Forest Ecology and Management 257 (2009) 994–1003

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Bryophytes and decaying wood in *Hepatica* site-type boreo-nemoral *Pinus sylvestris* forests in Southern Estonia

Elle Rajandu[a,b,*], Karin Kikas[a], Jaanus Paal[a]

[a] Institute of Ecology and Earth Sciences, University of Tartu, Lai St. 40, 51005 Tartu, Estonia
[b] Tallinn University, Narva Road 25, 10120 Tallinn, Estonia

ARTICLE INFO

Article history:
Received 26 March 2008
Received in revised form 3 November 2008
Accepted 5 November 2008

Keywords:
Coarse woody debris
Decay stage
Diameter class
Forest age
Log
Management
Stump

ABSTRACT

The aim of the study was to establish the amount of decaying wood (logs and stumps) in various groups of *Hepatica* site-type pine forests of different age and management intensity and to analyse the composition of bryophytes in dependence of these factors. The average volume of CWD in old unmanaged forests was 47.5 m^3/ha, which is rather well comparable with respective estimations from Fennoscandia. Reduced human impact contributes positively to the amount of CWD. Diversity of log diameter classes and decay stages is larger in old forests. Altogether 73 bryophyte species were recorded, 65 species on logs and 55 on stumps. Species richness on stumps was higher in managed forests than in unmanaged ones. At the same time, the species having high indicator value for man-cut stumps are very common species in boreal forests and grow on other substrata as well. Species composition and ecological conditions differed between stumps and logs. Logs are more humid microhabitats than stumps, therefore the occurrence of hepatics is more frequent on them. According to species composition on decaying wood the old unmanaged forests distinguished from others. As the differences of substratum characteristics were notable between old and young forests, the stand age described a considerable part of species variance on logs.

1. Introduction

Many species in forest ecosystems depend on decaying wood as a substratum, especially insects, fungi and bryophytes (Jonsson et al., 2005). Decaying wood is a temporary substratum, which changes during the decaying process until it finally disappears. This means that species can grow on logs or stumps only for a finite period of time and then have to disperse to another log or stump to maintain its population (Söderström, 1988b).

Characteristics of decaying wood (wood texture, moisture content, pH, diameter of fallen trees (logs) and stumps, etc.) vary in age, size and decay stage. Depending on the features of decaying wood, species having different life strategy and demands for substratum features, e.g. facultative epiphytes, early epixylics, late epixylics, ground flora species can grow on it (Söderström, 1988a). Large amount of decaying wood is especially characteristic of old natural forests (Qian et al., 1999; Christensen et al., 2005) as in those forests more logs are added continuously as a result of various disturbances. In old natural forests falling and decaying of logs are mostly in balance. Numerous studies show that bryophyte species richness and composition are dependent on stand age (Frisvoll and Presto, 1997; Söderström, 1988b; Jonsson and Esseen, 1990; Lesica et al., 1991). In the course of management large fallen logs are transported out of the forest and that reduces the amount of decaying wood considerably (Andersson and Hytteborn, 1991). In that way, human activities have an adverse impact to species richness and composition of forest bryophytes (Lesica et al., 1991; Söderström, 1988a,b; Andersson and Hytteborn, 1991; Trass et al., 1999; Vellak and Paal, 1999); and it is hepatics that are first of all negatively influenced (Söderström, 1988b; Vellak and Paal, 1999) as they are essentially associated with decaying wood in old forests (Lesica et al., 1991; Meier and Paal, in press).

One of the common direct results of human activities in forests is the appearance and increasing number of stumps. Similarly to logs they gradually moulder and serve as substratum for various bryophytes according to their decay stage. Quite little attention has been paid to differences of bryophytes on decaying logs and stumps. Still Andersson and Hytteborn (1991) have briefly discussed this problem; their results, however, do not demonstrate any good difference between logs and stumps as wood substratum for bryophytes.

As *Hepatica* site-type boreo-nemoral forests grow on fresh fertile soils and are productive, they have been mostly intensively

* Corresponding author at: Institute of Ecology and Earth Sciences, University of Tartu, Lai St. 40, 51005 Tartu, Estonia. Tel.: +372 7376382; fax: +372 7376222.
E-mail address: ellem@ut.ee (E. Rajandu).

0378-1127/$ – see front matter
doi:10.1016/j.foreco.2008.11.001

managed. In spite of this, results of our earlier study (Meier et al., 2005) showed that the richness of bryophyte species was higher in forests of *Hepatica* site-type, having better productivity than in less productive alvar forests though these generally have smaller human impact (Liira et al., 2007). In our previous study (Meier and Paal, in press) the decaying wood appeared to be the species richest substratum by cryptogams and it had quite a unique bryophyte species composition in alvar forests. In the current paper we focus in more detail on decaying wood and bryophytes on this substratum in *Hepatica* site-type forests.

The aims of the present study were:

(1) to describe the characteristics of decaying wood in *Hepatica* site-type forests of different management and age classes;
(2) to compare the composition of bryophytes growing on logs and stumps in these forests;
(3) to evaluate the effects of forests age and management on bryophyte species composition.

2. Material and methods

2.1. Study area and experiment design

The fieldwork was carried out in the summers of 2004–2006 in southern Estonia, in Otepää Nature Park and in Karula National Park (between 57°40′54″ and 58°06′50″ N and 26°21′44″ and 34′19″ E; Fig. 1). Studied stands represent *Hepatica* site-type boreo-nemoral forests (*sensu* Paal, 1997). Forests of this site-type are considered as degraded remnants of boreo-nemoral mixed spruce forests from a warmer Atlantic climatic period (Laasimer, 1965), they grow on the deep Rendzinas, Cambisols and Luvisols of moraine-rich areas, particularly on hillocks distributed throughout the Baltic region (Lõhmus, 2004).

In studied forests the dominant species in the tree layer was *Pinus sylvestris*, while in the second tree layer *Picea abies* prevailed. Forests of three age classes were selected: (1) young forests with age of 40–55 years, (2) mature forests with age of 65–70 years and (3) old forests with age of more than 120 years. All stands were divided into two classes according to the management index (see Section 2.3). All in all 25 stands were studied: five old unmanaged forests, seven old managed forests, six mature managed forests, three young unmanaged forests and four young managed forests.

2.2. Sampling

For data collection circular sample plots with a radius of 25 m were used. If necessary, for remaining within the same community, the shape of sample plots was changed a little, maintaining the surface area about 1950 m^2.

For logs taller than 1 m and having diameter $\geq$10 cm the following characteristics were recorded: length, diameters at both ends and decay stage. Average diameters were divided into four classes: 10–19 cm, 20–29 cm, 30–39 and $\geq$40 cm. Decay stages were estimated according to Renvall (1995) and Sippolaa et al. (2005) as: (1) recently died, wood hard, bark and phloem fresh, knife penetrates only a few millimetres into the wood, (2) wood hard, most of the bark is still staying but no fresh phloem present, knife penetrates 1–2 cm into the wood, (3) wood partly decayed from the surface or in the centre (depending on tree species), large pieces of bark are usually loosened or detached (conifers), knife penetrates 3–5 cm into the wood, (4) most of wood is throughout soft, usually without bark (conifers), the entire blade of the knife penetrates easily into the wood, (5) wood very soft, disintegrates when lifted, log surface covered by ground-layer mosses and lichens. Measurements were done with logs having a diameter of $\geq$10 cm and $\geq$20 cm around the sample plots central point within concentric circles with a radius of 10 m and 25 m respectively. Term 'coarse woody debris' (CWD) was used for logs with a diameter of $\geq$10 cm.

In the current study tree remains not higher than 0.4 m were considered stumps. They were classified as natural and man-cut, and their diameter and decay stage were measured. Stumps with a diameter of $\geq$10 cm were taken into consideration on areas with a radius of 10 m and stumps with a diameter of $\geq$40 cm on areas with a radius of 25 m.

Bryophyte species were registered separately on logs and stumps. Species abundance was evaluated by rank values from one to six according to the Braun–Blanquet' scale (Kreeb, 1983). The specimens that were not identified in the field were collected for further laboratory investigation. Nomenclature of species follows Ingerpuu and Vellak (1998).

2.3. Data treatments

The volume of a log was calculated according to the volume of the frustum of a cone:

$$V = \frac{\pi h}{12}(D_2^2 + D_1^2 + D_2 D_1), \tag{1}$$

where h is length of the trunk and D_2 and D_1 are the larger and smaller diameters of the trunk. The surface potentially covered with bryophytes was considered as 2/3 of the mantel area (S) of each log:

$$S = \frac{\pi l}{2}(D_2 + D_1), \tag{2}$$

where l is the length of the trunk (Andersson and Hytteborn, 1991). The logs surface area values in different diameter classes and decay stages were used further for calculation of the Shannon diversity index (McCune and Mefford, 1999). Respective indices in case of stumps were calculated according to stumps number *per* 0.1 ha. Volumes were calculated for the purpose of comparing the results with other studies and the available substratum area to associate this with species data.

To express human impact on stands, management intensity index (MI) was used (Liira et al., 2007). At each study site, visible signs of anthropogenic activities (e.g. cut stumps, forest tracks, trampling, ditches, trash, etc.) were recorded. Each indicator of anthropogenic activities got a score 1 or 2 that describes the proportional effect. The management intensity index is the sum of scores of indicators of anthropogenic disturbances, weighed by the distance class. The observation of any indicator within a radius of 0–25 m around the sample plot centre doubled the scores effect

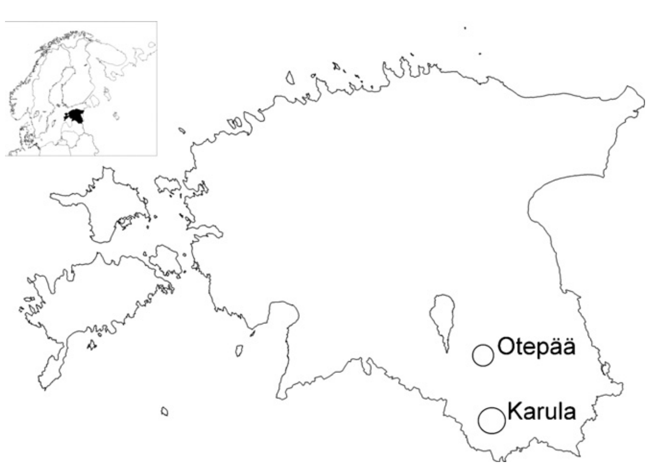

Fig. 1. Location of the study areas.