Forest Ecology and Management 328 (2014) 193–201

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Effects of retention level and fire on retention tree dynamics in boreal forests

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ARTICLE INFO

Article history:
Received 21 February 2014
Received in revised form 7 May 2014
Accepted 8 May 2014
Available online 16 June 2014

Keywords:
Retention forestry
Prescribed burning
Tree dynamics
Biodiversity
Tree mortality
Variable retention

ABSTRACT

Retention forestry has been used for over 20 years to reduce the unfavorable impacts of intensive forest management on biodiversity. The assumed positive effects of retention trees, however, depend on the dynamics of trees in providing substrates or structures for forest-dwelling organisms. In 2000 an experimental study was established to investigate the effects of different retention levels (10 m^3 ha^{-1} and 50 m^3 ha^{-1}) and fire on tree dynamics. In total, 2758 individually marked, initially living, retention trees were followed on 12 sites in eastern Finland over 10 post-harvest years. Over half (59%) of the total volume of the retention trees died during these initial 10 years, and burning resulted in much higher mortality (84% vs. 34% on unburned sites). At lower retention levels, retention trees did not provide continuity of habitat substrates since all trees died quickly. Fire shortened the tree availability, due to increased tree mortality. However, in higher retention levels, burned areas maintained diverse deadwood substrates for an extended period. Our study proved that tree retention can maintain the continuity of dead wood over early successional stages, if the level of retention is high enough. Fire, combined with higher retention level, created diverse assemblages of dead and living trees. At lower retention levels, however, the effect of fire can be too severe for maintaining living trees or continuity of diverse dead wood.

1. Introduction

Clear-cutting forestry has prevailed during recent decades in many parts of the world. Sometimes it is argued that clear-cutting emulates natural stand-replacing disturbances such as fire or windstorm (Mielikäinen and Hynynen, 2003). However, it is widely documented nowadays that natural disturbances, unlike clear-cuts, leave several legacies of pre-disturbance forests that are essential to maintain biodiversity (Franklin et al., 1997; Kouki et al., 2001; Angelstam and Kuuluvainen, 2004; Kuuluvainen, 2009; Swanson et al., 2011). A good example is the amount of dead woody biomass that reaches very high levels after natural stand-replacing disturbances (Siitonen, 2001; Uotila et al., 2001; Junninen et al., 2006). A clear-cut is very different, since in Fennoscandia the remaining dead wood is mostly in stumps, roots and small branches. Consequently, clear-cutting practices have profound impacts on forest biodiversity.

Retention forestry is gaining global interest because of its capacity to maintain biodiversity in the early successional forests after timber harvests (Gustafsson et al., 2012). The method was first introduced in the Pacific Northwest in North America in 1990s, and it has been practiced in many parts of the world since then (Gustafsson et al., 2012; Lindenmayer et al., 2012). Retention forestry is a harvesting system where some of the trees and snags are left in the harvested area, in order to create legacy patterns more akin to those that typically occur after natural disturbance events in young successional forests.

Retention trees potentially have several functions that may be beneficial to forest biodiversity (Gustafsson et al., 2010). Retention trees can maintain some of the pre-harvest structures of forest, such as large trees, deciduous trees and coarse dead wood, which increases the number of substrate types in early-successional forests and, consequently, help species to survive after logging (Franklin et al., 1997; Vanha-Majamaa and Jalonen, 2001; Gustafsson et al., 2010). Retention forestry can also enable persistence of some species in harvested areas through buffering of microclimate, and assist re-colonisation via proximity to source populations (Baker et al., 2013b), and enhance landscape connectivity by creating stepping stones that help in dispersal of species (Franklin et al., 1997).

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http://dx.doi.org/10.1016/j.foreco.2014.05.022
0378-1127/

Even though retention forestry is a promising harvesting method, it lacks some essential characteristics of natural disturbances, such as fires. Fire is a main natural large-scale disturbance in boreal forests (Wein, 1993; Engelmark, 1999), which many species have evolved with (Schütz et al., 1999; Boulanger and Sirois, 2007). In natural circumstances, fire not only increases the amount of dead wood, but can also create competition-free substrates and diversify available dead wood types (Wikars, 1992, 1997). Fire is especially important for pyrophilic (i.e. fire-dependent) species (Wikars, 1997; Hyvärinen et al., 2009), but also more broadly, e.g. via impacts on soil processes and habitat change (Hindrum et al., 2012). Due to effective fire prevention, the area of burned forests has decreased dramatically in Fennoscandia during the last century (Zackrisson, 1977; Pitkänen and Huttunen, 1999). Prescribed burning after logging is, however, a standard practice in some regions of the world, e.g. in southeastern Australia (Baker et al., 2004). Burning forests that have been harvested with retention methods can potentially add a significant element to harvest systems and further decrease ecologically harmful effects of clear-cutting.

To evaluate the effect and possible benefits of retention trees, it is essential to understand their dynamics during the post-harvest years because this determines their role and effectiveness as legacy structures. Previous studies of retention trees have shown that the windthrown mortality of retention trees is high, especially during the first few years after logging (Hautala et al., 2004; Scott and Mitchell, 2005; Busby et al., 2006; Hautala and Vanha-Majamaa, 2006; Jönsson et al., 2007; Rosenvald et al., 2008; Lavoie et al., 2012; Urgenson et al., 2013). Fire-caused tree mortality has been explored in North American coniferous species (Ryan and Reinhardt, 1988; Swezy and Agee, 1991; Hély et al., 2003; Butler and Dickinson, 2010), but few studies are available from Fennoscandian forests (Linder et al., 1998; Sidoroff et al., 2007; Eriksson et al., 2013). All these studies concern mature forests. Many studies have explored the effects of retention forestry on species diversity and many of those studies include also burning treatment (e.g. Gandhi et al., 2004; Hyvärinen et al., 2005; Lõhmus et al., 2006; Martikainen et al., 2006; Gitzen et al., 2007; Junninen et al., 2008; Halaj et al., 2009; Halpern et al., 2012; Baker et al., 2013a). There is, however, little information on the long-term dynamics and effects of retention trees on forest ecosystems (Jönsson et al., 2007; Sullivan et al., 2011; Halpern et al., 2012; Runnel et al., 2013). In particular, there are no previous studies of tree mortality in retention harvest that simultaneously address the emulation of fire effects.

We set up a large-scale experiment where retention trees were individually monitored over a period of more than 10 years. To our knowledge, this is the first exploration of retention tree dynamics with tree-level measurements, and the study markedly adds to those, often short-term studies, that have been published so far.

In this study, we aimed to reveal how the two factors that are thought to emulate natural disturbances affect retention tree dynamics, namely the amount of retention trees and fire. More specifically, we focused on the following questions:

(1) How fast do retention trees die and fall after logging?
(2) Does burning of the logged areas affect the dynamics of retention trees?
(3) Are there differences between different tree species in their dynamics?

2. Material and methods

2.1. Study area and sites

The experimental area is situated in eastern Finland (approx. 63°N, 30°E) in the middle boreal vegetation zone (Ahti et al., 1968) (Fig. 1). Forests are coniferous and dominated by Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) Karst.) with some additional deciduous species. Most of the forests in the region have been intensively managed, especially during the last 50–70 years. Clear-cutting has been the main method for timber harvesting.

Twelve forest sites (stands) were chosen for this study. Before the harvests, these sites were ca 150-year-old pine-dominated forests that were typical mature forests in the region. The sites had not been clear-cut previously, but had signs of selective cuttings from early 1900's or late 1800's. Based on dendrochronological fire scar analyses, the forests had not burned during the past 100 years (Kaipainen, 2001).

Before the treatments, the total volume of living trees was on average 288 m^3 ha^{-1} (S.D. = 67.8) and of dead wood 40 m^3 ha^{-1} (S.D. = 16.9). Scots pine was the dominant tree species with 73% of total growing stock. Other common tree species were Norway spruce (22%) and birches (*Betula pendula* Roth and *Betula pubescens* Ehrh.) (3%). The number of spruces was higher than the number of pines, but spruces were mostly undergrowth and thus much smaller than pines. Some aspen (*Populus tremula* L.), grey alder (*Alnus incana* (L.)) goat willow (*Salix caprea* L.) and rowan (Sorbus aucuparia L.) were also present.

2.2. Experimental design

The experimental design included 12 experimental units or study sites, each 3–5 ha in area (Fig. 1). The experimental treatments were randomly applied to the experimental units. Before the treatments, there were no statistically significant differences between the treatment categories in the total volume of dead or living trees.

The sites were logged during the winter 2000/2001 and prescribed burning took place in June 2001. Six of the sites were burned within two days and in similar weather conditions. The fuel in the burning consisted of logging residues left in place in logging. Fire was an intensive ground fire, occasionally also escaping to the crowns of retention trees, particularly spruce. Fire intensity was approximated by the changes in the thickness of humus layer, of which about one third was lost in both retention levels (Laamanen, 2002). Logging residues were located outside of retention groups, but due to small size of the groups also the trees within the groups were burnt or injured by flames. More details of the burning can be found in Hyvärinen et al. (2005).

The experimental design consisted of a two-factor factorial design combining prescribed burning treatments and harvesting treatments. We applied two levels of green-tree retention: 10 m^3 and 50 m^3 per hectare, equaling to on average 3.5% and 17.4% of pre-harvest volumes, respectively. The lower retention level was chosen to be close to the silvicultural recommendations during mid-1990s, about 5–10 trees ha^{-1} (Matila et al., 1997). The higher level corresponds to the dead wood volume where saproxylic species – species dependent on dead wood – in mature forests are well-represented (Martikainen et al., 2000). There were six replications of both retention levels, of which three were burned. Consequently, there were four different treatment combinations, each replicated three times (Figs 2 and 3).

All retention trees were living trees in 2000, before the treatments. The trees were retained mostly in small groups. Each group was about 200–300 m^2 in area at lower retention level and 300–500 m^2 at higher retention level, but some trees were also left as scattered individuals. Tree species, location (coordinates), diameter and height were documented and all trees were individually numbered. The total number of individually monitored trees was 2758. Mean diameter of all trees was 19 cm (S.D. = 9.8) and mean height 15.4 m (S.D. = 6.3). Mean diameter of pines was