” as an example, we investigated the post-fire forest recovery. A field survey was designed and a detailed statistical analysis on the collected data of structural parameters and LAI was performed. The objectives were to evaluate and compare the effects of different restoration treatments, based on which to determine which approach is most suitable for successional regeneration of local forest ecosystems. On the basis of the results, effective suggestions about post-fire forest recovery could be provided for reference in local forest utilization and management.

2. Methods

2.1 Study area

The study area of the Greater Hinggan Mountain area, located in the northern part of Heilongjiang Province and Inner Mongolia Autonomous Region, is the watershed of the Mongolian Plateau and the flat Songliao Plain, with geographic coordinates ranging from 50°10′ to 53°33′N in latitude and from 121°12′ to 127°00′E in longitude (Fig. 1). This region has a total length of over 1200 km, a width of 200–300 km, and an average altitude of 1200–1300 m.

This area is an important and crucial climatic zone. It has a typical cold temperate continental monsoon climate with warm summers and cold winters. The annual average temperature in this region is -2.8 ℃, with the lowest temperature being -52.3 ℃, and an average annual precipitation of 746 mm. It is China's northernmost and largest modern state-owned forest area, with a total ground area of 8.46×10^4 km^2 and a forest-covered area of 6.46×10^4 km^2. The forest coverage rate amounts to 76.4% and the total stand volume is approximately 5.01×10^8 m^3 which accounts for 7.8% of the national total stand volume. This mountain area has more than 400 species of wild animals and over 1000 varieties of wild plants, and hence is a great reserve of biological resources. It is a mixed forest area with the dominant coniferous species of Mongolian pine (*Pinus sylvestris L.*) and Larch (*Larix gmelini R.*), and the broad-leaved species of Birch (*Betula platyphylla S.*) and Aspen (*Populus davidiana D.*).

The annual burned forest area of this region ranks first in China, making it the most serious forest fire hazard area. These fires cause great impacts on local forest ecosystems. According to the records of fire in a period of 20 years from 1987 to 2006 (Tian et al., 2011), 1059 fires occurred, with a burned area of 2.81×10^6 ha, including 1.36×10^6 ha of forest area. The Greater Hinggan Mountain area has been regarded as a key focus region for forest fire prevention and post-fire forest recovery since the most serious forest fire in the history of P. R. China occurred in this region (Sun et al., 2011).

2.2 Sampling design and field data collection

After the "5.6 Fire", three totally different restoration treatments, namely artificial regeneration, natural regeneration, and artificial promotion, were conducted for forest regeneration. As the name suggests, artificial regeneration indicates an active role of humans in the recovery process through removing all dead or damaged trees belonging to the pre-fire stand from the burned area, followed by complete replanting. In these sites, the coniferous species of *P. sylvestris* and *L. gmelini* were selected and a regular plant spacing (1.5 × 1.5 m or 1.5 × 2 m) was adopted according to field conditions. Natural regeneration means allowing the forests to regenerate completely naturally without any human intervention. Thus no any salvage logging or harvesting was conducted, allowing natural restoration to take place. The third approach, artificial promotion, indicates essentially natural regeneration with a select number of artificial aids, which include removing all dead trees and snags, clearing the burned area, weeding, and digging some pits to promote seed germination and growth naturally. In a year with adequate seeds (as the case of forest regeneration in this study), only pits with regular spacing were dug to promote seed rooting, while in a year lacking in seeds, on the basis of the digging, some supplementary measures of artificial seeding was also taken. In any case, no plantation by means of transplantation was performed.

In order to investigate the forest restoration dynamics and compare the effects of different restoration strategies, we designed and performed a field forest survey within the burned area of the “5.6 Fire” during July 12–18, 2012, which was the 25th year after the fire. In this survey, we examined three forestry bureaus, Xilinji, Tuqiang, and Amuer, which covered over 85% of the burned forest area of the “5.6 Fire”. We selected and surveyed three plots of 10 m × 10 m in each forest bureau under each type of restoration treatment. With respect to the plot size, in all plots under artificial regeneration and artificial promotion treatments, the trees are evenly distributed within the plots and their surrounding areas, making the size of the plot effectively irrelevant. However, it was not such a case for the plots under natural regeneration. Thus, in future surveys, the size of sampling plots should be increased and the number of observations in each combination of treatment and region is also in need of augmentation.

The coordinates of the four corners and the centre of each plot were measured using a differential global positioning system (DGPS). Within each regeneration plot, the species of each individual tree was recorded and the corresponding structural parameters including tree height, Diameter at Breast Height (DBH), and crown width (in the direction of both North-South and West-East) were measured using such devices as an altimeter rod, a tape measure, and a NIKON Forestry Pro 550. The young trees with DBH $<$ 2 cm were recognized as seedlings and being counted; however, their structural parameters (tree height, DBH, and crown widths) were not measured and incorporated in the subsequent statistics. The dominant shrub species were also identified, but not measured. The LAI of each plot was measured using the LAI-2200 canopy analyzer with a height of just above the shrub under stable weather conditions (Chen and Cao, 2012). For all plots in the three forest bureaus, forest regeneration began during the 1987–1989 period, regardless of the restoration treatments, and never suffered any disturbance thereafter. The spatial distribution of these plots was shown in Fig. 2.

Fire severity is a crucial element to understanding and interpreting post-fire forest dynamics, as it is one of the main factors affecting post-fire forest regeneration (Schimmel and Granstrom, 1996; Keeley, 2009; Hollingsworth et al., 2013; Marzano et al., 2013). For example, Hollingsworth et al. (2013) proposed that patterns of forest community composition were primarily related to gradients in fire severity, which could thus determine early patterns of community assembly because it has a greater influence than do environmental constraints. In this study, since all the dead and damaged trees had been removed from the burned sites under the artificial regeneration, it was difficult to measure the fire severity in all sites using field survey data. As an alternative, we proposed estimating the disturbance index (DI) (Healey et al., 2005), calculated from remote sensing data, as a proxy of fire severity. The DI image for the entire burned area of the “5.6 Fire” was acquired (Chen et al., 2013) and the values of all surveyed plots were extracted and analyzed. The results indicated that there was no significant difference in fire severity among the three forestry bureaus, and among the areas restored using the three restoration treatments. Therefore, in this study, we did not consider this factor for subsequent analyses and comparisons.

2.3 Statistical analysis

The species composition, structural parameters (tree height, DBH, and crown widths), and LAI of the forests in each forestry bureau under each type of restoration treatment were statistically analyzed. Firstly, the basic statistics (mean and standard deviation) of these attributes were calculated and compared. Then the quantitative Analysis Of Variance (ANOVA) was performed to further demonstrate the comparison. In the ANOVA setting, it was hypothesized that no significant difference existed among different regions and restoration treatments. As the interaction effect of “treatment” by “region” was tested and proven insignificant in all these forest attributes, it was incorporated in the “error effect” to emphasize the “main effect” (“treatment effect” and “region effect”) in the final model. Here the factor of restoration treatment was taken as a fixed factor and the region effect was tested as a random factor. Before ANOVA, a test of normal distribution was performed by using Kolmogorov-Smirnov and Shapiro-Wilk statistics, and the equivalence of variances was tested through Levene's statistic. When the assumptions for the parametric statistical tests of normality and homoscedasticity on original data were not met, logarithmic transformation was carried out to meet ANOVA requirements. The *p* value (significant probability) was used to determine whether the difference was significant or not. When a significant effect was found (the null hypothesis was rejected), multiple comparisons (post-hoc test) among the three restoration treatments for all attributes were performed using the algorithm of Tukey's Honestly Significant Difference (HSD) and the results were further analyzed to explore the relative relationship between any two of the restoration treatments.

3. Results

3.1 Species composition

There were only four arbor species in the surveyed plots, which were the coniferous species of *P. sylvestris* and *L. gmelini*, as well as the broad-leaved species of *B. platyphylla* and *P. davidiana*. The species composition of regenerated forests in the burned area under the three restoration treatments was quite different due to the different effects of the three restoration treatments (Table 1).

It was found there were only coniferous species of *P. sylvestris* and *L. gmelini* in the forest area under artificial regeneration. This result was determined by the species selection in the planting process. The species selection was made according to the local climatic and topographic conditions and considering the recommendations of local forestry engineers and technicians. Additionally, *P. sylvestris* and *L. gmelini* were relatively more suitable for human production, including the paper industry and construction activities, when compared with the broad-leaved species. In the forest area under natural regeneration, there were both the coniferous species (Mongolian pine and Larch) and broad-leaved species (Birch and Aspen), and the latter accounted for the main part. The dominant species in the completely naturally regenerated forest area was *P. davidiana* in Xilinji (78.02%), as well as *B. platyphylla* in Tuqiang (86.24%) and Amuer (84.61%). This suggested that the broad-leaved species had stronger resilience than coniferous species in the naturally regenerated forest area.

Besides, from field records, we found more coniferous seedlings and shrub species in forest plots under natural regeneration. For the comparison studies, their structural parameters were not measured and included in the statistical analysis. In the forest area under artificial promotion, the coniferous species became dominant, which was the same as that in the artificially regenerated area.

3.2 Tree Height

The statistics of tree height in the three forestry bureaus, and all regions under the three restoration treatments, was performed and compared (Fig. 3). The results indicated that the average tree heights of forests under artificial regeneration was higher than those under natural regeneration and artificial promotion, with that of artificial promotion being the lowest. The ANOVA result (Table 2a) suggested that the difference in tree height was significant among the three restoration treatments ($p = 0.031 < 0.05$), but not among different regions ($p = 0.705 > 0.05$). Based on multiple comparisons by Tukey's HSD (letters of a and b on Fig. 3), we were able to conclude that there was no significant difference in tree height between the restoration treatments of artificial promotion and natural regeneration, while they were both significantly lower than that of forest under artificial regeneration.

3.3 Diameter at Breast Height

The statistics (Fig. 4) indicated that the recovered forest under artificial regeneration had a higher average DBH than those under the other two restoration treatments. As shown in Table 2(b), the difference in DBH among the three restoration treatments was extremely significant ($p = 0.004 < 0.01$). However, there was no significant difference in DBH among different regions ($p = 0.432 > 0.05$). The multiple comparison (Fig. 4) gave the result that there was no significant difference in DBH of forests under the treatments of artificial promotion and natural regeneration, however, they were both significantly lower than that under artificial regeneration. It was similar to the analysis result of tree height.

3.4 Crown Width

3.4.1 Crown Width in North-South direction

The statistics of crown width in the N-S direction (Fig. 5) suggested that the parameter differed in the three forestry bureaus. By qualitative comparison, crown width was larger for trees under artificial regeneration treatment than under the other two treatments. But ANOVA results (Table 2c) indicated that the difference among the three restoration treatments was marginally insignificant ($p = 0.075 > 0.05$) and that among the three regions was also insignificant ($p = 0.160 > 0.05$). Consequently, here further multiple comparison was not necessary. It was quantitatively different from the results of tree height and DBH. Since these sites were located in high latitudes, the subtle difference of solar radiation in the N-S direction may produce an impact on the dynamics of crown width.

3.4.2 Crown Width in West-East direction

The statistics of crown width in the W-E direction were also analyzed (Fig. 6), from which we came to similar conclusion to that in N-S (Fig. 5). However, ANOVA results (Table 2d) indicated that the crown width in W-E had a marginally significant difference among the three treatments ($p = 0.043 < 0.05$), but not for the three regions ($p = 0.306 > 0.05$). By multiple comparison (Fig. 6), we could conclude that there was a significant difference in crown width in W-E between the restoration treatments of artificial regeneration and artificial promotion. The differences between the two and natural regeneration were both insignificant.

3.5 Leaf Area Index

The statistical result (Fig. 7) suggested that the LAI of forest under natural regeneration was the highest. ANOVA results (Table 2e) indicated that there was no significant difference in LAI among different regions ($p = 0.544 > 0.05$), however, an extremely significant difference in LAI was observed among the three restoration treatments ($p = 0.007 < 0.01$). Multiple comparisons (Fig. 7) further indicated that a significantly higher LAI was achieved in forest under natural regeneration than under the other two restoration treatments. The average LAI of forests under artificial regeneration was a little higher than that under artificial promotion. It was completely different from the results of structural parameters (tree height, DBH, and crown widths). The structural parameters characterized the states of individual trees, while LAI was a characterization of the overall condition of forest within specific range of regions.

4. Discussion

Forest fire is a common disturbance regime, and post-fire forest recovery following these disturbances plays a crucial role in a variety of fields, including climate change, forest utilization and management which have been widely studied (Pausas et al., 1999; David et al., 2008; Huang et al., 2012; Hollingsworth et al., 2013; Senici et al., 2013). Extensive studies have been conducted to investigate and compare the effects of different strategies on post-fire forest recovery (Moreira et al., 2009, 2013; Beghin et al., 2010; Ascoli et al., 2013b). For example, Moreira et al. (2009) compared two restoration treatments, direct planting and natural regeneration through resprouting, by focusing on the survival and size (height and basal diameter) of *Fraxinus angustifolia* and *Quercus faginea* in Central Portugal. The results suggested that, using natural resprouting may be a cheaper and more effective technique than direct planting to restore burned forests. Beghin et al. (2010) evaluated the impacts of five post-fire management options (no intervention; salvage logging; broadleaved plantation; *L. decidua* plantation; and *P. sylvestris* or *Pseudotsuga menziesii* plantation) on natural regeneration structure and composition, and found that density, size, and structural diversity of natural regeneration were higher in the area with no intervention. Aiming at our study area of the Greater Hinggan Mountains, there were three different post-fire forest restoration strategies, artificial regeneration, natural regeneration, and artificial promotion, which had never been comparatively studied in previous research. Here, we proposed to evaluate and compare the effects of the three restoration treatments on forest ecosystem using several forest attributes of structural parameters and LAI simultaneously.

On the basis of the field collected data, we concluded that there was significant difference in the dominant species of the forests under different restoration treatments. In the burned area under the treatment of artificial regeneration, the regenerated forest was dominated by the species selected for the planting. However, in the burned forest area, which was allowed to recover completely by natural regeneration, especially in boreal forests, broad-leaved species dominated in the initial stage after the disturbance event. This conclusion has been demonstrated by many previous studies (Uemura et al., 1997; Johnstone et al., 2004; Schulze et al., 2005).

Further analysis of the structural parameters (tree height, DBH, and crown widths) suggested that forest under the restoration treatment of artificial regeneration recovered significantly faster than those under the other two treatments. This probably resulted from the different species composition in forests under the three restoration treatments, which in turn, would affect the ecological functions and values of the ecosystems (Johnstone et al., 2004; Gauthier et al., 2010). However, the fact that the forest under natural regeneration recovered marginally faster than that under artificial promotion should be given attention as it indicated that the effect of the restoration treatment of artificial promotion is insignificant and hence its application as a restoration approach need to be reconsidered.

As LAI reflects the “layers” of leaves within a certain area in various ecosystems and can characterize the canopy-atmosphere interface effectively, it can be used to indicate the vertical density of vegetation canopy as well as species richness in forest ecosystems (Arias et al., 2007; Schleppi et al., 2011). Besides, LAI is not influenced by the species composition which benefits the comparison among different forest ecosystems. By the analysis of measured LAI of forests under the three different restoration treatments, we found that the completely naturally recovered forest had a higher canopy vertical density and relatively abundant forest species. The fact that the forest under artificial regeneration achieved a larger LAI than that under artificial promotion also raises a question on the need for the latter.

By the combined analysis of structural parameters and LAI, we concluded that the artificial regeneration treatment could be adopted in the actual forest management of post-fire recovery if the goal is timber production since the planted coniferous species of *P. sylvestris* and *L. gmelini* are more suitable for human utilization, including the paper industry and construction activities, than the broad-leaved species of *B.*

platyphylla and *P. davidiana*. Additionally, a variety of other forest species can also be selected in consideration of local climate and soil conditions. However, when the aim of forest restoration is to promote species richness in local forest ecosystem, the burned forest area should be allowed to recover completely under natural regeneration process without any anthropogenic interference. The restoration treatment of artificial promotion, which did not make sense and demonstrate its importance or necessity, should be carefully evaluated and reconsidered. It could probably serve as a means of balance in forest management.

In previous studies, it has been found that there is a transition in the dominant species of naturally regenerated forests, usually from dominance of broad-leaved pioneers (such as *Betula* and *Populus*) in the early period to that of conifers (including *Picea* and *Pinus*) in the late-successional stage (Gromtsev, 2002; Johnstone et al., 2004; Gauthier et al., 2010; Otoda et al., 2013), particularly 60–180 years after the fire. Therefore, we need to continue the field observations on forest regeneration in the future, as it has been only 26 years since the serious “5.6 Fire” occurred. This observation will be accomplished with the assistance of local forestry bureaus at a predesignated interval of five years. Moreover, we would design to investigate more sampling sites and increase the plot size in the future field studies. Furthermore, the time-series monitoring of forest disturbance and recovery would be focused on in combination with remote sensing data (McMichael et al., 2004; Masek et al., 2008). In this synergy application, scale matching between the size of the field plots and spatial resolution of remote sensing images should be carefully studied (Mitri and Gitas, 2013).

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Tables

Table 1. The species composition of forests in the forestry bureaus of Xilinji, Tuqiang, and Amuer under three different restoration treatments of Artificial Regeneration (AR), Natural Regeneration (NR), and Artificial Promotion (AP) (unit: %)

Restoration treatments	Coniferous species		Broad-leaved species	
	Pinus sylvestris	*Larix gmelini*	*Betula platyphylla*	*Populus davidiana*
(a) Xilinji				
AR	66.67	33.33	0.00	0.00
NR	6.59	10.99	4.40	78.02
AP	76.79	16.07	7.14	0.00
(b) Tuqiang				
AR	91.89	8.11	0.00	0.00
NR	3.67	9.17	86.24	0.92
AP	59.18	6.13	34.69	0.00
(c) Amuer				
AR	38.05	61.95	0.00	0.00
NR	3.13	10.94	84.61	1.32
AP	16.67	77.78	5.55	0.00

Table 2. Tests of between-subjects effects (ANOVA) in the structural parameters (Tree height, DBH, and Crown width) and LAI. The "Treatment" and "Region" denote three forestry bureaus and three restoration treatments

Source	Type III Sum of Squares	df	Mean Square	F statistics	Significant difference (*p*)
(a) Tree Height					
Treatment	29.233	2	14.617	9.294	0.031^{*}
Region	1.202	2	0.601	0.382	0.705
Error	6.291	4	1.573		
(b) DBH					
Treatment	85.203	2	42.601	29.488	0.004^{**}
Region	3.018	2	1.509	1.044	0.432
Error	5.779	4	1.445		
(c) Crown Width in N-S					
Treatment	3.528	2	1.764	5.288	0.075
Region	2.004	2	1.002	3.003	0.160
Error	1.334	4	0.334		
(d) Crown Width in W-E					

Treatment	3.351	2	1.676	7.603	0.043*
Region	0.712	2	0.356	1.616	0.306
Error	0.882	4	0.220		
(e) LAI					
Treatment	3.551	2	1.775	22.571	0.007**
Region	0.112	2	0.056	0.711	0.544
Error	0.315	4	0.079		

* $0.01 < p <= 0.05$; ** $p <= 0.01$.

Figure captions

Fig. 1. The location of the study area in the Greater Hinggan Mountain area. The background is the mosaic of two Landsat TM scenes representing the burned area of the “5.6 Fire” in dark color.

Fig. 2. The spatial distribution of the experimental sites and survey plots within the burned forest area of the “5.6 Fire”.

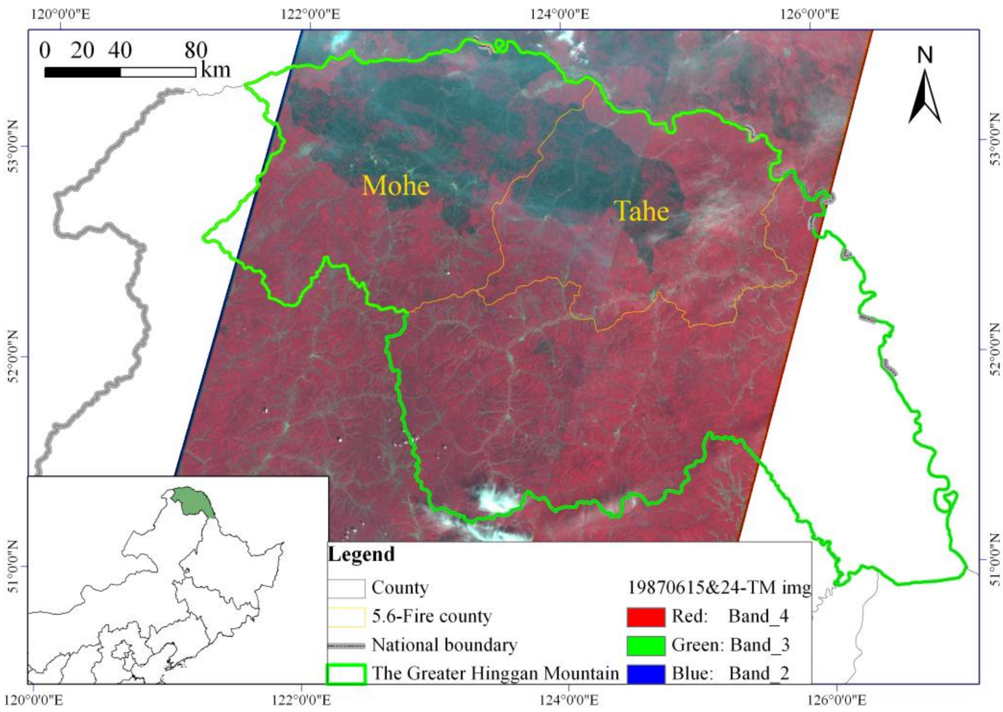
Fig. 3. The statistics (mean±S.D.) and comparison of tree height in different regions under different restoration treatments. The letters a and b indicate the results of multiple comparison.

Fig. 4. The statistics (mean±S.D.) and comparison of Diameter at Breast Height (DBH) in different regions under different restoration treatments. The letters a and b indicate the results of multiple comparison.

Fig. 5. The statistics (mean±S.D.) and comparison of crown width in N-S direction in different regions under different restoration treatments.

Fig. 6. The statistics (mean±S.D.) and comparison of crown width in W-E direction in different regions under different restoration treatments. The letters a and b indicate the results of multiple comparison.

Fig. 7. The statistics (mean±S.D.) and comparison of Leaf Area Index (LAI) in different regions under different restoration treatments. The letters a and b indicate the results of multiple comparison.



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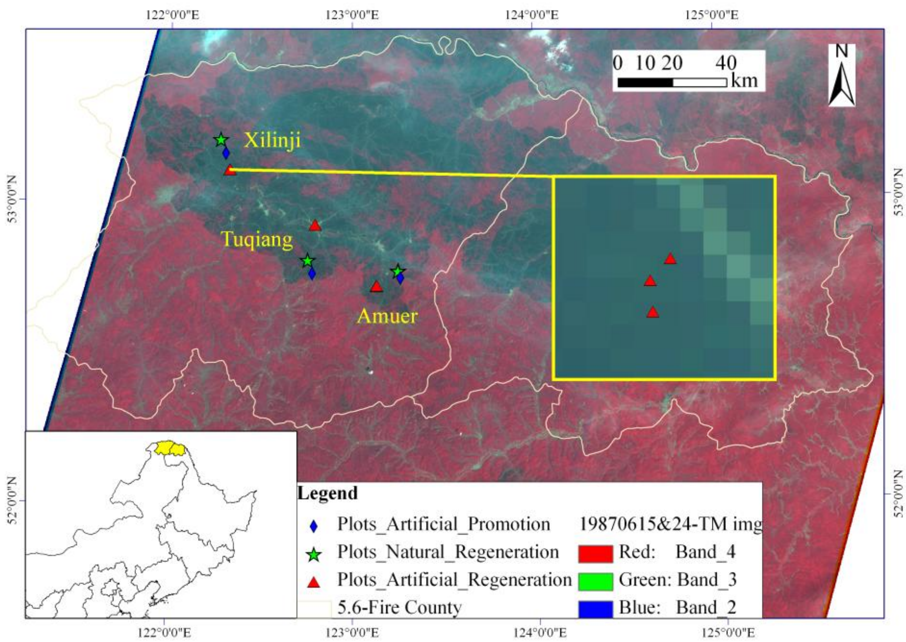

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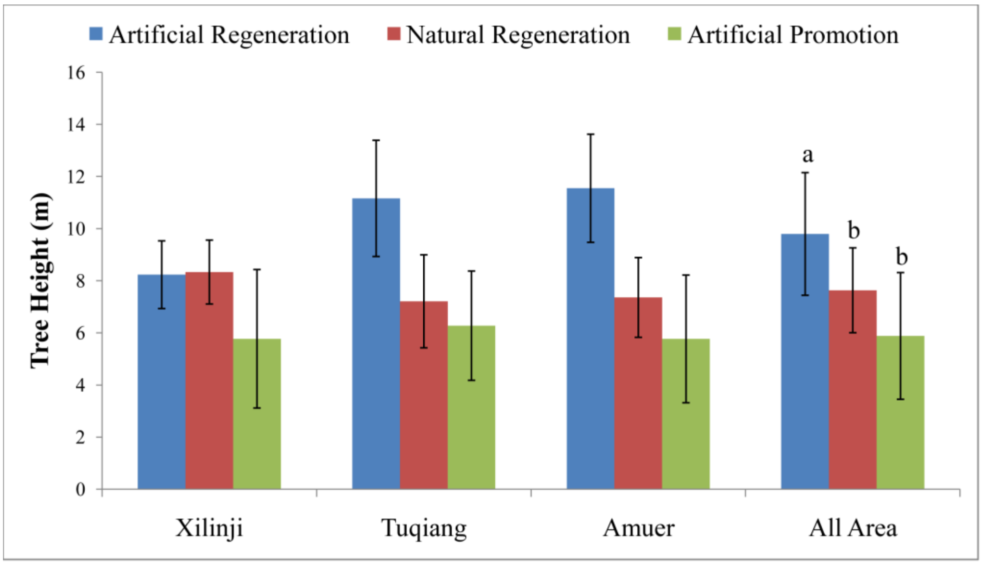
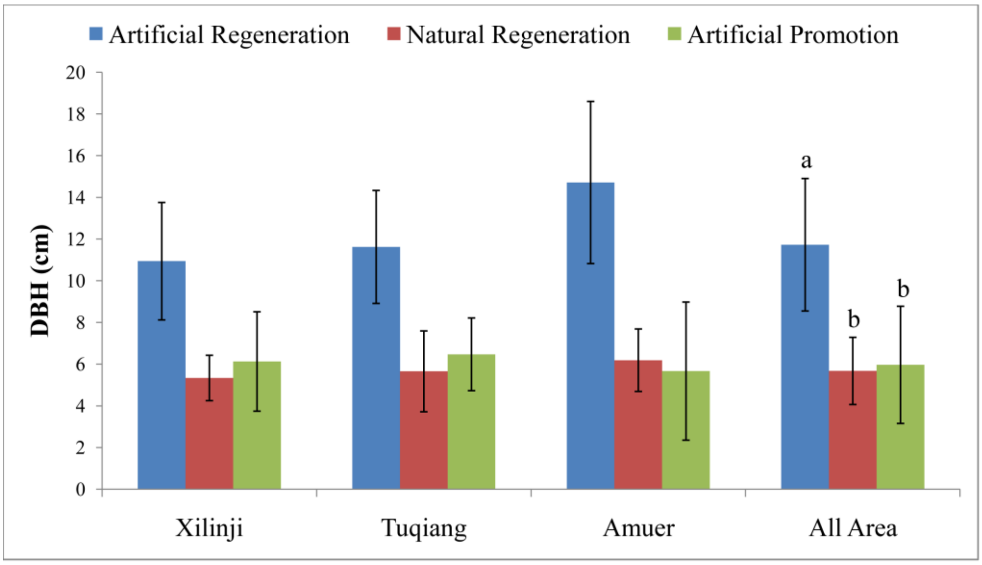


Fig. 3. The statistics (mean±S.D.) and comparison of tree height in different regions under different restoration treatments. The letters a and b indicate the results of multiple comparison.



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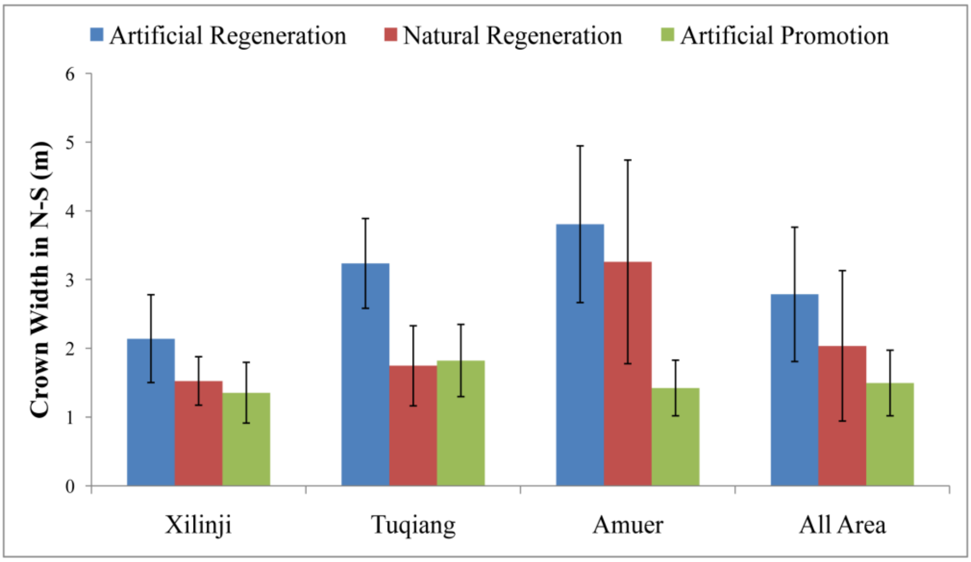

Fig. 5. The statistics (mean±S.D.) and comparison of crown width in N-S direction in different regions under different restoration treatments.

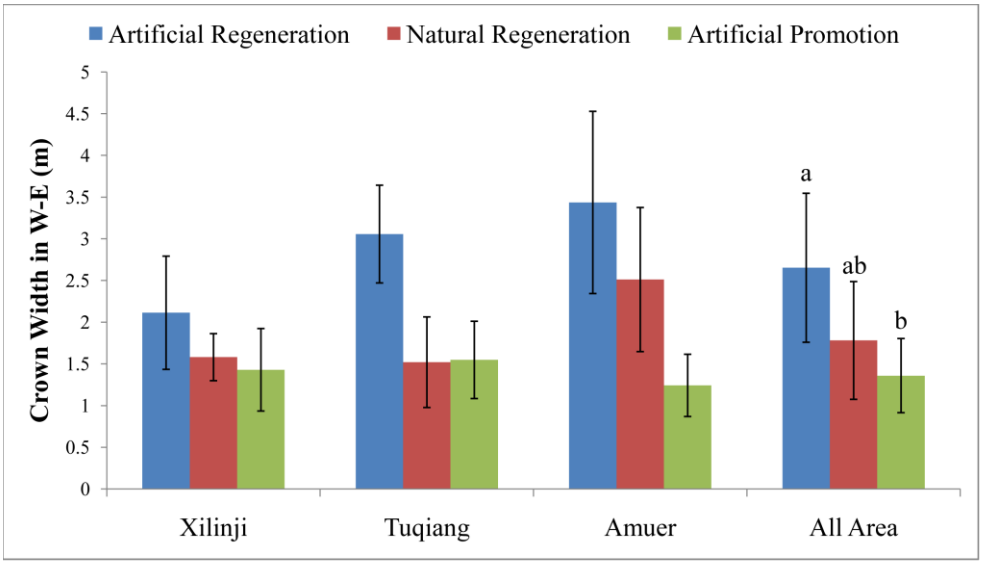

Fig. 6. The statistics (mean±S.D.) and comparison of crown width in W-E direction in different regions under different restoration treatments. The letters a and b indicate the results of multiple comparison.

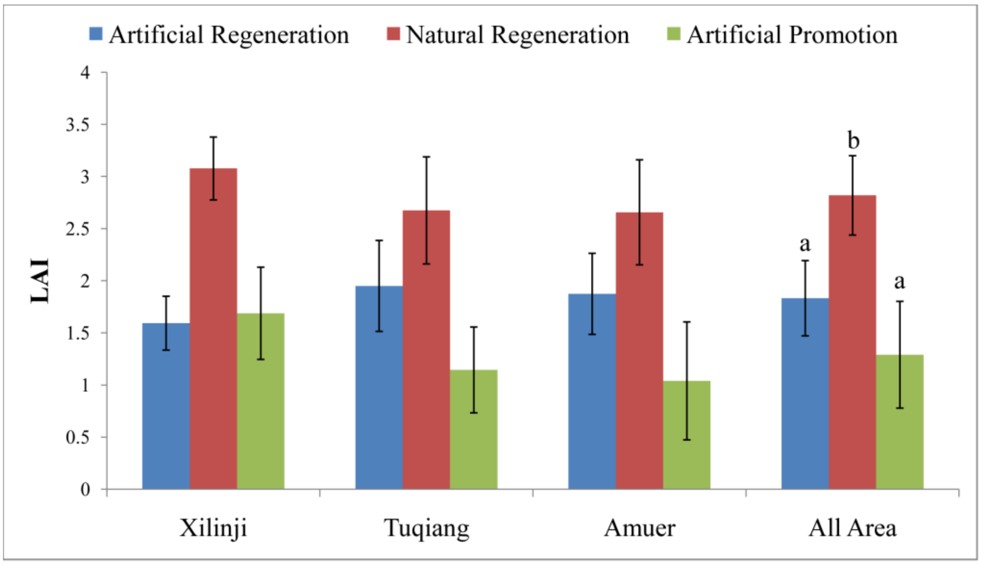

Fig. 7. The statistics (mean±S.D.) and comparison of Leaf Area Index (LAI) in different regions under different restoration treatments. The letters a and b indicate the results of multiple comparison.