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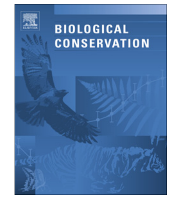

Winter – the optimal logging season to sustain growth and performance of retained epiphytic lichens in boreal forests

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Epiphytic lichens, comprising an important biodiversity component with significant functions in old boreal forests, are susceptible to logging. Leaving retention trees may partly compensate for the adverse effects of logging, but the impact of logging season on retained lichens is unknown. To identify the least harmful logging season seen from an epiphytic lichen perspective, we simulated logging events by transplanting two old forest model species – *Lobaria pulmonaria* (cephalolichen) and *Lobaria scrobiculata* (cyanolichen) – in summer, autumn, winter and spring, respectively. Lichens were collected in intact old forests and transplanted in clear-cuts. They were placed on five aspects (N, E, S, W, and top) on artificial stands covered with bark. They all gained biomass and area in the following year. However, logging in January resulted in subsequent higher relative growth rates than in lichens being exposed to clear cuts in other seasons, consistent with clear seasonal logging effects. Aspect impacted lichen growth less than logging season, despite significant bleaching and chlorophyll contents in the most exposed aspects. The high annual growth rate and the low level of damage after transplantation to clear cuts during winter suggest that green tree retention (GTR) logging practices in winter can support life-boating of susceptible old forest lichen epiphytes. Logging simulation during other seasons than winter resulted in lower growth, implying higher risk of permanent damage. Successful use of GTR cannot compensate for the loss of epiphytes at timber harvest, but supports local retained lichen populations that subsequently may boost re-colonization of the young stand.

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1. Introduction

Epiphytic lichens significantly contribute to the biodiversity of photosynthetically active organisms in old forests (e.g. Lesica et al., 1991; Neitlich and McCune, 1996). However, logging adversely affects forest lichens (e.g. Esseen et al., 1996; Berglund and Jonsson, 2005; Hedenås and Hedström, 2007). Recent forestry certification systems aim to establish more sustainable forest management practices, like green tree retention (GTR) practices (Gustafsson et al., 2012), to compensate for biodiversity loss. GTR has a potential to combine the need for timber harvest and protect at least some biodiversity components, but its potential for biodiversity conservation varies among species (Fedrowitz et al., 2014). Epiphyte survival at local stand scales requires retention tree practices. However, remaining epiphytes after logging are suddenly exposed to increased light, wind and desiccation. Increased light may stimulate their growth (Gauslaa et al., 2006), but excess light may cause photoinhibition and chlorophyll degradation (Gauslaa and Solhaug, 1996, 2000; Färber et al., 2014). Early studies showed satisfactory lichen survival (Hazell and Gustafsson, 1999) and growth (Muir et al., 2006) in GTR patches. Common habitat generalists persist at least 5 years after logging, and suffer mostly by post-logging host tree loss (Lõhmus and Lõhmus, 2010). The diversity of generalist species may increase over the years in GTR patches, although not of old forest lichens like the cephalolichen *Lobaria pulmonaria* (Gustafsson et al., 2013). In general, long-term studies of monitoring responses and survival of old forest lichens are few.

Because changed microclimate affects epiphyte performance (Sundberg et al., 1997; Gaio-Oliveira et al., 2004; Gauslaa et al., 2007), the season of logging likely influences subsequent survival and growth of retained epiphytes (discussed in Muir et al., 2006). Also the aspect of remaining epiphyte-inhabited surfaces greatly influences the level of irradiance and lichen performance in an open field (Gauslaa et al., 2001). Because the solar radiation exposure changes in aspect-dependent ways during a year, it is important also to study how effects of aspect interact with those of logging season. Thus, there is a need for factorial experiments studying effects of aspect and logging season on growth and performance of retained lichens.

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This study aims to quantify annual growth and viability in lichens transplanted on stands in clear-cut situations at contrasting, but standardized aspects in each of the four seasons. To do so, we re-analyze a data set (Larsson et al., 2012) focusing on short-term (3 month periods) seasonal-wise acclimation and growth of two old forest model lichens (the cyanolichen *Lobaria scrobiculata* and the cephalolichen *L. pulmonaria*). However, in this paper we will search for growth patterns across entire year cycles. Unlike cyanolichens, depending on rain or dew for activation of photosynthesis, lichens with green algae as their only (chlorolichens) or main photobiont (cephalolichens) can additionally activate photosynthesis in humid air (Lange et al., 1986). Therefore, cephalo- and cyanolichens have only partly overlapping ecological niches, with cyanolichen dominance inside rainforests (e.g. Marini et al., 2011) and cephalolichens extending to exposed edges (Green et al., 1993). Thus, there is a need to study effects of aspect and logging season on both these functional groups often restricted to forests with long ecological continuity (e.g. Rose, 1976). Our experiment mimics seasonal logging by transplanting lichens from intact forests into clear-cuts in summer, autumn, winter, and spring, respectively. By computing annual relative growth rates and assessing lichen viability proxies one entire year after transplantation in each respective season, we can test the hypothesis that logging season alone and/or in aspect-dependent ways influences growth of old forest epiphytic lichens. By studying taxonomically related species in two important functional groups, we will search for patterns that may help to understand cyano- versus cephalolichen occurrences in managed forests.

2. Material and methods

2.1. Lichen material and collection sites

The two foliose lichens *L. pulmonaria* (L.) Hoffm. and *L. scrobiculata* (Scop.) DC., were collected in four seasons in boreal *Picea abies*-dominated forests in Namsos, western Norway. At each of the four sampling occasions, lichens were collected from *Picea abies, Salix caprea,* and *Alnus incana* in a number of localities (64°20–25′N, 11°16–30′E) where the two species occurred abundantly. Air-dried lichens were transported to the lab, and 2–6 healthy, full-size lobes (*L. pulmonaria*: 0.12 ± 0.001 g; 11.9 ± 0.13 cm^2, *L. scrobiculata*: 0.13 ± 0.002 g; 10.0 ± 0.11 cm^2) were cut from each specimen. Lobes across specimens and localities were randomized, cleaned from debris and attached bark, and rinsed in deionised water. Area (A) was measured while hydrated with a leaf area meter (LI3100 Licor; Lincoln, Nebraska). Afterwards, the lichens desiccated at room temperature in the lab for 48 h before recording their mass. Ten additional samples of each species, subjected to the same treatment as the transplants, were used for correction of residual water content. After recording mass of these additional samples, they were dried at 70 °C for 24 h and re-weighed. The mass reduction, representing the water content in air-dried samples, was used to transform the air-dry mass of transplanted thalli into oven-dried mass (DM).

2.2. Transplantation sites and experimental design

Lichens were transplanted in boreal clear cut patches (2.2 ha) differing in aspects and slope in a gently undulating rocky terrain in Ski, E Norway (59°45′N, 10°56′E) to mimic logging events. Surrounding forests were dominated by *P. abies* ⩾ 70 yrs. Both lichen species sparsely occurred in nearby surroundings. Climate was sub-oceanic with cold winters and mild to warm summers with total precipitation of 931, 1086, 1164 and 997 mm, respectively (Thue-Hansen and Grimenes, 2010), in the four annual transplantation periods July 2007-July 08, Oct. 07-Oct. 08, Jan. 08-Jan. 09, and April 08-April 09 (climatic details, see Larsson et al., 2012).

Collection of lichens was done 7–12 days prior to transplantation in each season (4 July, 6 Oct, 3 Jan and 7 April). Each seasonal set consisted of 120 lobes of each species. Two randomly selected mature lobes of each species were fastened with flax thread (as illustrated in Gauslaa and Goward, 2012) to each of 60 plastic nets. The lobes were attached in their basal parts, leaving the pendant tips free as in their natural position to allow curling during desiccation. Curling is a mechanism to reduce photoinhibition during desiccation by self-shading (Barták et al., 2006).

The nets were attached by plastic staples to five aspects; south, west, north, east, and top on twelve wooden boxes covered with *Alnus incana* bark (Fig. 1). The top was tilted 25° toward south to face the sun perpendicularly at noon in summer, and to allow water runoff. The vertical aspects are ecologically relevant for lichens on exposed tree trunks, whereas the top represents a position for lichens on exposed, south-facing branches. The boxes were fastened 1.5 m above ground on twelve wooden poles inserted into the soil. These twelve stands were randomly placed at sites located away from the edge of clear-cuts (at least twice the tree height of the neighboring stand away from the edge). Thus the slope and aspect of the soil surface varied between the sites, although no stand was shaded by adjacent vegetation.

All transplants in each of the four sets experienced a clear-cut environment for one year. Transplant DM and A were measured at the start and at the end of each entire one year transplantation period. Every new season all nets were brought to the lab to attach another set of freshly collected lichens from the source forests in vacant positions between the already transplanted specimens. The name of each annual set referred to the month (January, April, July and October) for transplantation.

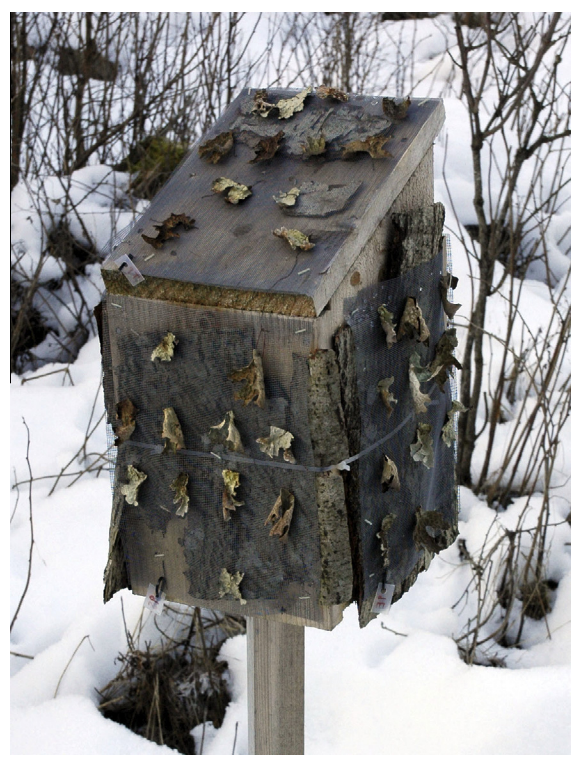

Fig. 1. The transplantation stand (box) with lichen transplants during a dry period in winter. The south, top, and eastern sides are seen. The photo was taken in winter while three of four sets of transplants were in place.

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