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Dead wood as an indicator of forest naturalness: A comparison of methods

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ABSTRACT

Several measures related to dead wood have been used as indicators of forest naturalness, but their general applicability and comparability is unclear. We compared five dead wood related measures: volume of dead wood, dead wood diversity index, number of cut stumps, dead wood continuity profile and number of kelo trees (specific type of dead pine trees). Furthermore, we studied if these indicators provide similar relative ranking of forest sites. Study sites were located on 40 islands of the Archipelago Sea in south-western Finland in the hemiboreal zone. Islands included sites that apparently varied in their naturalness. The total volume of dead wood was on average 16.6 m^3 ha^{-1} (range 4.1–42.9 m^3 ha^{-1}). The dead wood diversity index varied from 4.4 to 56.2 (median 23.6), and the number of cut stumps from 0 to 173.3 stumps ha^{-1} (median 33.0). The dead wood continuity profiles indicated four patterns: strong continuity (5 islands), weak continuity (13 islands), old continuity gap (15 islands) and low abundance (4 islands). The number of kelo trees varied between 0 and 42.9 kelos ha^{-1}. The dead wood diversity index and the number of cut stumps were significantly related to the volume of dead wood. The volume of dead wood and the dead wood diversity index varied significantly along with the continuity patterns. The number of kelos was negatively correlated with the number of cut stumps, but not with other measures. Ranking order of the study sites according to the three indicators (volume of dead wood, dead wood diversity index, number of cut stumps) showed significant similarity. The volume of dead wood provided the best overall agreement with other indicators but requires considerable effort to measure. The number of cut stumps, however, provides direct information on human activity. The indicators of naturalness provide data for many purposes, like conservation priorization. Based on our results, the selected indicator can affect the output of the assessment considerably. Therefore, it important to consider these differences when interpreting assessments that are based on different indicators.

1. Introduction

Inventory and assessment of forest biodiversity patterns are often based on quick methods that are related to forest naturalness and act as surrogates for biodiversity (Noss, 1999; Thompson, 2006; Rondeux and Sanchez, 2010). However, there are no well-established methods to assess forest naturalness, and the applicability and comparability of the applied methods have largely remained unexplored. There is an urgent current need to improve assessment of naturalness of forests, for example, for forest policy and conservation purposes (Winter et al., 2010; European Environment Agency, 2014; Machado, 2014).

Forest naturalness can be defined at different levels and using several criteria. Naturalness is commonly defined as “the similarity of a current ecosystem state to its natural state” (Winter, 2012). Basically, forest naturalness has three dimensions: structure, species, and processes (Brūmelis et al., 2011; Ikauniece et al., 2012). Of these, structure is often easiest to measure, and it can also serve as a surrogate for number of species and processes (Similä et al., 2006; Lassauce et al., 2011). In principle, specific structural properties could be used as quick measures to assess the degree of naturalness (Uotila et al., 2002; Storaunet et al., 2005; Brūmelis et al., 2011).

In the boreal zone, the most important components of the structural dimension of natural forests include the amount and type of dead wood and their continuity (Stokland et al., 2004). Dead wood is an essential characteristic of natural forests and its proportion in natural boreal forests is on average 25% of the total above-ground

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wood biomass (Siitonen, 2001). It is also a key factor affecting species diversity of forests (e.g. Jonsson et al., 2005). Therefore, dead wood is among the most often considered indicators of forest naturalness (e.g. Similä et al., 2006; Winter, 2012). In addition to the total volume of dead wood in a forested area, several more detailed or more quickly assessed methods have been proposed and recently applied for quick assessment of naturalness in boreal forests, all based on characteristics of dead wood.

The diversity of dead wood can be expressed as the number of combinations formed by tree species, quality, decay class and 10 cm diameter classes present on each sample plot (Siitonen et al., 2000). This method has been used mainly to examine relationships with species diversity (Martikainen et al., 2000; Similä et al., 2003; Penttilä et al., 2006), but also to estimate forest naturalness (Siitonen et al., 2000).

The number of cut stumps per hectare has been used as a negative quickly measured indicator of forest naturalness (Uotila et al., 2002; Rouvinen and Kouki, 2008; Wallenius et al., 2010). On the basis of the cut stumps found, however, it is possible to determine only fairly recent loggings (<100 years ago), whereas due to the decaying of stumps, the older loggings are much more difficult to detect (Storaunet et al., 2000; Groven et al., 2002).

The dead wood continuity profile summarizes the quantitative and qualitative composition of dead lying wood at the stand level (Stokland, 2001). The profile includes a two-dimensional matrix where the dimensions include dead wood diameter and decay classes. The dead wood continuity profile is a result of four main processes: regeneration, tree growth, tree mortality and decomposition. It can provide information of forest history from the most recent 200–500 years, depending on the local productivity and climate that affect tree growth and decomposition rates. It is assumed that the occurrence of different size classes and decay stages of dead wood is a key character of a natural forest (Stokland, 2001).

Primeval forests have special kinds of substrates that are thought to be formed only in the absence of human-caused disturbances. One such substrate in European boreal forests is a kelo tree which is an old, dead Scots pine (*Pinus sylvestris*) with hard and grey, decorticated surface of the trunk (Niemelä et al., 2002). Formation and decaying of a kelo is a very slow process: Scots pines can live 300–800 years, and they can become a kelo trees 35–40 years after dying (Sirén, 1961; Leikola, 1969). Kelo trees can remain standing for over 700 years, especially on exposed slopes, heath forests and sandy soils (Niemelä et al., 2002). After falling down, it can take another 200 years before a kelo trunk is totally decayed (Tarasov and Birdsey, 2001). Thus, the formation of kelo trees is impossible in commercially managed forests with a rotation cycle of c. 80–120 years, depending on forest habitat type.

In this study, we analyze the structure of dead wood characteristics on forested islands in southern Finland and explore relationships between the five different dead wood indicators. More specifically, we ask: Do the different methods to assess forest naturalness (volume of dead wood, dead wood diversity index, number of cut stumps, dead wood continuity profile and number of kelo trees) provide similar indications of naturalness? We also explore if the different indicators rank different islands similarly. Islands were selected as sites for comparisons, because they provide defined entities for measurements and represent areas commonly considered in practical conservation priorization.

2. Materials and methods

2.1. Study area

We selected 40 islands from the eastern part of the Archipelago Sea within the Baltic Sea (approx. 60° N, 22° E), based on their size, dominant forest habitat type and location in the archipelago zone (Fig. 1). The sizes of study islands were 8–191 ha (median 23 ha), and the total area of the 40 islands was 1731 ha. Forest area of islands ranged from 3 to 159 ha (median 20 ha) and covered 1442 ha of the total area. The characteristics of the study islands are given in Appendix A.

The islands were classified to belong to either the outer or middle archipelago zone (Stjernberg et al., 1974; Lindgren and Stjernberg, 1986). The zonation is based on the relative prevalence of the sea and land and also on general features of vegetation. The forests in the study area are dominated by *Pinus sylvestris* L., *Alnus glutinosa* (L.) Gaertn. and *Betula pubescens* Ehrh (Fig. 2). Also *Picea abies* (L.) Karst. and *Populus tremula* L. occur fairly commonly. *Betula pendula* Roth grows in the middle archipelago zone, but not in the outer zone. The islands can be classified into three groups based on their habitat types: herb-rich, mesic and dry forests (Fig. 2). The group was determined according to the dominant habitat type on each island (at least 40% of the area). Forests were located 0–42 m a.s.l.

The study area was situated in the hemiboreal zone where the length of the growing season is approximately 180 days and the temperature sum 1200–1300 (Ahti et al., 1968; Nurmela, 1994). The mean annual temperature in the outer part of the study area is +6,1 °C, and the annual precipitation 523 mm. Wind affects the

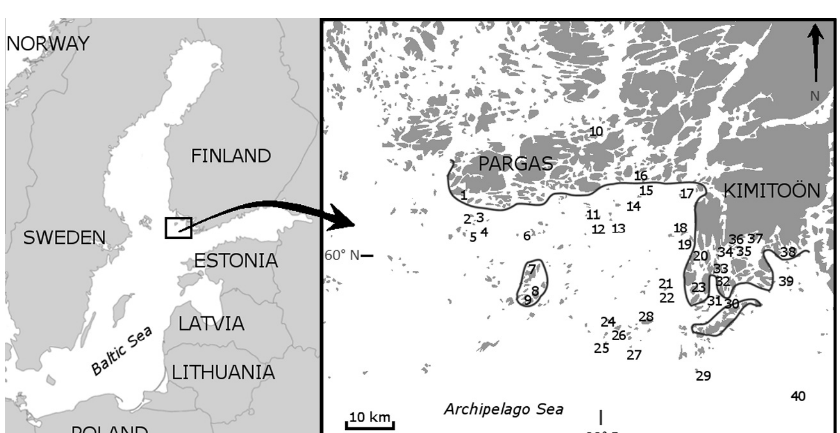

Fig. 1. Location of the study area in the Archipelago Sea. The black line shows the division of outer and middle archipelago zones. The numbers refer to study islands (listed in the appendices).