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# Short communication. Restoring monoculture plantation using stand spatial structure analysis

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## Abstract

*Aim of study*: To improve the quality of monoculture plantations in China.

*Area of study*: Structure-based forest management was conducted in Rocky Mountain Area of Northern China.

*Material and methods*: Stand spatial structure indicators of mingling degree, uniform angle index, neighborhood comparison and opening degree were comparably investigated to understand the changes of *Pinus tabulaeformis* plantations.

*Main results*: The results indicated that structure-based forest management accounted for 0.403 and 0.448 of the significant variations in mingling degree and opening degree increments, and had no essential changes in uniform angle index and neighborhood comparison. Structure-based forest management is greatly beneficial to plantation quality, and it can be a source of improvement on stand structure.

*Research highlights*: This improved information is essential to provide a firm basis for future policy-making on how best to restore degraded forests in China as well as the rest of the world.

**Key words**: forest restoration; monoculture plantation; stand spatial structure; structure-based forest management.

## Introduction

Afforestation has become a booming business to combat forest, land and environmental degradation in China (Li, 2004; Xu *et al.*, 2006; Wang *et al.*, 2008). During the past few decades, a large-scale increase of plantations in non-forested areas has increased total forest area, stock and coverage from 15.89 million $hm^2$, 11.27 billion $m^3$ and 16.55 % to 19.33 million $hm^2$, 13.36 billion $m^3$ and 20.36%, respectively. Although afforestation has many positive impacts on ecosystems and environments, unfortunately, cumulative plantations in China often fail to replace natural ecosystem because of the disregard for such environmental protective practices. Inefficient plantations management has become a major problem for forestry and environmental quality in China.

Forest structure and functions are closely interconnected and interdependent (Osorio *et al.*, 2009). Unsuitable planted species and densities always imply dysfunctional forests. Silvicultural options can modify species composition and structural diversity and therefore have important potential role in securing ecological functions (Pommerening, 2006; Oliver *et al.*, 2011). As a "close-to-nature" forest management solution, structure-based forest management focuses on stand structure rather than timber production, improving stand spatial structure in accordance with natural forest growth and succession process for a healthy and stable forest (Hui *et al.*, 2007). This approach is greatly beneficial to restoring sustainability to monoculture plantations; however, little research regarding this topic has been conducted. It is essential to conduct a study to improve forest structure so as to restore monoculture plantations by using structure-based forest management. The mingling degree, uniform angle index, neighborhood comparison and opening degree were selected to indentify the effects of structure-based forest management on stand spatial structure of *Pinus tabulaeformis* plantations, one of the most important dominate plantations in Rocky Mountain Area of Northern China (Guo *et al.*, 2008). The objectives of this study were: (1) to characterize the *Pinus tabulaeformis* plantation using stand spatial structure indicators; (2) to restore monoculture *Pinus tabulaeformis* plantation including stand mingling and randomness, dominated trees growing space and competitive advantages; and (3) to explore the possibility of whether structure-based forest management can be used in monoculture plantation restoration.

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# Material and methods

## Study Area and field inventory

The study was conducted in Mulan-Weichang Forestry Administrative region of Hebei Province, 350 km north to Beijing (41° 50' N, 117° 35' E; 750~1829 m *asl*). This area belongs to the Rocky Mountain Area of Northern China, and is characterized as a continental monsoon climate with an average annual temperature of –1.4 to 4.7°C and annual precipitation of 380 to 560 mm. The natural vegetation in this area is mainly broad woody trees *Betula platyphlla* and *Populus davidiana* with few conifer species. These natural tree species are now only present in remnants and have been replaced by conifer plantations including *Pinus tabulaeformis* and *Larix principis-rupprechtii* that cover 51.9% of the area.

A typical site of a *Pinus tabulaeformis* plantation was selected, with an area of 40 m × 100 m for classical field investigation as follows: tree species, diameter at breast height (DBH), height, under-branch height and crown radius, spatial location, as well as mechanical and biological damages.

## Analytical methods

The forest structure was calculated based on the stand spatial structure indicators (Pommerening, 2002; Aguirre, 2003; Deng *et al.*, 2010). The equations are expressed as follows:

— Mingling degree:

$$M_i = \frac{1}{4}\sum_{j=1}^{n} v_{ij} \quad ; \quad M_i \in [0,1] \qquad [1]$$

$$\text{where } v_{ij} = \begin{cases} 1, \text{species}_j \neq \text{species}_i \\ 0, \textit{otherwise} \end{cases}$$

— Uniform angle index:

$$W_i = \frac{1}{4}\sum_{j=1}^{n} z_{ij} \quad ; \quad W_i \in [0,1] \qquad [2]$$

$$\text{where } z_{ij} = \begin{cases} 1, \alpha_j < \alpha_0 \\ 0, \textit{otherwise} \end{cases} ; \quad \alpha_0 = 72°$$

— Neighborhood comparison:

$$U_i = \frac{1}{4}\sum_{j=1}^{n} k_{ij} \quad ; \quad U_i \in [0,1] \qquad [3]$$

$$\text{where } k_{ij} = \begin{cases} 1, DBH_i \geq DBH_i \\ 0, \textit{otherwise} \end{cases}$$

— Opening degree:

$$K_i = \frac{1}{4}\sum_{j=1}^{n} \left(D_{ij}/H_j\right) \quad ; \quad K_i \in [0,\infty] \qquad [4]$$

where $D_{ij}$ and $H_{ij}$ are the distance between the reference tree *i* and the neighbor tree, as well as the height of the neighbor tree *j*, respectively.

$M_i$, $W_i$ and $U_i$ assume five possible values (0, 0.25, 0.5, 0.75 and 1.0) revealing multi-relationships between reference and neighbor trees on the following categories: zero, weak, middle, strong and relative strong. $K_i$ also assumes five possible value intervals (0, 0.2), (0.2, 0.3), (0.3, 0.4), (0.4, 0.5), (0.5, ∞), and describes five types of tree's growing space as follows: relatively insufficient, insufficient, essentially sufficient, sufficient and relatively sufficient.

## Forest management design

The plan is divided into two parts: thinning and planting steps. The trees with higher economic values (W = 0.5 or U = 0) were selected as the target trees (signed as "T"). All the other species of trees living around "T" that have negative impacts on "T" (W ≥ 0.75 or U ≥ 0.75), trees with curved, damaged trunk or injured trees were selected as disturbing trees (signed as "D"); "D" trees were objective trees for thinning in early steps. In order to preserve the stability of stand structure and ecological functions, the other trees (0 ≤ W ≤ 0.25 or 0.25 ≤ U ≤ 0.5) were selected as assistant trees (signed as "A"). To improve stand structure and biodiversity in a "close-to-nature" approach, native tree species including *Betula platyphlla*, *Larix principis-rupprechtii* were selected as ecological-restoration trees for planting (signed as "E"). "E" trees were planted in the empty space resulting from thinning based on the stand spatial structure analysis. According to local forest density plans, the total stand density was roughly of 1,000 stems/hm$^2$ (Table 1). No matter which steps to take —thinning, or planting—, the purpose is to adjust stand spatial structure actively to accelerate stand optimization rather than achieve gradual natural succession.

# Results and discussion

## Mingling degree

Unitary tree species are a significant characteristic of plantations in this region discussed. However, there

**Table 1.** Statistics of stand factors in the site

| Sign | DBH/ cm | Height/ m | Basal area/ $m^2 \cdot hm^{-2}$ | Density/ $stems \cdot hm^{-2}$ | Forest crown closure/(%) |
|---|---|---|---|---|---|
| T | 17.12 | 12.72 | 12.18 | 523 | — |
| D | 13.61 | 11.35 | 9.80 | 658 | — |
| A | 15.52 | 11.79 | 4.36 | 228 | — |
| E | 3.00 | 1.50 | 0.18 | 250 | — |
| Before thinning | 15.22 | 11.93 | 26.33 | 1,408 | 79 |
| After thinning | 16.63 | 12.44 | 16.53 | 750 | 65 |
| After planting | 13.22 | 9.70 | 16.71 | 1,000 | 67 |

was an increasing trend in terms of structure-based forest management for the average mingling degree. Obviously, in the early steps, the only species indicated that average mingling degree was zero. In the later steps, we introduced two new species; stand mingling degree began to disintegrate. Compared to the early steps, zero-mixed (0) individual trees after the later steps decreased by 74.37%. The weak-mixed (0.25), mid-mixed (0.5), strong-mixed (0.75) and relatively strong-mixed (1) individual trees were also higher than the early steps. The stand average mingling degree increased from 0 to 0.403 (Table 2). Nevertheless, the main mixed forms of the stand were still zero-mixed and weak-mixed with a total proportion of 54.08%. The variability in mingling degrees showed that the structure-based forest management made a great contribution towards the promotion of tree species segregation in the interim from simple to middle mixed form.

## Uniform angle index

Uniform angle index in the plantations had a large fluctuation over the management steps, but there was still an increasing trend and symmetrical change. Primarily, most of the individual trees (56.23%) were distributed in a random distribution pattern (0.5), and the stand average uniform angle index was $0.489 \in (0.475, 0.517)$ in a random distribution as well. In the early steps, due to random distribution of disturbing trees, the uniform angle index showed a fluctuating change. The stand average index decreased from 0.489 to $0.474 \in (0, 0.475)$ in an aggregative pattern, but still remained close to a random pattern. It was shown that planting can adjust tree distribution patterns artificially. In the later steps, the exotic species caused a significant decrease of individual trees in a regular pattern, and an increase of individuals in a random and aggregative pattern. As a result, the stand average uniform angle index increased to 0.497 in a random pattern resulting in a higher stochastic than the primary level (Table 2). Further, taking $\overline{W} = 0.5$ as a benchmark, the trial enhanced the symmetry of the uniform angle index frequency revealing a positive promotion on stand distribution patterns.

**Table 2.** Changes of stand structural parameters of the plot

| Parameters | Before thinning | After thinning | After planting |
|---|---|---|---|
| Mingling degree | 0 | 0 | 0.403 |
| Uniform angle index | 0.489 | 0.474 | 0.497 |
| Neighborhood comparison | 0.498 | 0.481 | 0.532 |
| Opening degree | 0.202 | 0.267 | 0.650 |

## Neighborhood comparison

The fluctuating variability of neighborhood comparison was very similar to that of uniform angle index, and there was also an increasing trend of stand average neighborhood comparison caused by extensive planting. Originally, the stand average neighborhood comparison was 0.498 with approximate frequencies (21.2%, 17.5%, 20.8%, 22.0% and 18.5%, respectively). The early steps represented a cutting-off period of disturbing trees so that the inferior (0.75) and absolutely inferior (1) individuals decreased in levels corresponding to the increasing levels of sub-dominant (0.25) and middle (0.5) trees. Further, the stand average neighborhood comparison was less than original level of 0.481. The later steps represented a planting period of ecological-friendly trees. In the structure unit, the seedlings were absolutely inferior to *Pinus tabulaeformis* in DBH and height. This resulted in a sharp increase of absolute inferior individuals. Although the stand average neighborhood comparison increased in a small-scale to 0.532, the competition intensity had

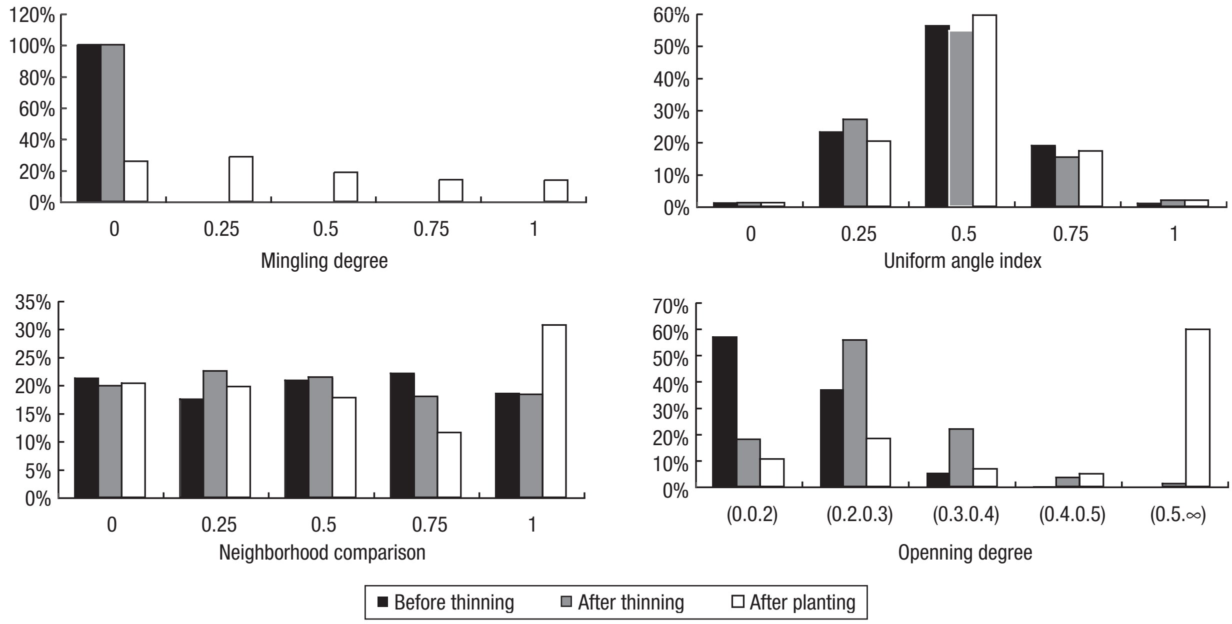


**Figure 1.** Changes of stand spatial structure indicators.

no essential change because of the exotic seedlings added (Table 2).

### Opening degree

A higher stand density showed a lower growing space and the mean stand opening degree was only 0.202. Fig. 1 indicated that the individuals in relatively insufficient (0, 0.2) and insufficient (0.2, 0.3) groups were 57.76% and 37.21%, respectively; this corresponded to a much lower growing space for individuals in essentially sufficient (0.3, 0.4), sufficient (0.4, 0.5), relatively sufficient groups (0.5, ∞) (5.6%, 0.4% and 0, respectively). The early steps represented a mechanical enlarging period in which the individuals in relatively insufficient growing space sharply decreased 38.82%; trees in other conditions increased by different ranges. The stand average opening degree increased to 0.267 which was still insufficient, but better than initial levels. The later steps represented an ecological diversifying period. Due to the smaller growing space requirements of seedlings, there was an aggressive change of trees' growing space in which individuals were essentially sufficient, insufficient and relatively insufficient growing experienced decreased growing space. Trees with insufficient growing space decreased from 55.73% to 18.31%. Accordingly, trees in relatively sufficient and sufficient growing space increased from 3.44% and 1.15% to 4.79% and 59.72%, respectively. Meanwhile, the stand average opening degree increased to 0.650 in sufficient conditions (Table 2).

## Conclusions

Structure-based forest management is proved to be an efficient approach for restoring monoculture plantations, in terms of its significant positive impacts on spatial structure in plantations. An understanding of stand spatial structure is also crucial for the sustainable management of mixed, uneven-aged forests (Pommerening, 2006), as well as our understanding of the afforestation policy in China. As ecologists and agroforestry practitioners, we highly recommend that China's forestry policy should focus on forest management rather than the large-scale afforestation in order to meet the complex requirements of environmental restoration (Gao *et al.*, 2011). Meanwhile, our example is also relevant to many other countries, and particularly to developing countries with a poor forestry base but a large area of monoculture plantations.

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