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Analyzing selective harvest events in three large forest observational studies in North Eastern China

Chunyu Zhang [a,*], Xiuhai Zhao [a], Klaus v. Gadow [b,c]

[a] Key Laboratory for Forest Resources & Ecosystem Processes of Beijing, Beijing Forestry University, Beijing 100083, China
[b] Faculty of Forestry and Forest Ecology, Georg-August-University Göttingen, Büsgenweg 5, D-37077 Göttingen, Germany
[c] Dept. of Forest and Wood Science, University of Stellenbosch, South Africa

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ABSTRACT

This study presents an analysis of selective harvest events in three 10-ha field plots with mapped trees, representing different forest successional stages in the temperate multi-species forests of North-Eastern China. Non-spatial methods of analyzing the harvest events include species and size selection preference and an assessment of harvest intensities for four species groups (identified using bivariate mixed dbh/height distributions). Spatial aggregation increased very slightly after the harvest event, but in most cases, the change was hardly noticeable. In addition, tree selection preferences involving nearest neighbor structure units are presented, using the attributes "species mingling" and "dominance". The removals occurred within a broad array of neighborhood constellations, involving suppressed as well as dominant individuals. Previous approaches involving harvest event analysis in multi-species forests were limited to assessing size and species selection preferences. This study uses more advanced methods and presents more detailed interpretations, due to the large and detailed observational datasets and improved analytical tools that have become available recently. Models of tree growth and survival, which represent the overwhelming result of traditional observational studies, only describe a part of forest dynamics. Equally important are the modifications caused by regular human disturbance. There is thus increasing motivation for analyzing selective harvesting activities as presented in this contribution.

1. Introduction

Uneven-aged multi-species forest ecosystems are managed by particular silvicultural methods which are referred to as "uneven-aged management" (North America; Haight, 1987), "near natural", "close to nature" or "continuous cover" forestry (Europe; Schütz et al., 2012). Specific varieties of continuous cover forestry (CCF) are applied in different parts of the world. CCF has been practiced, for example, for more than a century in Europe and in the community forests of the Mexican *Sierra Madre Occidental* (Pérez-Verdín et al., 2009). There is increasing motivation in several countries, including China, for testing the suitability of selective silviculture in uneven-aged multi-species ecosystems. However, the challenges are not trivial. Sustainable forest use not only implies limitations on the harvested timber volume, but also requires some kind of monitoring of ecosystem disturbance caused by structural modifications through harvest events. Selective harvesting of trees in continuous cover forest management modifies growing spaces and spatial niches. Forest management influences tree size distributions and spatial mingling of tree sizes and tree species, thus causing major changes in forest structure. Sometimes we wish to know the spatial context of the trees that were removed during a harvest event: did the harvest event preferably target the dominant or the suppressed trees in the vicinity of their immediate neighbors? Were trees selected for removal located preferably in groups composed of one species or in mixed groups?

A particularly challenging objective of CCF silviculture is to derive economic benefits without modifying the key features of the natural ecosystem. A range of practical silvicultural rules and "recipes" have been developed in various regions of Europe, North America and in some tropical and sub-tropical forests of South Africa, Asia and South America. In all these applications, forest development oscillates around some level of stocking, which is assumed to be "near natural" (Schütz et al., 2012). In theory, the degree of "naturalness" of an ecosystem is the difference between its current observed state, relative to some assumed natural state (Gaston and Blackburn, 2000). Unfortunately, however, the "natural state" is not known. Naturalness is a "moving target" because

* Corresponding author. Address: Forest College in Beijing Forestry University, No. 35 Qinghua East Road, Haidian District, Beijing 100083, China. Tel.: +86 01062336189.

E-mail addresses: zcy_0520@163.com (C. Zhang), zhaoxh@bjfu.edu.cn (X. Zhao), kgadow@gwdg.de (K.v. Gadow).

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ecosystems are subject to continual change, even when they are protected from human use (Sprugel, 1991). The "natural state" is something that cannot be defined. We cannot measure and objectively evaluate the degree of "naturalness". However, it is possible to describe human interventions and interpret their effects, and this implies a need for detailed monitoring of harvest events.

Zhao et al. (2012) presented a new network of forest observational studies that has been developed during the past 10 years in China. The network includes managed and unmanaged field plots which are designed to provide empirical evidence about ecosystem structure and dynamics, including tree growth, recruitment and mortality. Research in the unmanaged series covers a range of topics, including species-habitat associations; natural ecosystem structure and diversity; response to natural disturbances such as wildfire; seed dispersion and seedling survival. The development in the managed experiments is characterized by regular human disturbance through selective harvesting and the main objective in the managed series is to study forest dynamics under management, in particular to assess modifications of ecosystem structure through harvest events.

Accordingly, the objective of this contribution is to explore several new approaches to assessing the effects of selective harvesting by: (a) using quantitative tools to group species into cohorts to evaluate the change of forest composition involving large and small canopy species and subcanopy species; (b) evaluating harvesting preferences within tree neighborhoods to evaluate the size and species selection preference in the vicinity of individual trees; (c) explore some aspects of the modification of tree size distributions and spatial patterns.

2. Materials and methods

2.1. Study sites

The study was carried out in the temperate forests at *Jiaohe* in Jilin province, in Northeastern China. The forest type is a typical mixed broadleaf-conifer forest. The average annual temperature is 3.8 °C. The hottest month is July with an average daytime temperature of 21.7 °C. The coldest month is January with an average day temperature of −18.6 °C. The average annual precipitation is 695.9 mm. The soil type is a brown forest soil with a rootable depth ranging between 20 and 100 cm.

This study is based on measurements obtained in three large permanent field study areas which have been designated as *HM, NM* and *MF*. They represent different forest successional stages. The HM study area covers 10.08 ha (240 × 420 m) and it is located at 43°57.928′–43°58.214′N, 127°45.287′–127°45.790′E. The study was established in the summer of 2010 and selectively harvested during the winter of that year. Elevations range from 462 to 519 m above sea level. Altogether 32 woody species occur in the plot. The NM study area covers 10.88 ha (320 × 340 m) and is located at 43°58.207′–43°58.558′N, 127°44.092′–127°44.541′E. The plot was established in the summer of 2009 and harvested in the winter of that year. Elevations are ranging from 425 to 585 m above sea level. Altogether 40 woody species occur in the plot. The MF study area covers 10 ha (200 × 500 m) and is located at 43°57.524′–43°58.042′N, 127°44.111′–127°44.667′E. The study was established in the summer of 2010 and harvested in the winter 2011. Elevations are ranging from 463 to 510 m above sea level. Altogether 28 woody species occur in the plot.

In each plot, all trees which had a diameter at breast height (DBH) of 1 cm or more were identified, measured and mapped. Because only bigger trees were harvested, the analysis of the harvest events was limited to the trees with a DBH of 10 cm or more. Harvest intensities and species selection preferences are presented in Table 1 for the three study areas.

2.2. Non-spatial analysis

2.2.1. Bivariate mixed DBH-height distributions

Mature and immature canopy trees often occur in two subpopulations with different diameter-height relations. Thus, the population of canopy trees is composed of a mixture of two subpopulations having different diameter-height distributions. Zucchini et al. (2001) presented a model for the diameter-height distribution that is specifically designed to describe such populations. A simple height–diameter curve, describes how the mean height varies with diameter at breast height, but it does not quantify the complete distribution of heights for each diameter which is essential for identifying mature and immature canopy trees. Therefore, a mixture of two bivariate normal distributions was fitted to the diameter-height observations of the canopy species. The parameters have familiar interpretations and were estimated using the *R*-function mclust (Fraley et al., 2012). Let $f(d, h)$ denote the bivariate probability density function of diameter and height. The proposed model then is:

$$f(d,h) = \alpha \cdot n_1(d,h) + (1-\alpha) \cdot n_2(d,h) \quad (1)$$

where α, a parameter in the interval (0, 1), determines the proportion of trees belonging to each of the two component bivariate normal distributions $n_1(d, h)$ and $n_2(d, h)$. The parameters of $n_j(d, h)$ are the expectations u_{dj}, u_{hj}; the variances $\sigma^2{}_{dj}$ and $\sigma^2{}_{hj}$, and the correlation coefficients, $\rho_j (j = 1, 2)$.

2.2.2. Grouping of species

There are numerous examples showing that undisturbed forests exhibit structures which include more than one layer of tree heights (Korpel, 1992). Typically, temperate forests display three reasonably well-defined layers of vegetation. The tallest trees are the canopy trees which intercept most of the radiation. Beneath the canopy there is another layer of vegetation, called the subcanopy or understory. The shrub layer is formed by low woody plants, sometimes with multiple stems from the base that attain a height at maturity which is usually less than one third of the canopy height. In this study, each of the 38 tree species observed in the three study areas, belongs to one of these groups: canopy trees, subcanopy trees and shrubs. This classification, which is straight forward for most species, has been adopted following standard ecological textbooks (e.g. Fu, 1995). However, in contrast to the usual subjective grouping, a more objective approach was followed in this study. The bivariate DBH/height distributions of the canopy species and the shrubs show typically two clusters, in contrast to the subcanopy species which are characterized by a single cluster. The relationship between DBH's and heights is quite different between the dominant cluster and the understorey cluster of the canopy species. Fig. 1 presents a visual impression for four canopy species.

Before reaching the canopy, the height/DBH ratio of the understorey trees of the canopy species considerably exceeds that of the dominant individuals. For example, the average ratios of height/DBH for the canopy species with less than 20 cm DBH is 1.25, while that with a DBH exceeding 20 cm is only 0.59 in MF. The same phenomenon has been observed in European beech forests (Zucchini et al., 2001). Immature canopy trees in the understorey seem to invest more into height growth to avoid long periods of shading. Once they reach the canopy, diameter growth continues unabated. The trees of the canopy species can thus be classified into two cohorts.

Accordingly, we subdivide canopy trees into large (DBH ⩾ 20 cm) and small (DBH < 20 cm) individuals. Roman numerals are used to identify the four cohorts, i.e., I: large canopy trees (DBH ⩾ 20 cm); II: small canopy trees (DBH < 20 cm); III: understorey trees; IV: shrubs.

The number of trees per unit area is not a useful measure of population density because it does not incorporate tree size. There-