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Research paper

Forest history and epiphytic lichens: Testing indicators for assessing forest autochthony in Switzerland

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ABSTRACT

Epiphytic lichens are widely used to indicate old undisturbed forest stands with a long forest history that are of outstanding interest for biodiversity conservation. Swiss forest stands without any significant human impact like clear-cut or afforestation that have natural tree species composition and a continuous forest cover during the last 120 years are considered to be autochthonous. In this study nationwide indicators of forest autochthony were developed using the Swiss National Forest Inventory data on forest structure, forest history and forest management from about 6500 sample plots across the country. We selected a set of epiphytic lichen taxa (n = 19) that due to their low dispersal range or specific substrate requirements are mostly restricted to old-growth forests and are easy to recognize in the field by forest practitioners. The indicator species analysis was performed separately for Swiss mountain (n = 3510) and lowland forests (n = 2952). Overall, the number of indicator lichens was higher in autochthonous forests and varied significantly with biogeographical region. Forest autochthony had a significant impact on the occurrences of indicator lichens at high altitudes but not in lowland forests. This effect was probably due to habitat and substrate preferences of some indicator lichens and also the fact that Swiss mountain forests were less affected by forest management. The fruticose species, i.e. *Bryoria* sp., *Evernia divaricata*, *Letharia vulpina*, *Usnea* sp., pin lichens as well as *Chrysothrix candelaris*, *Cetrelia olivetorum* and *Lobaria pulmonaria* were found to be reliable indicators of forest autochthony in Swiss mountain landscapes. However, these species were not exclusively present in autochthonous forest habitats, which is why the co-occurrence of several different indicator lichens should be considered to adequately indicate autochthonous forest stands. In Swiss lowlands we did not reveal the association of indicator lichens tested to autochthonous forest stands and thus further research is needed to select an effective set of lichen indicators for such lowland forests. Our results are, however, valuable for the development of a national monitoring program to detect autochthonous forest stands that are target areas for biodiversity conservation.

1. Introduction

Biodiversity conservation is a priority in regions where the proportion of protected areas or unmanaged forests is relatively low. Several studies have highlighted the importance of old undisturbed forest stands with a long forest history for conservation of different taxa, especially of species with low dispersal abilities (Graae and Sunde, 2000; Nordén and Appelqvist, 2001; Sverdrup-Thygeson and Lindenmayer, 2003; Graham et al., 2006; Kriebitzsch et al., 2013; Brin et al., 2016). This has resulted in a growing need for appropriate approaches to indicate the long-term persistence of forest habitats for effective forest monitoring and conservation planning.

Many forest organisms, including epiphytic lichens, have been used as indicators of ecological continuity of forests although some methodological approaches have been criticized as being ambiguous and lacking a solid scientific basis (Nordén and Appelqvist, 2001; Rostald et al., 2002). However, several studies clearly showed that some epiphytic lichens are more restricted to old-growth than young forests because their low dispersal range or specific substrate requirements (Kondratyuk et al., 1998; McCune, 2000; Coppins and Coppins, 2002; Will-Wolf et al., 2002; Ellis, 2012; Giordani et al., 2012; Nascimbene et al., 2013; Nelson et al., 2015; Whittet and Ellis, 2013; Arsenault and Goward, 2016). Epiphytic lichens as indicators of forest continuity, which can be evaluated by comparing the presence of forest stands on

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historical (mainly 17th–19th centuries) and current maps, were first tested in Great Britain (Rose, 1974, 1976) and since then are widely applied in different geographical regions (Coppins and Coppins, 2002; Fritz et al., 2008a; Josefsson et al., 2005; Ellis and Coppins, 2007; Whittet and Ellis, 2013; Boch et al., 2013; Marmor et al., 2011). The required duration of forest continuity for enabling indicator lichens to colonize a forest stand was assumed to be at least 350–400 years in beech-dominated forests (Fritz et al., 2008a) and about 200–350 years in coniferous forests (Gauslaa and Ohlson, 1997; Tibell, 1992; Marmor at al., 2011).

In most European countries ancient woodland has been defined as wooded sites for at least 200–250 years (Wulf, 2015) and more than 400 years in Great Britain (Peterken, 1994). Today, only 0.4% of forest stands in Switzerland are older than 250 years (Brändli et al., 2015) because they were generally over-exploited during the 18th–19th centuries (Lanz et al., 2016). Besides the first Swiss forest maps available at a national level are dating back to 1880 (‘Siegfriedkarten’) and thus, forest history in Switzerland cannot be characterized with the terms ecological continuity or ancient forest. In our study we focus on the concept of forest autochthony. The notion of forest autochthony plays an important role in the respective European Communities legislation and regulations that define autochthonous forest stands as ‘one which normally has been continuously regenerated by natural regeneration’ (Council Directive 1999/105/EC, Article 2d). When applied to tree populations the term autochthony is used to strictly indicate continuous existence at a specific site for ‘sufficiently’ long time span (Schoppa and Gregorius, 2001; Kleinschmit et al., 2004). Thus, in our study we define autochthonous forest stands with regard to these main criteria, i.e. having natural tree species composition and existing continuously during the last 120 years or more. This also means that no evidence of significant human impact like clear-cut or afforestation should be available for these forest plots.

Large-scale monitoring programs using lichens as indicators of forest biodiversity and ecosystem function have been developed at the local and national levels in many regions of the world (Ek et al., 2002; Will-Wolf et al., 2002; Stofer et al., 2003; Giordani et al., 2006). Such broad monitoring studies are usually restricted to macrolichens or easily recognized subsets of lichen communities. This approach allows large geographical regions to be investigated without involving highly trained lichen specialists and is, therefore, cost and time effective (Bergamini et al., 2007). However, preliminary evaluative research in monitoring areas has to be performed to establish the statistical and causal relationships between the selected indicator species and the aspects of ecosystem function for which it is considered to be indicative (Will-Wolf et al., 2002). A detailed lichen monitoring in Switzerland was performed by experienced professional specialists to assess the overall epiphytic lichen diversity and to evaluate endangered forest lichens that require conservation measures at the national level (Scheidegger et al., 2002; Scheidegger et al., 2015). In 2004–2006 a set of epiphytic lichens was surveyed by forest practitioners during the third National Forest Inventory (NFI) to evaluate their utility for indicating the autochthonous forest stands in Swiss landscapes. The NFI is the most important source of data on the condition and development of the Swiss forests (Brändli and Brändli, 2015). One of its objective is to monitor the ecological quality of forest habitats and develop appropriate survey methods. The NFI monitoring program was started in 1983 and to date, the fourth cycle has almost been completed with a total of about 6500 forest sample plots surveyed all across the country (www.lfi.ch, Brändli and Speich, 2005).

The aim of this study is to develop nationwide indicators of forest autochthony in Swiss forest landscapes using NFI data on forest structure, forest history and forest management. These indicators are considered as a simple and efficient complementary tool for forest practitioners to detect autochthonous forest stands that are target areas for biodiversity conservation. Specifically, we addressed the following questions: i) what is the importance of forest autochthony for the occurrence of the selected lichen species; ii) does the distribution of the selected lichens in autochthonous forests differ between Swiss mountain and lowland areas? iii) how does tree age affect the distribution of the selected lichens? This also involves assessing whether the data recorded by non-specialists in the NFI survey of indicator lichens are of adequate quality.

2. Materials and methods

2.1. Study area

The study area is the whole of Switzerland, which covers 41,244 km^2 in Central Europe. The altitude ranges from 193 m a.s.l. to 4634 m a.s.l. The climate is temperate, with strong oceanic and continental influences due to mountain effects. The mean annual temperature ranges from −10.5 °C to 12.5 °C, and the annual precipitation from 438 to 2950 mm (Zimmermann and Kienast, 1999). More than 30% of the country is covered by forests (Cioldi et al., 2010) with the climatic timberline at 1800 m a.s.l. in the West and up to 2450 m a.s.l. in the Central Alps. The tree species composition varies considerably along the altitudinal gradient. The montane belt consists mainly of mixed broadleaf-conifer forests with dominant European beech and silver fir. In the driest areas, pine trees occur more often, while conifer forests with mainly Norway spruce or larch predominate in the subalpine belt. In the lowland the forests are largely broadleaved and mostly dominated by European beech, but much of the area today is either built-up or used for intensive agriculture (Vittoz et al., 2013).

2.2. Lichen survey by Swiss NFI

A total of 19 epiphytic lichen taxa were tested in the field as potential indicators of forest autochthony in Switzerland (Table S1). These were selected because they are supposed to be easy to recognize in the field by forest practitioners and have been proved to be good indicators of old-growth forests in other regions (Coppins and Coppins, 2002; Ek et al., 2002; Fritz et al., 2008a). A balanced number of lichen species in low- and high altitude forests as well as in suboceanic and subcontinental regions was also taken into consideration. Any small specimens of *Dolichousnea longissima* and *Sphaerophorus* sp. found were always sent to the lichenologists to confirm the identification, but were then excluded from further analysis because of frequent misidentification. Lichen species recorded only once, i.e. *Mycoblastus sanguinarius, Nephroma* sp. and *Sticta* sp. were also not analyzed. Thus, only 14 lichen taxa were included in the final analyses.

The lichen survey was conducted during the third NFI inventory in 2004–2006. A total of 6462 circular sample plots (500 m^2) 1.41 km apart from each other were surveyed in the forest areas across the country (Lanz et al., 2016). The lichen survey was done by 12 field teams, each consisting of a forester and a forest engineer, who had attended a preliminary one-day introductory course on how to observe and identify selected lichen indicators in the field with the help of a field manual (Keller, 2011). The manual contained a short description of the morphological features and photographs of the indicator lichen taxa. Each field team was also provided with a set of reference specimens of indicator species to confirm species identification on the spot during the inventory of each plot. Nearly 10% of all plots were additionally surveyed by an independent field team to check the reproducibility of the data (quality assessment).

Lichen species growing up to a height of 2 m above ground were assessed with a magnifying glass, on standing living or dead trees within the 0°– 90° sector of the sample plot (on average 3 trees per plot). The abundance of each lichen indicator at the plot level was calculated by adding up all its occurrences recorded on different trees within one sample plot.