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Initial vegetation recovery following a blowdown of a conifer plantation in monsoonal East Asia: Impacts of legacy retention, salvaging, site preparation, and weeding

Junko Morimoto*, Miho Morimoto, Futoshi Nakamura

Laboratory of Forest Ecosystem Management, Graduate School of Agriculture, Hokkaido University, KITA 9 jo, NISHI 9, KITA ku, Sapporo city, 060-8589, Japan

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ABSTRACT

All or a part of a sequence of forest practices (i.e., salvage logging, site preparation, planting crop trees, and weeding) has been implemented after natural disturbances for the rapid re-establishment of tree cover. Forest policies in Japan have recently changed from monocultural planting of coniferous crop trees to planting native broadleaved trees to restore forests and nurture local biodiversity following large windthrows. However, the effects of this new practice on preserving biodiversity, as well as the effects of legacy retention, have never been verified in Asia. Thus, the objective of our research was to compare the effects of legacy retention with plantation after salvaging on the initial stage of vegetation recovery in a blowdown area, specifically focusing on plant species diversity, the occurrence of alien species, and the composition of plant species. Following the analysis of our results, we finally describe appropriate practices to alter disturbed coniferous plantations to bring the species composition closer to that of the original natural mixed forests.

A control (A, legacy retention) and three experimental treatment sites (B, salvage logged, site prepared, and *Quercus crispula* seedlings planted; C, same as B, but weeded once during the summer; and D, residual rows that emerged after establishing sites for planting) were prepared, and quadrats were set. Eleven indicators of the ground condition and the number of vascular plant species, including ferns, were quantified, and the number and abundance of residual and newly colonized plants of the main woody species were estimated.

Our main findings were as follows: (1) in unsalvaged sites and residual rows, the diversity of plant species was poor, but a variety of plant species compositions were observed due to the heterogeneous conditions of the ground and ample residual plants; (2) in the planting site, many species appeared, but little variety of the species composition was observed due to the homogeneous condition of the ground and the destruction of residual plants; (3) a large number of alien species emerged in broad, unvegetated areas; (4) the impact of site preparation overwhelmed the impact of salvage logging on the initial recovery of plant species; and (5) to restore a natural mixed forest, a combination of legacy retention and plantation after salvaging would be the most appropriate.

1. Introduction

Salvage logging after large-scale natural disturbances, such as windthrows and wildfires, is a common practice worldwide (Elliott et al., 2002; Mountford et al., 2006; Weishampela et al., 2007). Its main purposes are to recoup economic losses before the trees decay (Lindenmayer and Noss, 2006; Prestemon et al., 2006), to reduce fire risk by removing dead trees (Sessions et al., 2004), and to prevent outbreaks of beetles (Sessions et al., 2004). Site preparation before planting crop trees (traditionally by burning and, recently, by using heavy machinery) (Titus and Householder, 2007) and weeding for several years after planting (Macdonald, 2007; Nyland, 1996; Nagai and Yoshida, 2006) are also common practices after salvage logging to reduce the plants that compete with crop trees. A sequence of practices, including salvage logging, site preparation, planting crop trees, and weeding, has traditionally been performed to rapidly establish and increase the growth of crop trees that will later be harvested for timber production.

Over the past century, public demands for forest resources have shifted from wood production and recreation to wilderness protection and biodiversity conservation (Aber et al., 2000). However, an empirical study is required to determine appropriate practices

* Corresponding author. Tel.: +81 11 706 2515; fax: +81 11 706 2517.
E-mail addresses: jmo1219@for.agr.hokudai.ac.jp (J. Morimoto), mihoshi@for.agr.hokudai.ac.jp (M. Morimoto), nakaf@for.agr.hokudai.ac.jp (F. Nakamura).

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to satisfy the new demand for biodiversity conservation because limited knowledge exists in this field. While few studies on this topic concerning Asian countries have been published (Nagai and Yoshida, 2006; Hino and Hiura, 2009), many empirical studies focusing on the relationships between forest practices after natural disturbances and the recovery of the diversity of flora have been conducted in North America and Europe. It has been suggested that there are advantages of leaving all biological legacies in such disturbed areas (including residual plants and microtopography) (Lindenmayer et al., 2004; Stokstad, 2006; Peterson and Leach, 2008), and salvage logging does not always produce the expected outcomes (Anderson et al., 2007; Donato et al., 2006; Lindenmayer and Noss, 2006).

The effects of forest practices on spermatophytes (herbaceous and woody plants) have been investigated in many cases, but the effects on pteridophytes (ferns) and lycopodiophytes have been ignored. Because the responses of vascular plants to forest practices differ depending on their life-form (Nagai and Yoshida, 2006), all vascular plants should be given equal attention when assessing the recovery of floral diversity.

Additionally, the residual plants and newly colonized plants that are present after disturbances are expected to play different roles in the earliest stage of succession (Roberts, 2004; Haeussler et al., 1999), which has seldom been analyzed separately in previous studies. Furthermore, the collective effects of the sequential practices from salvage logging to site preparation, planting, and weeding on the recovery of natural forests have never been examined in comparison with the effects of legacy retention.

Because tree species diversity and the structural complexity of a forest also enhance the diversity of animal species (Tews et al., 2004; Donald et al., 1998; Palik and Engstrom, 1999), multi-species planting (rather than monocultures), lower-density planting, and longer rotation of tree harvesting to facilitate the establishment of various plant species on the forest floor are recommended to encourage higher biodiversity in forests (Carnus et al., 2006; Hartley, 2002). In Japan, forest policies have recently changed from monocultural planting of coniferous crop trees to planting native broadleaved tree species to restore forests and nurse local biodiversity following large windthrows (Ministry of Agriculture Forestry and Fisheries of Japan, 2009). This procedure is similar to traditional planting practices, i.e., salvage logging, site preparation, planting native broadleaved trees (instead of coniferous crop trees), and weeding. However, the effects of this practice on the initial recovery of plant communities have never been verified.

Thus, the aim of our research was to examine the effects of legacy retention and plantation after salvaging on the initial recovery of all vascular plants in a region of monsoonal Asia, where typhoon disturbances dominate. In this study, the terms "unsalvaged sites" and "legacy retention" refer to areas in which human interventions (e.g., salvage logging, site preparation, planting, and weeding) are never conducted and which are, therefore, left to natural recovery. We targeted plant communities in the early stage of succession after a large windthrow because relatively small differences in species responses in the initial years after a disturbance can have a great influence on the future development of the communities therein (Halpern and Spies, 1995; Bråkenhielm and Liu, 1998). The plants at the study sites were distinguished as either residual or newly colonized plants to quantitatively evaluate each of their contributions to the recovery of the forest. Moreover, alien species were distinguished from native species because alien species may alter the trajectory of forest succession (Titus and Tsuyuzaki, 2003). Based on our results, we discuss an appropriate treatment to direct disturbed coniferous plantings to more closely resemble the natural mixed forests that previously grew in the studied area The research area was located in plantation forests of *Abies sachalinensis* Fr. Schm. Masters that were largely blown down by a typhoon in 2004. In one part of the area, fallen trees were left as they had fallen, while in another part of the area, *Quercus crispula* Blume seedlings (i.e., one of the main species in local mixed natural forests) were planted after salvage logging. Precise environmental conditions, plant species diversity, the emergence of alien species, and plant species composition were investigated.

2. Methods

2.1. Study area

Typhoon no. 18 hit northern Japan in September, 2004 and destroyed 369.6 km^2 of forest. Of the total windthrow area, 30% was concentrated in two adjacent cities, Chitose City and Tomakomai City (Tsushima and Saitoh, 2003). A study area was chosen in a management unit (0.47 km^2) of the national forest in Chitose City (42°45′N 141°30′E; altitude 150 m; average annual temperature 7.1 °C; average annual precipitation 1384 mm). The topography in the area is mostly flat, and the surface soil is volcanic ash and pumice, which were mainly delivered by the eruption of Mt. Tarumai (42°41′N 141°22′E; altitude 1041 m) during the 17th century. The dominant tree species of the natural forests were *Abies sachalinensis* Fr. Schm, *Picea jezoensis* (Siebold et Zucc.) Carrière, and *Quercus crispula* Blume based on forest inventory archives. Plantations of *A. sachalinensis* and *Picea glehnii* Fr. Schm. Masters were conducted in 1957 and in 1979, respectively, and the typhoon destroyed most stands of *A. sachalinensis* (stand density 900 trees/ha, stand volume 104 m^3/ha, average height 16 m) in 2004. The 15,000-m^2 study area was established in an area where a stand of *A. sachalinensis* was completely destroyed. No canopy cover was left, and only boles without crowns remained sporadically, though seedlings on the forest floor that did not receive any direct damage from fallen trees survived.

No manipulations were conducted, and woody debris was left as it lay in the northern part of the study area (east–west (EW) 70 m × north–south (NS) 50 m). In the southern part of the study area (EW 50 m × NS 150 m), salvage logging was conducted using bulldozers and harvesters with grapples in September, 2007. Thereafter, site preparation and flattening and clearing of a 4-m wide row for tree planting were performed using backhoes. Woody debris scattered on the forest floor was piled along the sides of each planting row, which are referred to as residual rows. Approximately 10 cm of topsoil was removed, and pumice stones that had been produced by Mt. Tarumai emerged during site preparation. Seedlings of *Q. crispula* (~60 cm in height) grown in a forestry nursery were transplanted after site preparation to restore the mixed forest of *Q. crispula* and *A. sachalinensis* that originally grew at the site.

The northern border of the study area was salvage logged. The artificial *P. glehni* forests at the western and eastern sides of the study area were not blown down. The southern border of the study area was salvage logged, followed by site preparation and planting of *Q. crispula* seedlings.

2.2. Setting of quadrats for surveys

In April, 2008, the year after salvage logging, site preparation, and planting were conducted, a control and three experimental treatment sites were established to examine the effects of legacy retention and plantation after salvaging on plant communities. The control site (A) was established in the northern part of study area, and treatments B–D were conducted in the southern part of the study area (Fig. 1). The conditions of the control and the three treatments were as follows: (A) the area was unsalvaged, and woody debris remained after the blowdown; (B) the area was salvaged; the