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Survival and vitality of a macrolichen 14 years after transplantation on aspen trees retained at clearcutting

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ABSTRACT

Industrial forestry has caused large biodiversity changes in European boreal forests. One recently introduced conservation measure in production forestry is retention of trees at clearcutting to benefit flora and fauna. Aspen *Populus tremula* is often retained for conservation purposes since it is a key tree species for biodiversity with many associated species, a number of which are red-listed. Still, the importance to biodiversity of aspen trees retained at harvest is largely unknown. In 1994, a transplantation experiment with the old-growth forest indicator lichen *Lobaria pulmonaria* was set up on 280 aspens at 35 sites in east-central Sweden with a total of 1120 transplants, with the aim to assess the habitat suitability of retained aspens following harvest. After 14 years 23% of *L. pulmonaria* transplants remained, with a significantly higher survival on retained aspens than on aspens in the surrounding forest, especially on the northern side of stems. Transplants were also more vital on northern than on southern sides of stems. There was no difference in survival or vitality of transplants between dispersed aspens and aspens in groups. Results largely agreed with a re-inventory made already after two years but the importance of the north side of retention trees became evident for species survival only after 14 years, indicating that to gain deeper insights longer time-spans may be necessary. This study, which is the longest lichen transplantation time-series from a well replicated experiment so far published, shows that retention of trees at harvest may be an efficient conservation action.

1. Introduction

The global trend of declining biodiversity (Butchart et al., 2010) is evident also in the boreal forest biome, which amounts to about 30% of the world's forest area, running circumpolar on the northern hemisphere (Hansen et al., 2010). Clearcutting, i.e. removal of all trees at harvest, is a main forest operation technique for industrial forestry in boreal forests. To counteract associated negative ecological effects, retention approaches have been introduced during the last two decades implying that e.g. some living old trees are left at harvest (Gustafsson et al., 2012). A key function of retained trees is lifeboating, i.e. to provide refugia for species that would otherwise be lost at harvest (Franklin et al., 1997). Studies on the retention approach in forestry point to positive biodiversity effects compared to traditional clearcutting (Rosenvald and Lõhmus, 2008), although low retention levels in Fennoscandia raise questions regarding its effectiveness to promote flora and fauna (Gustafsson et al., 2010).

European aspen *Populus tremula* L. and the closely related and ecologically similar Quaking aspen *P. tremuloides* Michx. in N. America are distributed over wide areas on the northern hemisphere (Farmer, 1997; Worrell, 1995), and are key hosts for hundreds of species (Kouki et al., 2004; Rogers and Ryel, 2008; Lõhmus, 2011), including red-listed species (Tikkanen et al., 2006). In Sweden it is a minority tree species comprising on average only 1.5% of the total tree volume on the productive forest land (Swedish Forest Agency, 2012). Aspen is prioritized as a retention tree and often large-diameter aspens are left un-harvested at clearcutting. There are uncertainties to which extent species associated with old, more closed forests can survive on retained aspens in the relatively large open environment after final harvest.

Transplantation of lichens is a common tool in research to monitor air pollution (e.g. Nimis et al., 2002), to study growth and ecology of species (e.g. Coxson and Stevenson, 2007a,b), and to assess if the technique can be used to relocate threatened species (e.g. Lidén et al., 2004). Most studies so far embrace only short time periods, e.g. up to one year: Sillett and McCune (1998), Gauslaa et al. (2006) or two to three years: Scheidegger et al. (1995), Keon and Muir (2002). The longest time-series published to date is a study on *Lobaria amplissima* (Scop.) Forssell on old deciduous trees in N. England, starting with 14 transplants of which six remained after 20 years (Gilbert, 2002). Very few studies on retention trees have used an experimental approach including transplantation. One exception is a study by Hazell and Gustafsson (1999) in which

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the macrolichen (large lichen, as opposed to small microlichens) *Lobaria pulmonaria* L. Hoffm. and the bryophyte *Antitrichia curtipendula* (Hedw.) Brid. were transplanted to aspens in clearcuts, as indicators for habitat suitability of retention trees to sensitive species, with adjacent forest trees as control. Two years after transplantation, distinct patterns emerged with high survival and vitality of both species on clearcut trees. The short time-span restricts conclusions though, and uncertainties have remained whether this is a long-lasting response. Transplants in long time-series are likely to be exposed to large variations in environmental conditions, such as altered microclimate in forest successions following clearcutting, due to change in tree density. They may also be affected by biotic interactions like competition from mosses. We here report a re-inventory of the *L. pulmonaria* transplantation experiment of Hazell and Gustafsson (1999), 14 years after its initiation and with an original sample size of more than 1100 transplants on 280 aspens at 35 sites. It is the longest lichen transplantation time-series so far published from a well replicated experiment. Our main question was if *L. pulmonaria* is able to survive, and if so, how vital it will be on aspen trees retained at final harvest in comparison with forest trees. Other important questions were: What are the differences in survival and vitality of transplants between scattered aspens and aspens retained in small groups?, What is the effect of transplantation occasion (spring or autumn)?, and Do response patterns found after the first inventory two years after transplantation correspond to those 12 years later? Our primal interest in the transplantation outcome was based on an aspiration to gain knowledge necessary for the formulation of more specific advice on how to retain aspen trees at final harvest to benefit biodiversity.

2. Materials and methods

2.1. The study species L. pulmonaria

L. pulmonaria is a large, epiphytic, foliose, macrolichen with a total distribution area embracing Europe, Asia, Africa and N. America (Yoshimura, 1971). In boreal Fennoscandia it mainly grows on aspen *P. tremula*, goat willow *Salix caprea* L., and *Sorbus* species (Jørgensen and Tønsberg, 2007), and is most abundant in old forest (e.g. Gjerde et al., 2012). The species disperses mainly vegetatively (isidia, soredia), and rarely sexually with spores. *L. pulmonaria* has declined drastically during recent decades in Europe due to forest management and air pollution (Gaio-Oliveira et al., 2004) and possibly also due to old forests becoming denser (Gauslaa et al., 2007). It is today found in small and isolated populations, and is red-listed in several countries, among them Sweden (Gärdenfors, 2010). The species is commonly used in lichen transplant experiments (e.g. Scheidegger, 1995; Gaio-Oliveira et al., 2004; Gauslaa et al., 2006). It has also since almost two decades been used as an indicator species to identify forest habitats with high conservation value in Sweden, as field experience has shown that it reflects the presence of other uncommon and declining species (Nitare, 2005). There are also indications that the species may reflect high conservation values at the landscape scale (Kalwij et al., 2005). At the initiation of our transplantation experiment in 1994, *L. pulmonaria* was not red-listed in Sweden (Databanken för hotade arter and Naturvårdsverket, 1990).

2.2. Study area and experimental design

The study area is located in the hemi-boreal zone (Ahti et al., 1968) in East-Central Sweden (60°02′N, 18°22′E). The proportion of forest >80 years old in the region is 24%, with Norway spruce *Picea abies* (L.) H. Karst. and Scots pine *Pinus sylvestris* L. being the dominant tree species, but the proportion of aspen is unusually high, 4% (Swedish Forest Agency, 2012). Altogether 1120 pieces of *L. pulmonaria*, each about 6 cm^2 large, were transplanted in spring and autumn of 1994 to 280 aspens at 35 sites (Table 1). Each site consisted of a forest and a clearcut, with four receiver aspen in each, i.e. altogether eight trees per site. In 19 clearcuts the receiver trees were solitary (scattered) and in 16 sites they occurred in groups of broad-leaved trees (grouped: >3 aspens >18 cm diameter at breast height and <15 m from each other). The 35 sites were situated within an area of 1900 km^2, with an average distance between them of 24.7 km (range 0.4 - 65 km). In spring as well as in autumn of 1994, two transplantations were made per tree, one on the north and one on the south side of the stems 140 to 180 cm above ground level, amounting to a total number of four transplants per tree. The thallus pieces were attached to the stem with the help of a plastic net (6 × 6 cm with 1 × 1 cm meshes) and metal staples to the bark. Each sample was sprayed with tap water immediately after transplantation.

Table 1
Numbers of receiver trees and *Lobaria pulmonaria* transplants in the different retention types at different years. Transplants include all survived transplants, i.e. exclude those that died or disappeared from tree fall, etc.

	Scattered	Grouped	Forest	Total
Original no of receiver aspens 1994	76	64	140	280
No of aspens with transplants 1996	74	64	132	270
No of aspens with transplants 2008	65	50	93	208
Original no of transplants 1994	304	256	560	1120
Transplants in 1996	252	234	462	948
Transplants in 2008	116	77	61	254

2.3. Assessment of survival and vitality of the transplants

All transplantation sites were visited in summer 1996 and spring 2008 to visually evaluate survival and vitality of the transplants. Prior to evaluation, transplants were sprayed with water in order to enable relevant comparisons since dry and wet *L. pulmonaria* thalli differ in color. If any thallus part remained, the transplant was judged as having survived. If ⩾50% of a survived thallus was in a viable condition (i.e. giving a healthy impression with a green, intact surface without necrosis or signs of damage), the transplant was assessed as being vital. Some transplants were lost due to tree fall, but in 1996 altogether 270 (96%) and in 2008 altogether 208 (74%) trees remained and transplants on these were surveyed (Table 1).

2.4. Control transplantation at collection site

During the setting up of the experiment in 1994, a control transplantation was made at the site of lichen collection, Skånberget, Ramsjö, in the province of Hälsingland, in south boreal Sweden, ca 300 km north of the experimental area. On the north and south sides of 20 trees material of two types was mounted, such that had been frozen for more than one month, i.e. resembling the treatment in the experiment, and also fresh material, in total amounting to 80 transplants. The survival and vitality of these transplants were re-assessed in August 2008.

2.5. Data analysis

Generalized linear mixed models (GLMMs) with logit link functions and Laplace approximation (Bolker et al., 2009) were first applied to test the effect of tree retention, aspect, and transplantation time for transplant survival and vitality in 2008, and second to assess if there was a significant difference in the variables that described survival and vitality in both survey years. The effect of