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Simulating Impact of Larch Caterpillar (*Dendrolimus superans*) on Fire Regime and Forest Landscape in Da Hinggan Mountains, Northeast China

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Abstract: Larch caterpillar (*Dendrolimus superans*) is very common in the Da Hinggan Mountains, Northeast China, affecting fire regime and forest ecosystem change at large spatio-temporal scales. In this study, we used a spatially explicit landscape model, LANDIS, to simulate the changes of fire regime and forest landscape under four larch caterpillar disturbance intensity levels scenarios in Huzhong forest area, northern of Da Hinggan Mountains. The results indicate that larch caterpillar disturbances would decrease fine fuel load and increase coarse fuel load in the 300 simulation years. Larch caterpillar disturbances would decrease fire frequency in the first 200 years, and the disturbances also decrease fire intensity and fire risk in the early and late stage of simulation. Larch caterpillar disturbances would decrease the area percent of larch cohorts and increase the proportion of white birch, and increase the degree of aggregation of white birch as a result of its strong seed dispersal and colonization ability. Disturbances would also decrease the mature and over-mature larch cohorts and increase all cohorts of white birch, especially the mature and over-mature cohorts. Larch caterpillar disturbances will decrease the stability of forest landscape, therefore, some measures preventing insect outbreak and ensuring the sustainable management of forest ecosystem should been taken in the study area.
Keywords: forest landscape; larch caterpillar; fire; disturbance; LANDIS model

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1 Introduction

Disturbance events exert a strong influence on forest structure, composition, and diversity by killing trees and altering the availability of plant resource (Connell, 1978; White, 1979; Gan, 2004). Many ecosystems are affected by multiple disturbances that create various impacts on forest landscape (Kulakowski and Veblen, 2002), and the disturbances are now considered as an essential driving force for forest ecosystem diversity and stability (Platt *et al*., 2002). Many researches focused on the natural and human disturbances on the forest, such as fire (He and Mladenoff, 1999), harvest (Gong *et al*., 2006) and wind (Rammig *et al*., 2007), but few studies examined the role of insect on fire regime and forest landscape, possibly due to the fact that large-scale spatial-temporal data on insect outbreak were difficult to obtain.

Biological disturbances, such as insect and disease outbreaks, are critically important agents of forest change (Breece *et al*., 2008), causing tree mortality at scales ranging from individual tree to entire regions. Damage caused by biotic agents can dwarf other natural disturbances (Fleming *et al*., 2002), and interact synergistically with fire disturbance by greatly enhancing fuel loading and the risk of high-intensity fires (Hessburg *et al*., 2008). Due to their host-specificity, biotic disturbances are also sensitive to host abundance and land-

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scape distribution, and therefore likely respond to feedback associated with forest succession and change (Bergeron and Leduc, 1998). Depending on their extent, these disturbances have important and long-lasting consequences for long-term forest composition and pattern at landscape scales (Hessburg *et al*., 2008). Fire is the most important natural disturbance in the forest ecosystem. It is well known that natural fire is a key process in regulating vegetation succession, plant regeneration, and maintain biodiversity in many forest ecosystems (Gardner *et al*., 1999). Some studies have explored the effect of forest insect disturbances on fire regime. For example, linear regression model have been used to analyze the relationship between the smoke height of poles and the amount of insects (Wang *et al*., 2005; Waldron *et al*., 2007). Results showed that stands damaged by spruce budworm would become more vulnerable to wildfires (Stocks, 1987; Candau and Fleming, 2005).

The cold temperate coniferous forests ecosystems of the Da Hinggan Mountains, Northeast China produce the more timber and woody supplies for the country than other forested regions (Zhou, 1991; Xu, 1998). However, the cold temperate coniferous forest has changed dramatically since 1965 as a result of natural and human disturbances. As the virgin forest is transformed into secondary forest, the insect disturbances become more serious than before and fire also departure from the historical state significantly (Chang *et al.*, 2007). In the past 50 years, there are many kinds of forest defoliators presenting in the Da Hinggan Mountains of northeastern China, such as larch caterpillar (*Dendrolimus superans*), larch webworm (*Laspeyresia Zebeana*), larch casebearer (*Coleophora dahuric*), and they can destroy the needles of stand, even kill the stand when breakout seriously (Zhang and Sen, 1999). However, little attention has been paid to the influence of insect disturbances on the change of fire regime and forest landscape in this area.

In this paper, we used forest landscape disturbance and succession (LANDIS, version 4.0) model to simulate the change of fire regime under different insect disturbance scenarios, and analyze the change of forest landscape during a 300-year peroid in the Da Hinggan Mountains, Northeast China. Species composition, age structure, and spatial pattern of forest landscape at the large spatial-temporal scale were considered under different scenarios. We aimed to illustrate: 1) how larch caterpillar influences the change of fuel load and fire regime; 2) how forest landscape dynamics respond to different insect disturbance intensity.

2 Study Area and Methodology

2.1 Study area

The study area is located in Huzhong forest area, northern of Da Hinggan Mountains, Northeast China, with a total area of 937244 ha (Fig. 1). It falls within the cold temperate climate zone with a mean annual temperature of –4.7℃, and monthly mean temperature ranging from –28.9℃ in February to 17.1℃ in July. The mean annual precipitation is about 500 mm, with great inter-annual variations, and more than 60% of rainfall occurs between June and August. Uplands and small hills occupy this region, though it has a relatively smooth topography. Slopes are generally less than 10° with the maximum slope less than 35°. Hills fluctuate throughout this area, and the mountain range mostly runs in east to west directions, elevation ranges from 500 m to 1000 m. The brown coniferous forest soil is representative in the study area. The vegetation of this area is classified as cool temperate coniferous forests, which are the southern extension of eastern Siberian boreal forests. The forest area accounts for 86.98% of the study area and the canopy species composition is relatively simple. The dominant tree species are larch (*Larix gmelini*) and white birch (*Betula platyphylla*). Other species, including Mongol Scotch pine (*Pinus sylvestris* var. *mongolica*), spruce (*Picea koraiensis*), two species of aspen (*Populus davidiana*, *Populus suaveolens*), and willow (*Chosenia arbutifolia*) cover less than 5% of the study area, and Siberian dwarf pine (*Pinus pumila*) occurs mostly in areas with elevation higher than 800 m (Hu *et al*., 2004).

2.2 LANDIS model

LANDIS is a spatially explicit forest landscape succession and disturbance model that facilitates the study of the effects of natural and human disturbances, vegetation succession, and management strategies on forest landscapes (Mladenoff *et al.*, 2004). LANDIS, composed of fire, fuel, harvest, wind and biological disturbance agent (BDA) module, has been successfully used in a variety of locations (Shifley *et al*., 2000; Franklin

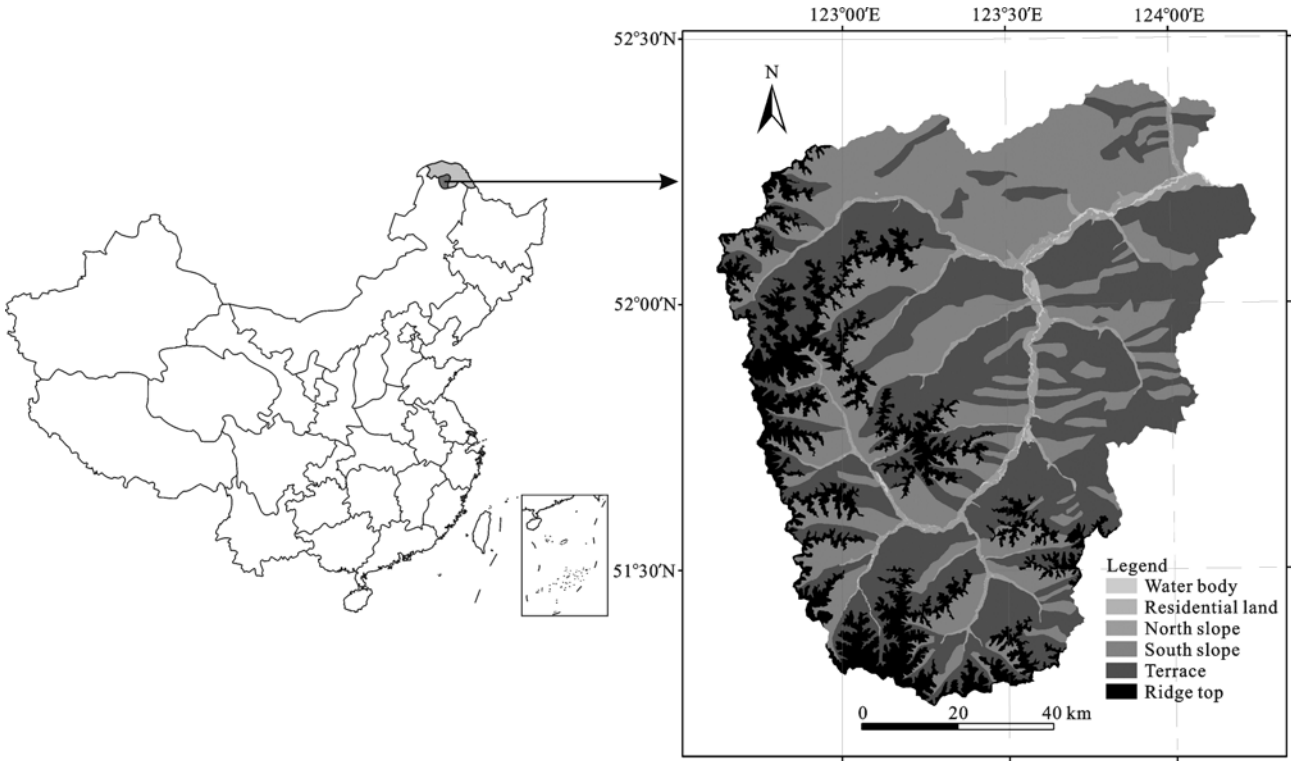

Fig. 1 Location and land type map of study area

et al., 2001; Birt *et al*., 2009), and it is a raster-based model that simulates species bourgeon, growth, death, regeneration, random mortality, and vegetative reproduction based on species establishment coefficients and species vital attributes at the cell scale (He *et al*., 2002). Meanwhile, in LANDIS, a heterogeneous landscape is organized as grid of cells, with vegetation information stored as attributes for each cell, and cell size varies from 10 m to 500 m depending on the scale of study areas. LANDIS stratifies a heterogeneous landscape into different land types which are generated from GIS layers of climate, soil or terrain attributes (slope, aspect and landscape position). It is assumed that a single land type contains a somewhat uniform suite of ecological conditions, resulting in similar species establishment patterns and fire disturbance characteristics, fuel decomposition rates, and similar influence on the insect outbreak coefficient (He and Mladenoff, 1999; Sturtevant *et al*., 2004).

2.3 Data

2.3.1 LANDIS parameterization

LANDIS (version 4.0) involves both spatial and non-spatial parameters (He *et al*., 2004). The main spatial parameters include two maps. One is forest composition map that contains information of species and their age cohorts, and the other is land type map which contains a somewhat uniform suite of ecological conditions, resulting in similar insect disturbance intensity and mean fire return intervals. Non-spatial parameters include the vital attributes for each species simulated and disturbance regimes. The available data for parameterization of LANDIS consist of forest stand map and attribute database compiled from the forest inventory of 1990 in the Huzhong forest area, two Landsat TM scenes take in 1990, insect and fire records from 1990 to 2000, and a digital elevation model (DEM) generated from the contour lines delineated by the general staff of the Chinese Army from aerial photographs measured in 1971.

2.3.2 Vital attribute of species and forest composition

The forest composition map generated from 1990 forest stand map was incorporated into LANDIS. The tree attributes of eight species are shown in Table 1. The assignation of species and age cohorts for each cell is as following. It was assumed that all tree species randomly distributed in a stand but in different proportion based on forest inventory. For the dominant species, they were assigned in every cell, and for the non-dominant species, the probability of distribution was determined by the relative occurrence of the species (0–1) based on the combination of species and age cohorts in each stand map, we derived a forest composition map which contained individual species and species′ age class distributions for the study area. The forest composition map was specified to the resolution of 90 m × 90 m, which yielded 1480 rows × 1274 columns.

2.3.3 Land type map

LANDIS stratifies the heterogeneous landscape into relatively homogeneous units (land types or ecoregions), similar environments for species establishment are assumed in the same land type (Mladenoff *et al*., 2004). In this study, we derived six land types primarily based on the terrain attributes (Fig. 1), which were interpreted from the 1990 TM imagery and DEM. Non-active land types (not simulated in LANDIS), including water body and residential land, account for 0.76% of the total area. Active land types, including terrace, south slope, north slope and ridge top, account for 4.78%, 37.25%, 42.53%, 14.68% of the total area, respectively. To reduce the simulation time of LANDIS, land type map was also resample to the resolution of 90 m × 90 m. Based on the environmental conditions, each land type had the same species establishment coefficient (Table 2).

2.4 Fire regimes and larch caterpillar parameters

Fire and larch caterpillar are crucial disturbances to the forest landscape. In the study area, the most serious insect is the larch caterpillar with 10-year outbreak cycle, and the dispersal distance about 1000 m/yr (Chen, 1990), and 24-element had been used to represent the influence of neighborhood forest (Sturtevant *et al*., 2004). The host preference parameter provides a flexible method for defining the age range at which a given species exists within a given host preference class. For example, larch become hosts in the youngest, secondary hosts at ages of 20–40, and reach primary host status by age 50–160 (Sturtevant *et al*., 2004). Since Mongol Scotch pine is considered as a secondary host, it never reaches primary host status (Zhang and Zeide, 1999). The fire regime (e.g., mean return interval, mean fire size) for our simulations was parameterized based on a fire database from 1990 to 2000 in the study area (Chang *et al*., 2007). Forest fuel has two distinct types: fine fuel and

Table 1 Vital attributes of species in study area

Species	LONG	MTR	ST	FT	ED	MD	VP	MVP
Larch (*Larix gmelini*)	300	20	3	4	100	200	0	0
Mongol Scotch pine (*Pinussylvestris* var. *mongolica)*	210	40	1	2	50	200	0	0
Spruce *(Picea koraiensis)*	300	30	5	2	50	150	0	0
White birch (*Betula platyphylla*)	150	15	1	3	200	2000	0.8	40
Aspen-d (*Populus davidiana)*	180	30	1	3	–1	–1	1	40
Aspen-s (*Populus suaveolens*)	150	25	1	5	–1	–1	1	40
Willow (*Chosenia arbutifolia*)	250	30	2	2	–1	–1	0.9	30
Siberian dwarf pine (*Pinus pumila*)	250	30	3	1	50	100	0	0

Notes: ED, effective seeding distance (m); FT, fire tolerance class (1 to 5, with 1 for the least tolerant and 5 for the most tolerant); LONG, longevity (yr); MD, maximum seeding distance (m); MTR, age of maturity (yr); MVP, minimum age of vegetative reproduction (yr); ST, shade tolerance class (1 to 5, with 1 for the most shade intolerant and 5 for the most shade tolerant); VP, vegetative reproduction probability
Sources: Gong *et al*., 2006; Chang *et al*., 2007

Table 2 Attributes for each land type of study area

Land type	Species establishment coefficients								LTM
	Larch	Mongol Scotch pine	Spruce	White birch	Aspen-d	Aspen-s	Willow	Siberian dwarf pine	
South-facing slope	0.40	0.20	0.03	0.30	0.20	0	0	0	0.66
North-facing slope	0.40	0.10	0.05	0.20	0.20	0	0	0	–0.16
Ridge top	0.30	0.08	0	0.05	0	0	0	0.10	–0.16
Terrace	0.01	0	0	0.05	0.05	0.07	0.20	0	0.33

Note: LTM, ranging between –1 and 1, indicates that land types modify the occurrence of larch caterpillar
Sources: Zhao *et al*., 1997; He *et al*., 2002; Chang *et al*., 2007

coarse fuel. Fine fuels are primarily foliage litter fall and small dead twigs falling from live trees. Coarse fuels, also called coarse woody debris (CWD), include any dead tree materials that have a diameter ≥ 7.6 cm (He *et al*., 2004), and fuel load was classified form 1 to 5, and 5 represented the highest fuel load.

2.5 Simulation scenarios and data analysis

We started with the realistically parameterized forest composition and land type map with species/age classes that represented the initial status in 1990. Then four disturbance intensity scenarios: light biological disturbance (cause less than 1% forest dead), moderate biological disturbance (cause 1%–5% forest dead), severe disturbance (cause more than 5% forest dead), and non disturbance (P), were simulated by LANDIS over a 300-year period, and each scenario was simulated with five replication (He *et al*., 2002). We used APACK tools to analyze the change of fire regime and forest landscape, and ANOVA analysis by SPSS (13.0). The change of fuel load, fire frequency, fire intensity, fire risk and forest landscape under different larch caterpillar outbreak intensity scenarios, were present in our simulation. For a clear presentation change of forest landscape, we analyzed two representative species: larch and white birch. Larch is a late successional, climax and coniferous species, while white birch is an early successional, pioneer and broad leaf species.

3 Results and Analyses

3.1 Effects of larch caterpillar outbreak intensity on forest fuel

Rresults of ANOVA show that larch caterpillar disturbances significantly affect the fine fuel load in the first 200 years ($p < 0.01$). Under the light scenario, the fine fuel increases to about 3 classes in the first 100 years, and then decreases to 2 classes at the 200th year. The fine fuel load under light scenario is higher than those under the moderate and severe scenarios, and the fine fuel load under moderate scenario is higher than that under the severe scenario (Fig. 2). This might be the reason that the larch caterpillar under the moderate and light scenarios damage many stands needles and the fine fuel are also consumed by the larch caterpillar, so larch caterpillar disturbance would decrease fine fuel load in the simulation.

Coarse fuel varies with fuel accumulation time and disturbance history, which corresponds to the biological disturbance in this study without wind throw, harvest and planting. With the extension of simulation time, the coarse fuel load increases gradually to 4 classes (Fig. 3). The results of ANOVA indicate that larch caterpillar disturbances significantly affect the coarse fuel load ($p <$ 0.01). The coarse fuel load under severe scenario is higher than those under other scenarios in the first 250 years, and it may be the reason that larch caterpillar disturbances cause mortality of some susceptibility trees, which provides more coarse fuel.

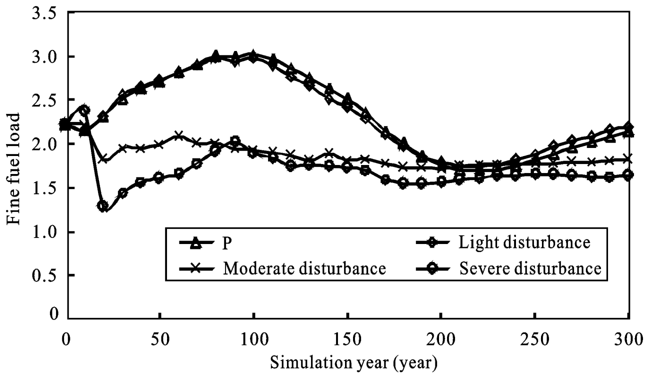

Fig. 2 Change of fine fuel load in different disturbance scenarios

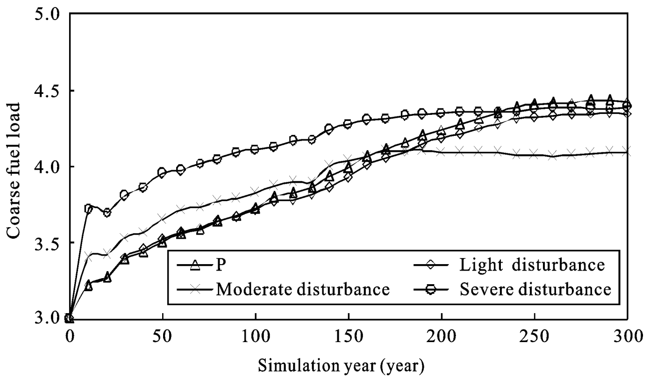

Fig. 3 Change of coarse fuel load in different disturbance scenarios

3.2 Effect of larch caterpillar outbreak intensity on fire regimes

Results of ANOVA show that larch caterpillar disturbances significantly affect the potential fire frequency in the first 200 years ($p < 0.01$), and mean fire frequencies under the P and light scenario are higher than those under moderate and severe scenarios in the first 200 years (Fig. 4). It is probably because larch caterpillar decrease the fine fuel load of the forest, and fine fuel is the major factor influencing fire frequency. Moderate and severe larch caterpillar disturbances might decrease the fine fuel load, and stimulate the proliferation of small non-woody understory, and non-woody understory would increase the air moisture of forest, therefore, the larch caterpillar disturbance would decrease the fire frequency. However, in the later 100 years, with the forest succession, there is not obvious distinction of fire frequency among different scenarios.

Fire intensity is determined by the combination of fine and coarse fuel load in each cell, and fire intensity is derived from the interactions of species fire tolerance and species fire susceptibility (He *et al*., 2004). The results of this study show that larch caterpillar disturbances significantly affect the potential fire intensity ($p < 0.01$). Under P and light disturbance scenarios, the fire intensity fluctuates between 2 and 3 classes, and fire intensity under light scenario is higher than those under severe and moderate scenarios in the first 150 years and later 220 years. However, under the moderate and severe scenarios, the potential fire intensities are approximate, except during 70–150 years (Fig. 5). It indicates

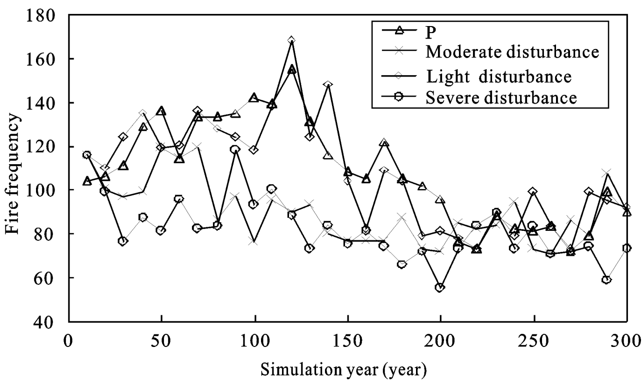

Fig. 4 Change of fire frequency in different disturbance scenarios

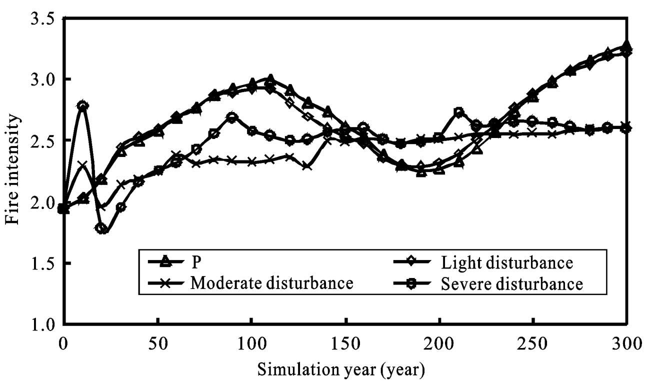

Fig. 5 Change of fire intensity in different disturbance scenarios

that larch caterpillar decrease the fire intensity in the early stage and late stage, and increase the fire intensity in the middle stage in this study.

The results of ANOVA show that larch caterpillar disturbances significantly affect the potential fire risk ($p < 0.01$). In the first 20 years, the potential fire risk fluctuates widely. Potential fire risk under the light scenario is higher than those under the severe and moderate scenarios in the first 150 years and later 220 years. In the different simulation scenarios, the highest potential fire risk occurs under the light scenario, and the lowest potential fire risk occurs under the P scenario (Fig. 6), and the potential fire risk under moderate and severe scenarios is similar. The results show that larch caterpillar decrease the potential fire risk in early and late stages, and increase the potential fire risk in the middle stage of the simulation period.

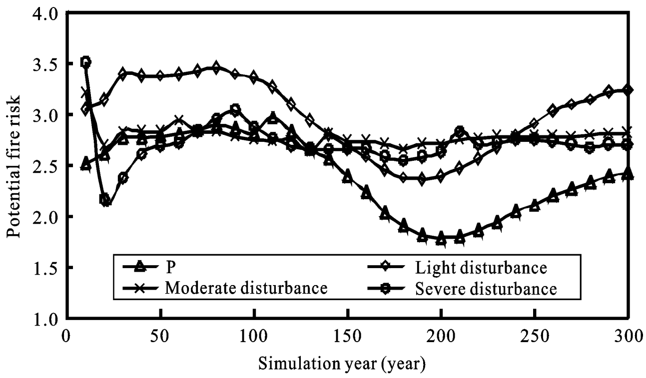

Fig. 6 Change of potential fire risk in different disturbance scenarios

3.3 Change of forest landscape

3.3.1 Species composition

Results of ANOVA show that the larch caterpillar disturbance can significantly affect the area percent of larch forest ($p < 0.01$). The area percent of larch under P and light scenario are similar, and area percent of larch in the light scenario is the highest, and the area percent of larch forest under moderate scenario is higher than that under severe scenario (Fig. 7a). It might be the reason that larch is the major food source for the larch caterpillar in the study area, and many larch trees would be damaged by the larch caterpillar (Liu, 1994). However, the change tendency of white birch forest is different. The area percent of white birch under severe scenario is the highest (Fig. 7b), the reason for this might be that larch caterpillar cause the death of many larch forest,

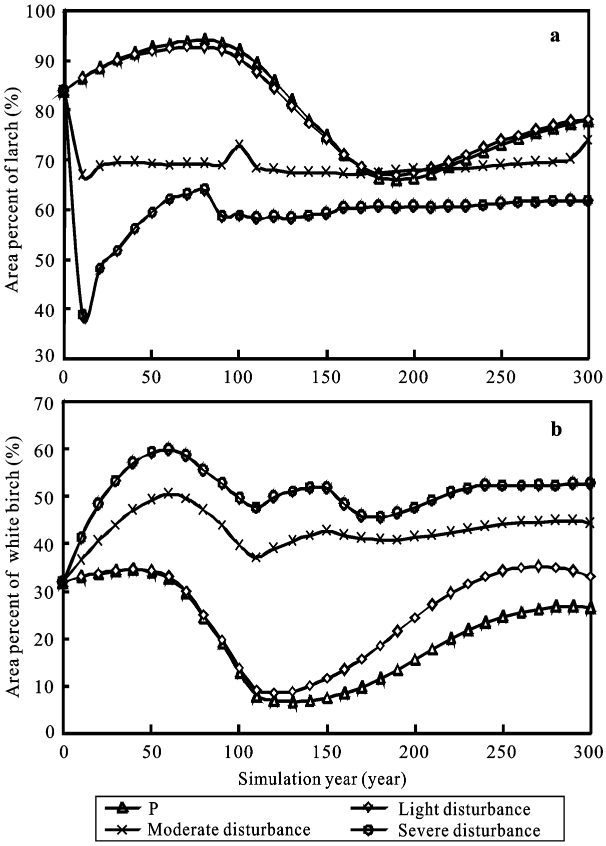

Fig. 7 Area percent of larch and white birch in different disturbance scenarios

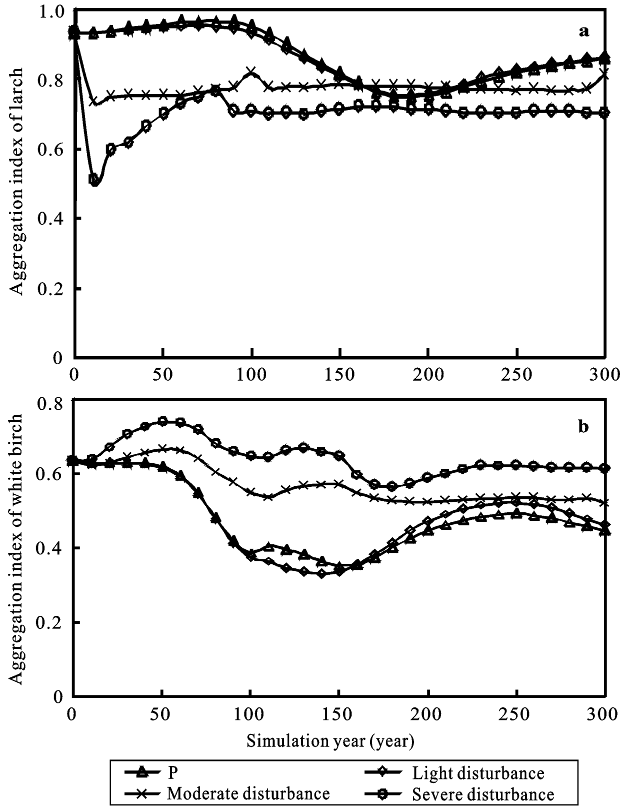

Fig. 8 Aggregation index of larch and white birch in different disturbance scenarios

and the vacant would be occupied by white birch as soon as possible, as a result of their strong dispersal and colonization ability (Rousi and Pusenius, 2005). Therefore, larch caterpillar disturbance increase the area percent of white birch in the study area.

3.3.2 Aggregation degree for dominant species

The aggregation index (AI) represents the species aggregation degree in the forest landscape, and the higher of AI, the higher of species aggregation (He *et al*., 2000). The results of this study show that the larch caterpillar disturbance significantly affects the AI of larch and white birch ($p < 0.01$). The AI values of larch under P and light scenarios are higher, and it is higher under moderate scenario than severe scenario (Fig. 8a). The AI values of white birch under severe scenario are higher than those under moderate and light scenarios (Fig. 8b). Larch caterpillar caused the death of many larch trees, and white birch and other pioneer tree species occupy the vacant, therefore, the AI value of larch forest decreases due to the larch caterpillar disturbances, and disturbances increase the AI value of white birch.

3.3.3 Age structure for dominant species

According to the classification standard of age structure in the Da Hinggan Mountains (Hu *et al*., 2004), five age classes (seedling, middle-aged, quasi-mature, mature, and over-mature) of coniferous and broad-leaved species were sorted (Table 3). The results reveal that the species age structure respond distinctly under different larch caterpillar disturbance intensity scenarios. Different levels of larch caterpillar disturbance have significant effects on age structure of larch, and there are more seedlings and middle-aged cohorts under light scenario than moderate and severe scenarios (Fig. 9). The age structure of white birch also has clear differences under different larch caterpillar disturbance intensity scenarios. Disturbance increases all cohorts of white birch, especially the proportion of mature and over-mature cohorts (Fig. 10). It is probably due to more open space created by the death of larch forest resulted from larch caterpillar disturbance, and there are more mature and over-mature cohorts of white birch under moderate and severe scenarios along with forest succession.

Table 3 Age cohorts classification

Tree species	Seedling	Middle-aged	Quasi-mature	Mature	Over-mature
Coniferous species	< 40	41–80	81–100	101–140	> 140
Broad-leaved species	< 30	31–50	51–60	61–80	> 80

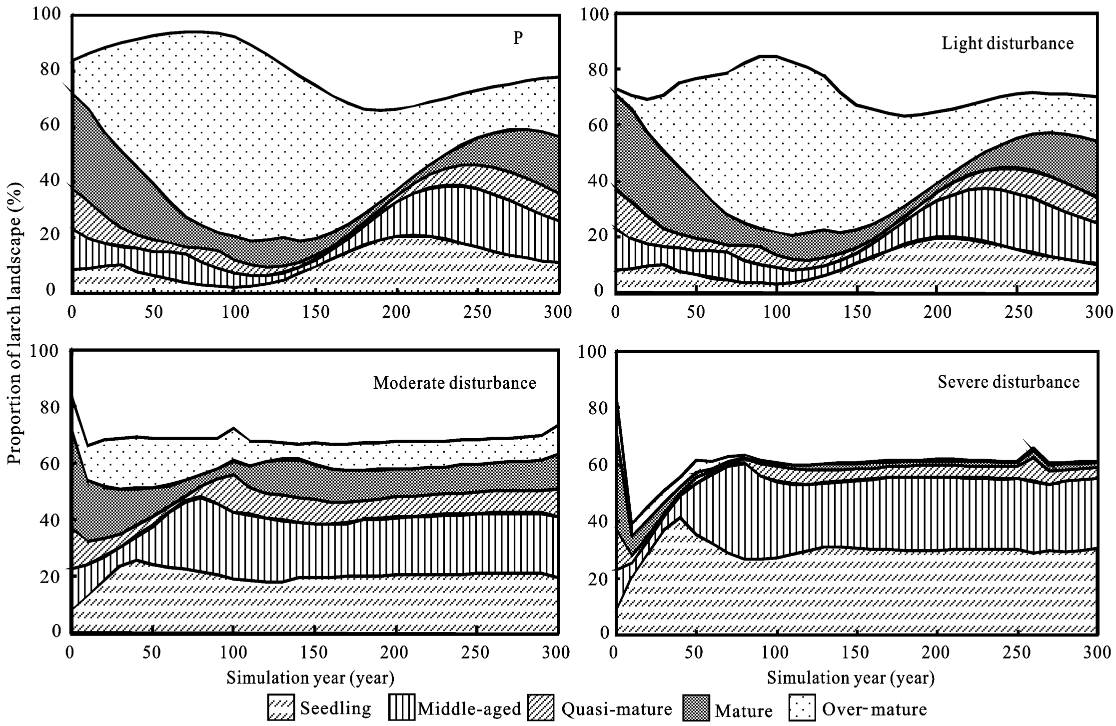

Fig. 9 Species age cohort composition of larch in different disturbance scenarios

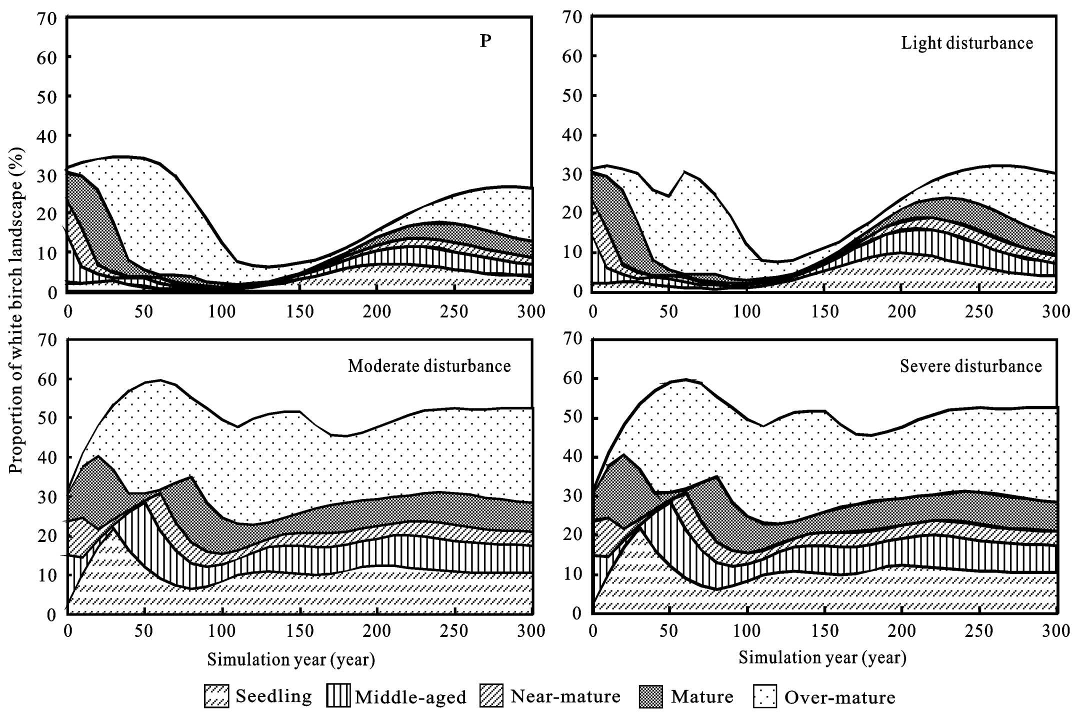

Fig. 10 Species age cohort composition of white birch in different disturbances scenarios

4 Discussion

4.1 Influence of larch caterpillar disturbance on fuel and fire regime

Larch caterpillar feed on needles and twigs of larch forest, so the larch caterpillar disturbances decrease the fine fuel load during our simulation course (Liang *et al.*, 1996). Moreover, the results of previous study indicate that fine woody fuel decrease dramatically in stands following the insect outbreak epidemic and gradually begin to increase again in post-epidemic stand (Jenkins *et al.*, 2008). Meanwhile, we found that larch caterpillar disturbance will increase the coarse fuel load because larch forest are damaged and form more snags or standing dead trees, and this is similar to the results from previous researches (Stocks, 1987; Schoennagel *et al.*, 2004). A considerable body of empirical research has studied the forest insect disturbance on fire regime, and the results indicated that breakage of dead tree tops gradually build up an accumulation of 'ladder fuels' in a stand, which provides small surface fires access to the canopy, and increase potential fire intensity (Fleming *et al.*, 2002), thus larch caterpillar disturbance is an important indicator for the forest fire regime. Therefore, we suggest that the insect disturbances should be considered by the forest manager, especially at large spatio-temporal scales (Agee and Skinner, 2005; Agee and Lolley, 2006).

Larch caterpillar disturbances decrease the fire frequency in the first 200 years, and this is consistent with the results of previous studies—high fire frequencies prevent the development of extensive areas of forest heavily populated by insect host tree species (Fleming *et al.*, 2002). However, the results in this study show that there is no significant difference in fire frequency in the later 100 years, probably because forest fire frequency was influenced by other factors, such as meteorology (Schoennagel *et al.*, 2004), topography (Lentile *et al.*, 2006), harvest (Pollet and Omi, 2002) and other human disturbances (Lauzon *et al.*, 2007; Burrows, 2008). In this paper, we concur with the results of previous study, which indicate the important effect of biological disturbance activity on fire risk is through the change of stand structure and composition (Bigler and Kulakowski, 2005). Moreover, identification of the biological disturbance leading to raise the potential fire risk will be needed in further study.

4.2 Change of forest landscape under larch caterpillar disturbance

Simulation results in this study suggest that larch caterpillar disturbances have important implications for the forest succession dynamics in the Da Hinggan Mountains. Species composition and aggregation index are the major indicators of the forest landscape change at the large spatio-temporal scale (Bogaert *et al.*, 2002; Ness and Morin, 2008; Graham *et al.*, 2009). It is found that the proportion of larch is decreased by larch caterpillar disturbance, while for white birch, it is opposite, which is similar to the results of previous study (Liang *et al.*, 1996).

Larch caterpillar disturbances decrease the aggregation degree of larch forest and increase the aggregation level of white birch cohorts. LANDIS model designed by Sturtevant who used biological disturbance agent (BDA) to simulate spruce budworm infestations, projected that greater landscape aggregation would lead to more highly aggregated outbreaks (Sturtevant *et al.*, 2004). Cairns *et al.* (2008) suggested that the aggregation degree of forest that characterizes a landscape influences the severity and extent of insect infestations. The researches results imply that highly aggregated forest landscapes will be characterized by more extensive insect infestations.

Larch caterpillar disturbances decrease the area percent of mature and over-mature cohorts of larch, and increase the area percent of larch seedlings and middle-aged cohorts, because mature and over-mature cohorts of larch forest present more 'food' for larch caterpillar. Larch caterpillar disturbances increase all age cohorts of white birch due to their strong seed dispersal and colonization ability. It is well known that the larch is the climax community in the Da Hinggan Mountains (Xu, 1998), and mature cohorts are more stable than seeding and middle-aged cohorts, thus larch caterpillar disturbances decrease the stability of forest landscape. Therefore, some measures to prevent insect outbreak should be carried out in the study area.

4.3 Result validations

A significant challenge facing spatially explicit forest landscape models is how to validate the simulation results. Validation in the traditional sense involves using independent data at a given time and space to check against model predictions for that time and space. However, landscape models such as the one presented in this study derive results for a large landscape, over a long period of time. Since landscapes are not spatially replicable and the temporal dimensions of model simulation often go beyond the experimental and field observations collected (Turner *et al*., 2001), model validation in the traditional sense is not applicable for spatially explicit landscape models (Rykiel, 1996). LANDIS has been subjected to typical model evaluation procedures, including sensitivity analysis, uncertainty analysis, and structural analysis (Mladenoff *et al*., 2004). Loehle (1997) proposed a hypothesis-testing framework for evaluating ecosystem models. This framework emphasizes biological and ecological realism in addition to the typical model evaluating techniques. The results in this study indicate that the distribution of each species conforms to the ecological realism in this region. For example, larch was the absolute dominant tree species, and birch occupied the second layer. The simulation results indicate in the different insect disturbance scenarios and all simulation years, larch was the dominant tree of broad coniferous trees, and white birch was the dominant tree of broad-leaved trees. These results are not predetermined in the model and the model does not have any barrier for these species, so it can be concluded that the LANDIS model is suitable for the study area.

4.4 Some limitations

Some model assumptions may affect the simulation results. For example, in the LANDIS model, once a species is established, mortality occurs only due to disturbance, harvest, insect and fire, reaching longevity through natural succession and small chance of random moralities. Some kinds of stress such as drought are not stimulated in the LANDIS model. LANDIS does not simulate the competition effects of shrubs and herbs on forest recovery (Wang *et al*., 2007), and shrubs or herbs could compete with trees for resource (e.g., light, nutrients). The results of previous studies in the Da Hinggan Mountains indicate that shrubs and herbs rapidly occupy the open spaces, and shrubs or herbs are favorable for the reproduction of larch caterpillar. For example, some larch caterpillars survive over winter in the litter, and climb on the trees and foraging and feeding the leaves in the next year.

5 Conclusions

In this paper, we used the spatially explicit landscape model, LANDIS, to simulate the changes of fire regime and forest landscape under pest disturbance. The results provide insights into fuel and forest dynamics under different disturbances scenarios. In the study area, larch caterpillar disturbance decrease the fine fuel load and increase the coarse fuel load. Disturbance decreases the fire frequency in the first 200 years, and it also decrease fire risk and fire severity in the early and late stage. In addition, disturbance decreases the larch proportion and increases white birch proportion at large spatio-temporal scale, disturbance also decreases the aggregation level of larch cohorts, and increases the aggregation level of white birch for their strong seed dispersal and colonization ability. With the increase of disturbance intensity, the proportions of mature and over-mature larch cohorts would decrease, while those of all cohorts of white birch would increase. Other nature or human factors, such as the global climate change, harvest behavior, would influence the disturbance and forest succession. These factors were not considered in this study, and the researches will be developed in the future.

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