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Research paper

Cross-taxon congruence and relationships to stand characteristics of vascular plants, bryophytes, polyporous fungi and beetles in mature managed boreal forests

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ABSTRACT

Multi-taxon analyses of ecological assemblages are needed when the effects of forestry on biodiversity are examined. Management usually simplifies the structure of forests, which results in quantitative and qualitative declines in many microhabitats and species associated with them. In Fennoscandia, most forests are managed for industrial use of wood, but relatively little is known about the relationships between structural components and biodiversity in managed forests. Abundance, composition or species number of different species groups reacting similarly to variation in their environment would be a useful tool e.g. in estimating responses of species that are more difficult to sample. Thus far evidence for, or the lack of, such congruence or indicator functioning is not conclusive. We therefore examined the associations between stand structural features and species diversity and congruence between species groups of vascular plants, bryophytes and lichens, polypores and beetles. Our study was carried out in mature managed Norway spruce dominated forests in Southern Finland in 2009. Our main findings were (1) cross-taxon congruence in species richness was generally low, suggesting that any single taxonomic group performed poorly as an indicator of overall biodiversity; (2) the volume and diversity of dead trees were the most frequently detected significant predictors of species richness of the studied groups; (3) in terms of species composition, only vascular plants co-varied significantly with bryophytes and lichens; in addition, bryophytes and lichens as well as polypores co-varied significantly with stand structural features; (4) species composition of vascular plants, polypores and saproxylic beetles was associated with the volume of living trees, and in polypores it was also associated with the volumes of both dead and living deciduous trees. These results suggest that biodiversity monitoring for management and conservation requires data from several taxa. However, the volume and diversity of dead wood are useful indicators of stand-level species richness of several taxa, whereas the volume of living trees is an important indicator for the stand-level species composition of several groups. Thus, these structural variables have the potential to function as easily attainable indicators of general forest biodiversity.

1. Introduction

A multi-taxonomical approach is required to find out overall forest biodiversity patterns. This is also a necessary premise for any conservation initiative. Because it is not possible to survey all taxa, there is an urgent need to develop surrogates to simplify and represent the diversity of ecosystems. Two broad kinds of surrogates are commonly applied in conservation and management: species-based and habitat-based (Lindenmayer et al., 2014). Species-based surrogates are individual species or species groups that are used as proxies of diversity within a taxon or for other taxa. Habitat-based surrogates are habitat attributes that are used as proxies of the presence of individual species or the diversity of certain taxa (Lindenmayer et al., 2014).

A large body of literature deals with co-variation of species diversity among different taxonomic groups, and many of these studies are connected with optimal reserve selection (see Rodrigues and Brooks,

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2007, for a review). Selection of sites for conservation would be easier if habitats that are rich in species for one taxon were species-rich for other taxa too, and if also threatened species occurred in such species-rich habitats (Prendergast et al., 1993). Recent reviews and meta-analyses about surrogate effectiveness have shown that there are few circumstances in which pairs of taxa will be consistent surrogates for each other across a range of locations and spatial scales (Lewandowski et al., 2010; Westgate et al., 2014). A species-based surrogate is more reliable when there is a direct functional dependency between the surrogate and the target taxon, e.g., through trophic relationships (Gioria et al., 2011). Sharing a mutual limiting resource is also a possible linkage between taxa though its effects can change over time and space (Lewandowski et al., 2010) or due to resource availability or competition (Lindenmayer et al., 2014).

Habitat-based surrogates have been searched for in many types of environments ranging from aquatic ecosystems to grasslands and forests. In forest environments, the different site and stand characteristics are potential surrogates for species diversity (Gossner et al., 2014; McElhinny et al., 2005). If a significant part of the variation in species diversity at the stand level can be explained with direct linkage to certain structural features, this knowledge can be used to select valuable sites for conservation purposes. On the other hand, the same knowledge, i.e., clear understanding of direct links between structural features and aspects of biodiversity, can also be used to improve the ecological sustainability of habitat management. Ways to concretely do this include increasing the amount of structural features of known biodiversity benefits in managed forests by means of silvicultural practices. Measuring structural features is generally less laborious and thus more cost-efficient than a thorough census of possible indicator taxa. However, the efficiency of a structural indicator depends on its ability to describe accurately the ecological needs of the target taxa (Lindenmayer et al., 2014). According to a recent review based on studies in Europe, the structural feature that was most frequently found to correlate with species richness of certain target taxa, especially saproxylic beetles and polypores, was the amount of dead wood (Gao et al., 2015).

Large-scale nature conservation inventories have been carried out in the Nordic and Baltic countries, with the aim of finding and setting aside valuable sites in managed forests (Timonen et al., 2010). These so-called woodland key habitats are considered important for rare and red-listed forest species (Nitare and Norén, 1992). Identification of potential key habitats is based on both structural surrogates, such as site type, stand structure and the amount of dead wood, and on a set of indicator species (see Timonen et al., 2010 for a review). Because of the political importance of woodland key habitats as a conservation strategy, most studies dealing with cross-taxon congruence and structural surrogates in the Nordic countries have concentrated on close-to-natural forests and on the reserve selection issues (e.g. Djupström et al., 2010; Jonsson and Jonsell, 1999; Similä et al., 2006). Until now, only few previous studies have explored variation of species richness and cross-taxon congruence in ordinary managed boreal forests (Dynesius and Zinko, 2006; Gjerde et al., 2005).

The aim of the present study was to assess the covariation of different taxonomic groups in boreal managed forests, and their relationship with stand structural features. Our approach is novel in that it combines quantitative data of several taxonomic groups with varying ecological requirements at a spatial level that corresponds to forest management operations, i.e. at the stand level. By using vascular plants, combined bryophytes and lichens, polyporous fungi, saproxylic (dead-wood dependent; Speight, 1989) beetles, and non-saproxylic beetles as focal taxa, the following questions were addressed:

1) Is there significant cross-taxon congruence in species richness or species composition in these stands? In other words, can any of the focal groups be used to predict the species diversity of the other groups (taxon-based surrogates)?
2) Which stand characteristics best predict the species richness and composition of the focal taxa (habitat-based surrogates)?

We hypothesized that the following relationships between different taxa and between taxa and structural features can be expected. Firstly, congruence between vascular plants and bryophytes and lichens is likely, based on their shared set of ecological requirements. Furthermore, since a large part of the non-saproxylic beetle species also occupy forest floor and use plants and their litter as food and living environment, congruence between vascular plants and non-saproxylic beetles is also possible. Secondly, polyporous fungi and saproxylic beetles are dependent on the same resource, dead wood, and therefore are likely to co-vary. Thirdly, regarding the relationships between species diversity and structural features, polypores and saproxylic beetles can be expected to depend on the volume and diversity of dead wood.

2. Material and methods

2.1. Study area and study stands

The study area, about 1, 000 ha in size, is located within the southern boreal zone (Ahti et al., 1968) in the county of Central Finland (Fig. 1). The mean annual temperature for the reference period 1960–2010 was 3.6 °C (February −8.2 °C and July 16.7 °C) and mean annual precipitation was 641 mm (data from the closest meteorological station of Mikkeli, located at 120 km from the center of the study area; Finnish Meteorological Institute, 2016). Forests in the region (Central Finland with an area of about 1.4 million hectares) are mostly dominated by Scots pine (*Pinus sylvestris* L.) (ca. 58% of the forest area) or Norway spruce (*Picea abies* L.) (ca. 33%), with downy birch (*Betula pendula* Roth), hairy birch (*Betula pubescens* Ehrh.) and European aspen (*Populus tremula* L.) as the most common deciduous tree species (Peltola, 2014).

The study area is managed by Metsähallitus, a state enterprise that administers most state-owned land and water areas in Finland. The area is designated to a large-scale ecological field experiment which aims at converting the forests from even-aged managed forests into uneven-aged forests by emulating natural disturbance dynamics (Koivula et al., 2014). However, at the time of this study in 2009, the forests had not yet been subject to experimental harvesting but represented ordinary even-aged managed forests. Standard management methods during the past decades include regeneration using clear-cutting and subsequent planting (most of the herb-rich and mesic sites) or seed-tree cutting and natural regeneration (part of the subxeric and xeric sites), followed by precommercial thinning and two to three thinnings before regeneration cutting. Rotation times typically vary from about 70–100 years depending on site type and dominating tree species. This practice has led into landscape structures in which relatively young age classes between 20 and 80 years dominate (about 76% of the forest area), and mature forests older than 80 years comprise about a tenth of the forest area.

Within the study area, 21 mature spruce-dominated stands on herb-rich sites (*Oxalis-Myrtillus* type; Cajander, 1949) or mesic sites (*Myrtillus* type; Cajander, 1949) were selected for the study (Table 1).

2.2. Stand characteristics

In each study stand, living and dead trees were measured on a 0.2 ha (20 m × 100 m, divided into five 20 m × 20 m quadrats) transect that was established in a random position in the stand, excluding a buffer zone of 30 m from the stand edges. Tree species and diameter at breast height (DBH) were measured for living trees ≥5 cm in diameter. Heights of 20–40 sample trees per stand were measured, depending on the number of tree species and size variation. All dead standing or downed trunks with a DBH ≥5 cm and length ≥1.3 m, and pieces of trunks with a diameter ≥5 cm at the thickest end and length