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Bryophytes as indicators of ancient woodlands in Schleswig-Holstein (Northern Germany)

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ABSTRACT

Ancient woodlands, with their long ecological continuity, frequently harbor a high number of typical, rare and threatened species, and are therefore of particular importance for nature conservation. To pinpoint these habitats, a common application is the use of plants as "ancient woodland indicators". The occurrence of these particular species allows for evaluating the continuity of woodland cover in time. While lists of ancient woodland vascular plants have been derived for many regions, the identification and use of bryophytes as ancient woodland indicators has been widely neglected. This is a bit surprising because certain woodland bryophytes are very sensitive to varying environmental conditions or changes in land management. It therefore appeared promising to compile an ecologically grounded list of ancient woodland indicator bryophytes for practical use.

In this study, we present a set of ancient woodland indicator bryophytes based on the analysis of datasets from the North German federal state of Schleswig-Holstein. To compile this list, we systematically evaluated the bryophyte distribution data from floristic surveys in relation to ancient woodland cover data from state-wide inventories. In this way, we were able to determine ancient woodland bryophytes using consistent and repeatable statistical methods.

The presented list of 31 ancient woodland indicator bryophytes is ecologically sound and corresponds well with data from the sparse literature. We could distinguish two groups of ancient woodland indicator bryophytes. The first group is linked to base-rich, semi-natural deciduous woodlands with high soil and air humidity. The second group comprises acidophilic bryophytes that occur not only in acidic beech and oak woods, but also in acidic mixed or coniferous forests on ancient woodland sites. Apart from the ancient woodland indicator bryophytes, we could identify one group of recent woodland bryophytes and four groups of bryophytes that are more or less indifferent with respect to woodland continuity.

Finally, we provide recommendations for the application of ancient woodland indicator bryophytes in nature conservation practice. Management suggestions for the conservation of the typical bryophyte diversity of ancient semi-natural woodlands are also given.

1. Introduction

The use of plants as ecological indicators is an important topic of applied vegetation research. Since the occurrence of many plant species is bound to certain site conditions or shows a linkage to the intensity of land use, indicator species lists have been developed for many purposes (Ferris and Humphrey, 1999; Ellenberg et al., 2001; Diekmann, 2003; Nordén et al., 2007; Culmsee et al., 2014). In European forest nature conservation, a common application is the use of particular plants as "ancient woodland indicators". The occurrence of these species allows for evaluating the continuity of woodland cover in time (Peterken, 1974; Rose, 1999; Hermy and Verheyen, 2007; Schmidt et al., 2014). Since woodlands with long ecological continuity frequently harbor a high number of typical, rare and threatened species, they are of particular importance for nature conservation (Hermy et al., 1999; Grove, 2002; Rolstad et al., 2002; Buse, 2012; Bhagwat et al., 2014).

The term "ancient woodland" indicates land that has been continuously wooded for several centuries. However, the length of this time span is not consistently defined among different regions. In the British definition, "ancient woodland" describes land that has been continuously wooded since at least 1600 AD (Spencer and Kirby,

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1992; Goldberg et al., 2007; Stone and Williamson, 2013). In Central Europe the term "ancient woodland" refers to land that has been continuously wooded since at least 1800 AD, since it is only from this point on that area-wide coverage data on historically old woodland sites are available. In contrast, the term "recent woodland" is used for woodland established after 1800 AD (Wulf, 2003; Glaser and Hauke, 2004; Buse, 2012; Matuszkiewicz et al., 2013). The Central European definition is applied in this study.

While lists of ancient woodland vascular plants have been derived for many regions or even on the supra-regionally scale (Hermy et al., 1999; Rose, 1999; Schmidt et al., 2014), the identification and use of bryophytes as ancient woodland indicators has been the subject of only a few studies (Rose, 1992; Gustafsson et al., 1992; Bates et al., 1993; Homm, 1999; Nitare, 2000; Woodland Trust, 2007; Fichtner and Lüderitz, 2013). This is a bit surprising because certain woodland bryophytes are very sensitive to varying environmental conditions or changes in land management (Ratcliffe, 1968; Laaka, 1992; Nordén and Appelqvist, 2001; Fenton and Frego, 2005; Schulz and Dengler, 2006; Baldwin and Bradfield, 2007; Kriebitzsch et al., 2013). Therefore, it appears promising to compile ecologically grounded lists of ancient woodland indicator bryophytes for practical use. In this study, we develop such an indicator species list for the North German federal state of Schleswig-Holstein (situated in the southern part of the Jutland Peninsula) by generally applying the innovative methodical approach recently described by Schmidt et al. (2014). Hence, we systematically evaluate the bryophyte distribution data from floristic surveys in relation to ancient woodland cover data from state-wide inventories. In this way, we are able to determine ancient woodland bryophytes using consistent and repeatable statistical methods (Schmidt et al., 2014). This methodical approach also enables us to identify recent woodland bryophytes. These species can be used, for example, for a "negative control" of ancient woodland sites.

In the Pleistocene lowlands of Schleswig-Holstein, ancient woodlands are scattered and embedded within an agricultural landscape (Härdtle, 1995; Hase, 1997; Mölder et al., 2014). We would therefore expect a strong association of certain woodland bryophyte species with these ancient woodlands. If, on the other hand, the ancient woodlands showed a smaller degree of ecological isolation, we would suppose a lower linkage between woodland continuity and the occurrence patterns of woodland plant species (Ferris and Humphrey, 1999; Schmidt et al., 2009). In addition, the study area is covered by a program mapping the distribution of bryophytes with a resolution of ca. 30 km^2 (Schulz and Dengler, 2006) and so provides a promisingly large data set.

In developing the list of ancient woodland indicator bryophytes for Schleswig-Holstein, we address the following questions:

(1) Which forest bryophyte species can be classified as ancient or recent woodland bryophytes for the area of Schleswig-Holstein?
(2) Are there groups of ancient or recent woodland bryophytes that are related to certain environmental conditions of different woodland types?
(3) Can the identified ancient woodland bryophytes be used as suitable indicators for application in forestry and nature conservation practice?

2. Material and methods

2.1. Study area

The study was conducted in the north German federal state of Schleswig-Holstein and the area of investigation covered 15,799 km^2. Based on the German network of topographical maps (scale 1:25,000), the study area was divided into a grid of 620 cells, of which each grid cell had a resolution of approximately 5.5 km × 5.5 km or 30 km^2 (Fig. 1).

In the Pleistocene lowlands of Schleswig-Holstein, natural woodlands would be dominated by deciduous tree species, especially beech (*Fagus sylvatica*). However, as elsewhere in Central Europe, there are no remaining woodlands that are completely unaffected by long-term human activity (Day, 1993; Härdtle, 1995; Szabó, 2009; Arnold, 2011; Wieckowska et al., 2012). By 1780, after centuries of unregulated logging and clearing for agriculture, only about 75,000 ha (ca. 4.7% of the present-day area of Schleswig-Holstein) was covered with woodland (Niemann, 1809; Hase, 1983). At the same time, initial attempts were made to establish conifer plantations on infertile heathlands. A century later, for the first time, coniferous and mixed forests (consisting of broadleaved and coniferous trees) reached significant proportions (Hase, 1997). Since the mid-19th century, even deciduous stands on ancient woodland sites have been converted to conifer plantations or mixed forests (see Table 1; "coniferous ancient woodland" or "mixed ancient woodland"). This is especially true for nutrient-poor sandy sites in the less fertile central Geest region. The eastern Schleswig-Holstein hill country is a young moraine landscape characterized by base-rich soils and with a long continuity of beech-dominated woodlands (Niemann, 1815; Hase, 1997; Schulz and Dengler, 2006; Wieckowska et al., 2012). Currently, 166,100 ha (10.5%) of Schleswig-Holstein are covered by woodlands and about 45% of these woodlands are ancient (Table 1). The proportion of deciduous ancient woodland amounts to 31% (Glaser and Hauke, 2004; DESTATIS, 2013).

2.2. Data sets

The floristic data were obtained from the joint database of the Schleswig-Holstein State Agency for Agriculture, Environment and Rural Areas (LLUR) and the AG Geobotanik (AG Geobotanik and LLUR, 2013) and were recorded between 1974 and 2003. From this data set, we considered the 328 bryophyte species that occur in forest habitats according to the German Forest Bryophyte Species List (Schmidt et al., 2011). 65 species belong to category 1.1 (largely restricted to closed forests), 11 species to category 1.2 (preferring forest edges and clearings), 144 species to category 2.1 (occurring in forests, as well as in open habitats), and 108 species to category 2.2 (may occur in forests, but prefers open land). Additionally, we determined the linkage of each bryophyte species to the four substrate classes "bark", "deadwood", "rocks", and "soil" (preferred substrates, multiple assignments were possible) according to the German Forest Bryophyte Species List (Schmidt et al., 2011) with some specifications for Schleswig-Holstein following the Distribution Atlas of Bryophytes in Schleswig-Holstein and Hamburg (Schulz and Dengler, 2006). The Red List of Bryophytes of Schleswig-Holstein (Schulz et al., 2002) was used to assess if a bryophyte species is endangered (three main endangerment categories; Fig. 7) or not. Finally, we ascertained the occurrence (presence or absence) of every bryophyte species in each grid cell. The nomenclature followed Koperski et al. (2000).

We determined the ancient woodland area (area_aw) and proportion (perc_aw) in each grid cell, distinguishing respectively between ancient woodland sites currently dominated by deciduous tree species (perc_daw), coniferous tree species (perc_caw) and a mixture of both types (perc_maw) (Table 1). Data on ancient woodland was obtained from Glaser and Hauke (2004) who utilized historical land survey maps (compiled mostly between 1750 and 1800) and younger topographical maps in order to determine whether current woodland has been continuously wooded since 1800 or not. Woodland with forest continuity since at least 1800 was regarded as ancient, and information on current tree species