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Time-lagged lichen extinction in retained buffer strips 16.5 years after clear-cutting

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A B S T R A C T

Tree retention on clear-cuts is a relatively new measure in forestry aimed at 'lifeboating' forest species during young seral periods. However, the effectiveness of tree retention for maintaining biodiversity for more than a few years is still poorly known. We investigated lichen persistence in retained buffer strips along small streams after clear-cutting of the surrounding forest, and compared with clear-cuts and un-cut references. Specifically, we compared richness and frequency of red-listed/signal species, calicioids and pendulous species before clear-cutting with 2.5 years and 16.5 years after clear-cutting, and also analysed their colonization-extinction dynamics over time. The results show that the richness of red-listed/signal species and calicioids in buffer strips had declined significantly after 16.5 years, but not after 2.5 years, while frequency displayed a significant difference already after 2.5 years. The richness of pendulous lichens remained relatively stable over time, but the frequency had declined significantly after 16.5 years. In clear-cuts all groups declined more than in buffer-strips (~2–3.5 times more) and the main decline had occurred already after 2.5 years. References remained stable over time. The colonization-extinctions dynamics reflected the richness declines, with high early extinction in clear-cuts and lower but late extinction in buffer-strips, and low (re)colonization. We conclude that retained buffer strips cannot maintain lichen richness over time due to time-lagged extinction, but they are clearly more effective than clear-cuts. Wider buffer strips could potentially reduce tree mortality and decrease lichen extinction. The large amounts of standing dead wood makes buffer strips potential future colonization targets.

1. Introduction

To reduce the functional and structural contrasts between natural forests and production forests several new management practices are currently being implemented (e.g. Burton, 2003; Fries et al., 1997; Larsson and Danell, 2001). Retention of live trees, either as single trees or in groups on clear-cuts, is one important and relatively wide-spread example aimed at, to some extent, mimicking natural disturbances, with the potential of 'lifeboating' terrestrial species (i.e. maintaining species over time) during clear-cut and young seral periods (Gustafsson et al., 2010, 2012; Lindenmayer and Franklin, 2002; Rosenvald and Lõhmus, 2008). Tree retention may also benefit local species richness at later stages by increasing the structural diversity in young forests (Kruys et al., 2013) and by increasing the amount of valuable substrates, such as coarse dead wood that are created when retained trees die (Lõhmus et al., 2013). Tree retention also has the potential to restore substrates that are currently lacking in managed forests (e.g. half-shaded alive trees and dead wood). A recent review suggest that clear-cuts with tree retention have a higher richness of 'forest species' compared to clear-cuts without retention, even if several forest interior species seem to suffer in the retention patches (Fedrowitz et al., 2014). However, tree retention is still a relatively new measure (implemented less than three decades ago) and there is therefore a need of studies evaluating its effectiveness in the long run, both as 'lifeboats' and as colonization targets of substrate specialists.

Cryptogams, such as bryophytes and lichens, are strongly affected by altered forest microclimate (e.g. Esseen and Renhorn, 1998; Sillett, 1994), and therefore suitable study organisms to detect potential declines of biodiversity in retention patches. Most studies of cryptogams in retention patches to date only follow rather short-term (< 7 years) effects (Hylander et al., 2005; Lõhmus and Lõhmus, 2010; Lõhmus et al., 2006; Perhans et al., 2009; Rudolphi et al., 2014). Despite this, at least bryophytes have already been shown to decline rather rapidly in retention patches after clear-cutting (Hylander et al., 2005; Lõhmus

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et al., 2006; Perhans et al., 2009), even if the declines are less severe than in the adjacent clear-cuts (Hylander et al., 2005). However, species composition seems to continue to diverge after more than a decade, suggesting time-lags in species colonization-extinction dynamics (Hylander and Weibull, 2012). For lichens, the short-term effects seem less severe (Perhans et al., 2009; Lõhmus et al., 2006; Lõhmus and Lõhmus, 2010; Rudolphi et al., 2014), indicating that the ability to persist in retention patches may differ among taxa.

Lichens have characteristics that may make them less sensitive, compared to e.g. bryophytes, to sudden exposure to a drier and lighter environment. These characteristics include: the ability to photosynthesize using only air humidity (Phinney et al., 2018)(excluding cyano-lichens), their general preference for higher light levels (Bates and Farmer, 1992), a relatively low optimum thallus water content (Green and Lange, 1994), and the capacity to acclimate to high light intensities (Hilmo, 2002; Jairus et al., 2009). If the forest interior species persist the overall richness in retention patches may increase, as they also may become colonized by early successional lichens (Lõhmus and Lõhmus, 2010; Lundström et al., 2013). However, lichen colonization-extinction dynamics are often slow (e.g. Johansson et al., 2012), and may therefore display long time-lags in their responses to environmental change (Johansson et al., 2013). No long-term study following lichen communities in retention patches has yet been conducted, and we therefore do not know if there are time-lags in lichen responses to clear-cutting of the surrounding forest.

Lichen persistence in retention patches will most likely differ among species that differ in e.g. substrate preferences and growth form. For example, epiphytes may suffer from increased extinction if the increased wind-exposure leads to more wind-thrown trees (Lõhmus and Lõhmus, 2010; Roberge et al., 2011). Wind exposure may also cause physical damage to e.g. large pendulous lichen thalli (Esseen and Renhorn, 1998). On the other hand, the semi-open retention patches may provide important habitat that has largely been lost in production forests, such as sun-exposed and half-shaded live trees and dead wood. It has, for example, been shown that some old-forest-associated lichens grew better on more exposed trees compared to trees in closed forests (Gustafsson et al., 2013; Muir et al., 2006). Moreover, much dead wood (both lying and standing) is created in smaller tree groups after clear-cutting of the surrounding forests (Hylander et al., 2005; Jönsson et al., 2007) and thus do retention patches have the potential to offer higher densities of substrates for dead-wood dependent species than in the pre-harvest situation. However, more research is needed on the effectiveness of retention patches in maintaining a pre-logging species composition in the long run (e.g. Caners et al., 2010; Rosenvald and Lõhmus, 2008) as well as their potential to develop into valuable colonization targets that are spread in the landscape.

Riparian buffer strips are a special case of tree retention that originally was designed to preserve water quality (Blinn and Kilgore, 2001), but today is an integrated part of overall tree retention strategies in many countries (e.g. Gustafsson et al., 2010). One example is Sweden, where leaving buffer strips along watercourses is regulated by law (Gustafsson et al., 2010). The width of these strips is, however, not regulated and overall they constitute a very limited proportion ($< 1\%$) of the total harvested area. Studies of lichen persistence in buffer strips are currently lacking.

The main aim of this study was to investigate lichen persistence over time in retained buffer strips along small streams after clear-cutting of the surrounding forest. Specifically, we compare lichen species richness and frequency in 13 buffer strips before clear-cutting, with 2.5 years after, and 16.5 years after clear-cutting of the surrounding forest, and analyse their colonization-extinction dynamics over time in 1000 m^2 plots. The results are compared with clear-cuts and un-cut references. The analyses were made separately for 1) all red-listed species and species that may indicate valuable nature (signal species, Nitare, 2005), 2) all calicioid lichens (a species-rich group of crustose lichens often called 'pin-head lichens'), and 3) all pendulous lichens (three families of mostly hanging lichens that are often called 'hair lichens'). A second aim was also to investigate how different variables related to tree density change over time in the buffer strips and how this relates to changes in lichen extinction, and if the current richness is related to newly created standing dead wood.

2. Material & methods

2.1. Study area and study design

The study was conducted in boreal forests in central Sweden in the counties of Västernorrland, Gävleborg, and Jämtland (midpoint of the area: 62°40′N 16°05′E). To a large extent, the area is a managed landscape with coniferous forests on acidic bedrock (for more details see Hylander et al., 2005). Clear-cutting did not become the main logging method until the 1950s and 1960s, which means that the forests subject to clear-cutting in this study, in most cases, have not regenerated after clear-cutting (Östlund et al., 1997). However, the forests have been managed for timber production for > 150 years using less intensive methods such as removing the largest trees and regularly taking out uprooted trees after storms. Hence, these forests have a wider distribution of tree ages (and tree species) compared to a stand that has regenerated after clear-cutting. They also probably contain slightly more dead wood, but compared to unmanaged forests the dead wood amounts are clearly lower.

In 1998, we randomly selected 13 stands, intersected by a small stream (0.5–1 m wide), which were planned for clear-cutting by the forest company SCA (Svenska Cellulosa Aktiebolaget). All the selected stands were mature stands with trees varying in age between 86 and 146 years, measured by coring an average sized tree in each stand. Dominant or frequent tree species were Norway spruce *Picea abies*, Scots pine *Pinus sylvestis* and birch *Betula* spp. In each stand, two 0.1 ha plots (50 × 20 m) were established along the stream with the stream crossing the middle of the short side of the plots (Fig. 1). One plot was placed in an area subjected to clear-cutting, and the other in a buffer strip (see below). The average minimum distance between two stands was 9.9 km. We also established one plot each in 9 reference stands not intended for clear-cutting (in formally protected or voluntary set aside areas). The references were dispersed in the same landscape as the treatment stands, and the average minimum distance to a treatment stand was 12.4 km. All plots (i.e. both treatments and references) were permanently marked with aluminium rods in the middle of each short side. The references were similar to the treatment stands in terms of tree species composition and no signs of recent disturbance, but were probably on average older, and a few of them had considerably more dead wood. This was not considered a major problem because the main aim with the references was to account for changes in inventory efficiency over the years. In all of these plots we surveyed both species (see below) and environmental variables. In the winter of 1998/99, the 13 stands were clear-cut according to our instructions, leaving a buffer zone (10 m on each side of the stream) along one half of each study site (containing the buffer strip plot), while removing living trees from the rest of the stand (Fig. 1). These sites were re-inventoried in 2001 (2.5 years after logging) and in 2015 (16.5 years after logging).

2.2. Study species and environmental data

We surveyed 1) all red-listed species (Gärdenfors, 2015) and species that may indicate valuable nature and a high probability of finding red-listed species (signal species henceforth, Nitare, 2005; Skogsstyrelsen, 2014), as these are of general interest for conservation. Moreover, we also included 2) all calicioid lichens ('pin-head lichens') and 3) all pendulous lichens ('hair lichens') as two groups that are known to contain many species that are negatively affected by production forestry (e.g. Esseen et al., 1996; Selva, 2003), but differ in growth form and substrate preferences. Calicioid species are crustose (i.e. grows