Effects of Cessation of Commercial Logging on Forest Structure and Aboveground Biomass in the Greater Khingan Mountains: Postprint

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Abstract

Logging is one of the most significant anthropogenic disturbances in boreal forests; past high-intensity logging has led to simplification and homogenization of forest vegetation composition. To enhance the ecological functions and economic benefits of forests, the state successively implemented the "Natural Forest Resource Protection Project" in 2000 and a complete ban on commercial logging of natural forests in 2014. To evaluate the direct impacts of different logging disturbances under these two policies on forests, this study takes the Daxing'anling forest region as the research area and employs the spatially explicit landscape model LANDIS PRO to simulate and compare the long-term dynamics and differences in forest species composition, age structure, and forest aboveground biomass between the "Natural Forest Resource Protection Project" and the complete ban on commercial logging policies from 2000 to 2100. The results indicate that: 1) The initialized stand density and aboveground biomass in the model are consistent with field survey data from 2000 ($P<0.01$), demonstrating high reliability of the model simulation results; 2) Compared with classified management, the implementation of the complete ban on commercial logging: increased the proportion of dominant species (larch and white birch) in species composition, while decreasing the proportion of protected species (spruce and Mongolian pine); exerted significant effects on species composition in the medium to long term ($P<0.05$), reducing the diversity of species composition structure; overall increased stand mean basal area while decreasing stand density; 3) Over the 100-year simulation period, the complete ban on commercial logging facilitated the transition of young and middle-aged forests to mature forest, thereby improving forest age structure; 4) Compared with classified management, the complete ban on commercial logging increased forest aboveground biomass and enhanced forest recovery rate throughout the simulation period, contributing to the restoration and accumulation of total forest aboveground biomass. However, the aboveground biomass of protected species (spruce and Mongolian pine) declined to some extent, which is detrimental to increasing the abundance of valuable species. These findings provide important reference value for evaluating the role of forest management scenarios in forest resource restoration and for effectively implementing forest ecosystem management.

Full Text

Preamble

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Long-term effects of commercial harvest exclusion on forest structure and aboveground biomass in the Great Xing' an Mountains, China
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Abstract

Forests are the dominant component of terrestrial ecosystems, providing critical ecological, economic, and social services. The boreal forests of the Great Xing'an Mountains represent the southern extension of the Eurasian boreal forest zone,

constituting 24%-31% of China' s total forest area and volume, and serving as a major timber production base and ecological barrier. Boreal forests at mid-to-high latitudes are highly sensitive to natural and anthropogenic disturbances, with timber harvesting being one of the most significant human impacts that alters forest species composition, distribution patterns, and carbon storage. Historical high-intensity harvesting has led to forest vegetation simplification and homogenization.

To address natural forest resource conservation and restoration, China implemented the Natural Forest Conservation Program (hereafter "Conservation Program") in 2000, which established a classification management system with selective harvesting focused on ecological benefits. Studies have shown that this program improved forest quality and facilitated effective vegetation recovery. To further promote rapid natural forest restoration and development, the central government proposed the complete cessation of commercial harvesting in natural forests (hereafter "Harvest Exclusion") in 2014, shifting from regional clear-cutting to tending operations only. However, critical questions remain unanswered: Can Harvest Exclusion further improve forest species composition? Can it increase forest distribution area and promote aboveground biomass recovery? Will both dominant and valuable species recover? Forest succession and its response to disturbance are long-term processes occurring over decades to centuries, necessitating long-term assessments of the new policy' s potential effects.

This study employs the spatially explicit landscape model LANDIS PRO, a mainstream international tool for studying long-term forest landscape dynamics, to simulate the long-term impacts of Harvest Exclusion on the Great Xing' an forest landscape. We aim to evaluate the ecological benefits of Harvest Exclusion and provide references for developing reasonable forest management strategies.

Key findings:
1) Model initialization using 2000 forest inventory data (second and third tier) showed strong consistency with actual 2000 landscape conditions (stand density and biomass, $P < 0.01$), confirming the model' s representativeness.
2) Compared to the Conservation Program scenario, Harvest Exclusion reduced species diversity by increasing the proportion of dominant species (larch and birch) while decreasing protected rare species (pine and spruce), with significant effects on forest composition in medium and long-term periods. Overall, basal area was higher and density lower under Harvest Exclusion.
3) Harvest Exclusion strongly decreased tree abundance in early stages but increased it in later old-growth stages.
4) Simulated biomass and forest regeneration rates increased under Harvest Exclusion across all periods, enhancing total forest biomass but reducing biomass of economically important pine and spruce, suggesting the need for more intensive silvicultural treatments.

Keywords: commercial harvest exclusion policy; classification management; Great Xing' an Mountains; forest structure; aboveground biomass; LANDIS

PRO

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1. Study Area Overview

The study area is located in Huzhong, central Great Xing' an Mountains, Heilongjiang Province (122°30 54 -125°35 8 E, 51°34 28 -53°24 41 N), covering approximately 2.8 × 10 km². The region extends 235 km north-south and 200 km east-west, with the main mountain range in the southwest. The terrain consists of low hills with elevations ranging from 170–1,520 m, gradually sloping from higher southwest to lower northeast.

The climate is cold temperate continental monsoon, with annual average minimum temperature below -2.8°C and extremes reaching -40°C to 35°C. Soils are primarily brown forest soil, with meadow soil and swamp soil generally containing permafrost layers. The zonal vegetation is typical cold temperate coniferous forest, with some temperate coniferous-broadleaf mixed forest.

Dominant tree species:
- **Coniferous:** Dahurian larch (*Larix gmelinii*), Korean pine (*Pinus koraiensis*), Siberian dwarf pine (*Pinus pumila*), and spruce (*Picea koraiensis*)
- **Broadleaf:** White birch (*Betula platyphylla*), David poplar (*Populus davidiana*), and sweet poplar (*Populus suaveolens*)

Dahurian larch and white birch are the absolute dominant species. White birch primarily forms secondary forests after disturbance, with strong environmental adaptability. David poplar occurs only on sunny slopes at low elevations. Siberian dwarf pine is distributed in high-altitude mountain areas. Mongolian pine is a cold- and drought-resistant light-demanding species with significant sand-fixing effects. Spruce species include *Picea jezoensis* and *Picea koraiensis*, with the latter listed as Least Concern (LC) on the endangered species red list. Both Mongolian pine and spruce are valuable species in the Great Xing' an forest region.

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2. Methods

2.1 LANDIS PRO Forest Landscape Model

LANDIS PRO is a spatially explicit landscape model that simulates forest succession and landscape processes such as harvesting. It effectively simulates the impacts of various disturbances and their interactions on forest landscapes at the landscape scale. The model divides the forest landscape into uniform grid cells, tracking species, age cohorts, and stand characteristics for each cell. Information recorded in each cell changes over time through natural succession, seed dispersal, competition, and landscape processes.

Key processes:
- **Succession module:** Species life history attributes control vegetation dynamics, determining tree establishment, growth, and mortality based on age cohort attributes. Stand density determines growth space and self-thinning processes.
- **Harvest module:** Implements harvesting simulations through management zone maps and harvest site maps. Management zones provide boundaries for harvest events, while site maps provide basic operational units composed of adjacent, relatively homogeneous stands.

2.2 Model Parameterization

Model inputs include spatial and non-spatial parameters. Spatial parameters (land type maps, forest management planning maps, harvest site maps) were resampled to 90 m × 90 m resolution to balance simulation accuracy and computational load. Non-spatial parameters include species life history attributes, species establishment probability (SEP), and harvest parameters.

Species selection: Five major species were selected, representing >90% of total biomass: Dahurian larch, Mongolian pine, white birch, David poplar, and spruce. Life history attributes (longevity, maturity age, shade tolerance, fire tolerance, maximum seeding distance, maximum diameter, maximum stand density, potential germination seeds) are detailed in Table 1.

Land type mapping: The forest landscape was divided into relatively homogeneous units based on 2000 forest inventory maps and field survey data, reflecting species-environment responses.

Harvest parameters: Three management zones were established (harvest banned: 35%, restricted: 40%, permitted: 25%). Harvest rules were based on basal area (BA), with selective harvesting from stands with highest BA to meet area targets. Commercial harvest targeted larch, birch, and poplar (ages 120-300, 60-150, and 40-120 years respectively). Pine and spruce were protected due to high economic value. Tending harvest prioritized removal of birch, larch, and poplar from smallest DBH trees. Detailed harvest parameters are in Table 2.

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3. Simulation Scenarios and Data Analysis

Three scenarios were simulated from 2000–2100 with 10-year time steps:

1. **Classification Management:** Simulated harvesting under the Conservation Program (commercial harvesting 2000–2014, tending only 2015–2100)

2. **Harvest Exclusion:** Simulated complete cessation of commercial harvesting after 2014 (tending only 2015–2100)

3. **No Harvest:** Simulated natural succession without any disturbance, providing a reference

Each scenario was replicated 10 times to reduce model stochasticity, with means calculated as final results. Variables including mean stand basal area (MBA), stand density, and aboveground biomass were analyzed using one-way ANOVA and Duncan' s multiple comparisons to examine differences in species composition and age structure across short (40-60 years), medium (60-100 years), and long (>100 years) terms.

Model validation: 2000 forest inventory data were used for initialization. Parameters were adjusted until simulated stand density and basal area matched survey data. Remaining survey data validated initialization. Since no harvesting occurred in banned zones, validation results from restricted and permitted zones reflected harvest event realism. Simulated 2013 values were compared with field survey data (stand density: 1,268, 1,729, 952 stems/ha; biomass: 58.09, 76.84, 65.67 t/ha for banned, restricted, permitted zones respectively).

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3. Results

3.1 Model Validation

Validation showed strong agreement between the initialized 2000 forest landscape and actual conditions (stand density $R = 0.82$, $P < 0.01$; aboveground biomass $R = 0.90$, $P < 0.01$) [Figure 2: see original paper]. Simulated 2013 mean stand density and biomass across management zones matched observed values, confirming model reliability [Figure 3: see original paper]. The pattern of higher density in banned zones and higher biomass in permitted zones aligned with theoretical expectations, as harvesting created space for pioneer species (birch and poplar) while mature stands in banned zones accumulated biomass.

3.2 Effects of Harvest Exclusion on Species Basal Area and Stand Density

Simulations revealed distinct species composition patterns under both scenarios, dominated by larch and birch with smaller proportions of poplar and spruce. However, composition diverged over time. Under Harvest Exclusion, larch and birch proportions increased while protected species (spruce and Mongolian pine) decreased, significantly reducing species diversity.

Basal area dynamics: Larch basal area increased continuously, while birch and poplar increased initially then declined after 60 years. Mongolian pine basal area decreased significantly across all periods ($P < 0.05$). Spruce showed no significant differences. Harvest Exclusion significantly increased larch and Mongolian pine basal area in the long term but decreased spruce basal area .

Stand density dynamics: All species densities were significantly lower under Harvest Exclusion ($P < 0.05$). Birch density showed the most pronounced reduction, decreasing significantly in the short and medium terms. Larch and Mongolian pine densities increased in the long term, while poplar density decreased only in the long term .

3.3 Effects of Harvest Exclusion on Species Aboveground Biomass

Forest biomass declined under harvesting from 2000–2014 (6.24 t/ha loss). After Harvest Exclusion implementation, this loss was recovered by ~2060, when biomass approached no-harvest levels (65.59 vs. 71.83 t/ha). Biomass accumulation rate ranked: Harvest Exclusion > No Harvest > Classification Management.

Species responded differently: Larch, birch, and poplar (harvested species) showed biomass increases, with larch increasing continuously while birch and poplar peaked then declined slightly. Protected species (Mongolian pine and spruce) showed biomass decreases, particularly significant for Mongolian pine ($P < 0.05$) [Figure 6: see original paper].

3.4 Effects of Harvest Exclusion on Forest Age Structure

Under Harvest Exclusion, stands were dominated by young and middle-aged trees. The policy significantly reduced basal area and density of young-middle aged stands while increasing mature/overmature proportions over time ($P < 0.05$). This facilitated transition from young-middle to mature stands, improving age structure compared to Classification Management [FIGURE:8, TABLE:6, TABLE:7].

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4. Conclusion and Discussion

Landscape model validation is challenging due to limited long-term datasets. This study' s simulations aligned well with inventory data, demonstrating LANDIS PRO' s suitability for the Great Xing' an region. The model effectively captured key processes: larch adaptation to permafrost, birch dominance in post-harvest secondary forests due to strong seed dispersal, and the current mixed larch-birch composition resulting from decades of harvesting.

Key findings:
1. Harvest Exclusion further increased dominant species (larch, birch) proportions while decreasing valuable species (Mongolian pine, spruce), reducing species diversity.
2. The policy lowered stand density (especially birch) while increasing basal area, reflecting self-thinning as short-lived pioneers (birch, poplar) died after reaching maturity.
3. Harvest Exclusion accelerated forest recovery, with total biomass exceeding

pre-harvest levels by ~2060. However, protected species biomass declined due to reduced light availability from increased canopy closure and competition.
4. Age structure improved as young-middle stands transitioned to maturity, though tending harvest intensity may need adjustment to better protect valuable species.

Management implications: While Harvest Exclusion benefits overall biomass recovery and age structure improvement, it negatively impacts valuable species conservation. Increasing tending harvest intensity could help maintain these species. The results provide crucial references for evaluating forest management policies and implementing ecosystem-based management in the Great Xing' an region.

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Note: Figure translations are in progress. See original paper for figures.