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# Biodiversity composition reflects the history of ancient semi-natural woodland and forest habitats—Compilation of an indicator complex for restoration practice

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ABSTRACT

For centuries, Fennoscandian wooded meadows and woodland pastures (Habitats Directive habitat types *6530 and 9070 respectively) covered large areas of Northern Europe. In the Twentieth Century, abandonment-driven encroachment has led to the wooded grasslands changing into what may be considered as old-growth deciduous forests. The present paper examined whether the present stand structure and the composition of three contrasting functional groups (herbaceous layer vascular plants, epiphytic bryophytes, and earthworms) could serve as indicators of the historic origin of the forest patches, i.e. to what extent changes in ecological conditions in overgrown woodlands have shifted towards broad-leaved forests with ancient trees. Indicators were tested for the objective of restoration planning of habitat quality, i.e. whether semi-open woodlands could be restored or if it would be more appropriate to preserve them as broad-leaved forests. The study was carried out by comparing the composition of ancient forest cores, forest edges and overgrown wooded grasslands. The land use history of sample sites was examined from historical topographical maps and aerial photos.

The results showed that as long as 60 years after abandonment, parts of the studied forests still retained some light-demanding plant species characteristic of historical wooded grasslands. The composition of earthworm communities was similar in all of the studied historical forest groups. Only some of the stand structure characteristics and epiphytic mosses indicated that there were differences between ancient forest cores and overgrown wooded grasslands. We conclude that the combination of various functional indicators should be used in the evaluation of successional woodlands for habitat restoration.

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## 1. Introduction

Fennoscandian wooded meadows and wooded pastures (Habitats Directive habitat types *6530 and 9070, respectively) covered large areas of Northern Europe for centuries. Semi-natural woodlands have received much attention from researches and conservation biologists, because these habitats have major resources of biodiversity, e.g. herb layer species, insects and lichens (Aavik et al., 2008; Einarsson and Milberg, 1999; Kukk and Kull, 1997; Kull and Zobel, 1991; Leppik et al., 2011; Lõhmus et al., 2007; Paltto et al., 2008). It has been shown that in order to prevent the loss of that biodiversity caused by grassland encroachment, it is essential to continue traditional land use practices, such as hay making and grazing (Aavik et al., 2008; Ekstam and Forshed, 1997; Halada et al., 2011; Ingerpuu et al., 1998; Kukk and Kull, 1997; Leppik et al., 2011; Paltto et al., 2011; Pihlgren and Lennartsson, 2008). However, traditional management of grasslands is expensive and labour-intensive. In addition, the restoration of species rich grassland ecosystem is slow and time-consuming (Liira et al., 2009, 2012; Paltto et al., 2011; Stampfli and Zeiter, 1999).

At the same time, process of the overgrowth of semi-natural woodlands has led to the formation of broad-leaved deciduous forests with various old-growth features originating from semi-natural woodland trees (e.g. dead branches, rot holes, and relatively stable microclimate). The old broad-leaved deciduous forest (Habitats Directive type *9020) is the climax community of these wooded grasslands and is also of high conservation value (for example, as a habitat for specialized bryophytes and fungi) (Gustafsson et al., 1992; Ingerpuu et al., 1998; Nordén et al., 2004; Paltto et al., 2008). Remnants of historically continuous and high biodiversity value old-growth deciduous forests also were represented by small residual patches within wooded grasslands for centuries (Herlin, 2001; Kukk and Kull, 1997; Skånes, 1996), but are even more rare in the

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landscape with contemporary silviculture and forest management (Adermann and Tamm, 2010; Gustafsson et al., 1992; Ikauniece et al., 2012; Lõhmus and Kraut, 2010; Lõhmus and Liira, 2013; McGee and Kimmerer, 2002; Vellak and Paal, 1999).

Many structural elements of wooded grasslands overlap with old forests, because the veteran deciduous trees are the structural backbone of both habitats. Structural similarity is presumed to increase during the encroachment succession of wooded grasslands, therein the quantity of dead wood (Andersson et al., 2003; Hæggström, 2000; Leppik et al., 2011; Nordén et al., 2004; von Oheimb and Brunet, 2007; Paltto et al., 2008; Trass et al., 1999). Typical ancient semi-natural woodlands may be easily distinguished from old deciduous broad-leaved forests. Today, in overgrown conditions, the distinction of each individual patch in the historic mosaic of habitats is not straightforward, and decisions about conservation or restoration may be influenced by the subjectivity of experts. Common unified principles are needed to distinguish between overgrown woodlands suitable for wooded grassland restoration, as opposed to well developed stands of deciduous forest, which should be maintained as old-growth habitats (Andersson et al., 2003; Kuris and Ruskule, 2006; Paltto et al., 2008, 2011).

The assumption of the project was that herbaceous layer plant species, epiphytic bryophytes and earthworms could provide valuable information about the historical origin of the forests and that continuity would also be useful for decision-making. However, it is necessary to consider the ecology of these groups. The abundance of herbaceous layer species in semi-open wooded grasslands is affected firstly by the light conditions created by selective tree cutting and mowing or grazing, and secondly the herb and tree litter affects ground and soil conditions (Aavik et al., 2008; Eek and Zobel, 1997; Einarsson and Milberg, 1999; Hemerik and Brussard, 2002; Kull and Zobel, 1991; Liira and Zobel, 2000; Pihlgren and Lennartsson, 2008; Wulf, 2004). Woodland overgrowth causes a reduction in light availability, which triggers a loss of plant diversity, changes in the life form spectrum, and an increase in the abundance of shade tolerant species (Aavik et al., 2008; Liira et al., 2011; Palo et al., 2008; Sepp and Liira, 2009).

Epiphytic bryophytes of woodlands are primarily dependent on the host tree species, but also on the age and diameter of the trees, and are less sensitive to changes in light conditions (Gustafsson and Hallingbäck, 1988; McGee and Kimmerer, 2002; Mežaka et al., 2008; Paltto et al., 2008; Vellak and Paal, 1999). Some forest epiphytic bryophytes are more sensitive to changes in microclimatic conditions and may be used as indicators of the long-term continuity of tree cover in forest stands and forest quality for biodiversity (Andersson et al., 2003; Gustafsson et al., 1992; Ikauniece et al., 2012; Lõhmus et al., 2007; Norden and Appelquist, 2001; Trass et al., 1999).

The earthworm communities in woodland soils have been studied sporadically in open meadows (Cole et al., 2006; Hemerik and Brussaard, 2002; Porazinska et al., 2003), wooded meadows (Ivask et al., 2012) and deciduous forests (Cesarz et al., 2007; Ivask et al., 2000; Räty and Huhta, 2004). Litter quantity and quality, but also microclimatic conditions in the soil, particularly soil moisture control the composition of earthworm communities. During the succession after abandonment and encroachment, litter accumulation declines and litter composition becomes more similar to that of forests, consisting of small debris and the leaves of trees and shrubs. It has been shown that changes of habitat conditions during woodland succession affect the quantity and quality of plant litter, which then alter the soil food web, and the constituent soil invertebrate fauna (Peres et al., 2011; Wardle, 2002). In response to debris and soil quality, the earthworm community is dominated by either endogeic or epigeic species (Bouche, 1977; Ivask et al., 2012; Lukac and Godbold, 2011). The composition of an earthworm community according to the ecological categories (including epigeic, endogeic, anecic and subgroups) is a potential measurement endpoint for the biological assessment of soil quality (Römbke et al., 2005).

We studied whether the composition of three contrasting taxonomic groups (herbaceous layer vascular plants, epiphytic bryophytes and earthworms), their functional groups and stand structural characteristics were able to indicate historical origin and management of patches in present-day broad-leaved deciduous forest landscape. It was intended that any indicators identified should help to evaluate the potential of a patch to be restored as wooded grassland, or whether it should be maintained and conserved as a broad-leaved forest.

## 2. Materials and methods

### 2.1. Study area

The study region is located in Lääne County in the Western Estonian Lowland (defined by sample sites with coordinates 58°59′16.99″ N, 23°40′31.55″ E; 58°55′19.54″ N, 23°55′29.38″ E; 58°33′09.97″ N, 23°39′49.08″ E). The base rock of the regional soils consists of Silurian and Ordovician Limestone and its surface is covered by thin layer of Holocene moraines and predominantly sedimentary materials from the floor of the Baltic Sea (Jussila and Kriiska, 2004). For many centuries, agricultural management was extensive and nearly all the deciduous forests were used as pastures and for haymaking (Jussila and Kriiska, 2004; Kukk and Kull, 1997). During the Twentieth Century, forest cover in Lääne County has changed from about 13 to 50%, and the area of semi-natural wood grasslands fell from 21% to less than 1% (Adermann and Tamm, 2010; Luhamaa et al., 2001; Mathiesen, 1939).

### 2.2. Study design

Databases of Natura 2000 Habitat and Forest Key Habitat projects were used for the selection of sampling sites. Forests growing on Calcaric gleyic Leptosols (Kg; Estonian Soil Map – WMS Estonian Land Board Geoportal) were selected for the study, because such soil type is among the most common in semi-natural woodlands in the region (Kukk and Kull, 1997). The selected type of woodland corresponds to the Estonian boreo-nemoral *Aegopodium podagraria* forest site type (Kalda, 1995; Paal, 2002). In order to avoid the present day edge effect, only patches larger than 0.4 ha were chosen. The pre-selected patches were evaluated in the field to have tree crown coverage greater than 30%, according to the international and Estonian forest definition. In addition at least some trees of mature age (>60 years) needed to be present and no evidence of agricultural or silvicultural use in the last 20–30 years.

The historical origin of the forests was obtained from available topographical maps of the beginning, middle and end of the Twentieth Century (WMS from Estonian Land Board Geoportal; scales 1:50,000–20,000), and aerial orthophotos from the 1950s and 1970s (WMS and records from Estonian Land Board; scale 1:10,000). Within the continuous forest area on the map, one study site was selected, unless a different land use history was detected from aerial photos or maps. Based on the information concerning each location, the 27 sample sites were classified into one of three categories: (1) historic forest cores (11 sites, large areas of dense tree crown cover on historic map and aerial photo); (2) forest-woodland edge type, which consists of small-grain (20–30 m) mixture of forest and open woodland or ecotone affected small-area patches of forest, and therefore cannot be classified as pure forest woodland (8 sites); (3) semi-open woodlands (8 sites; large homogeneous areas, estimated tree crown coverage on aerial photos less than 30–40%). Open wooded meadows have remained rare and

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