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Uneven-aged silviculture can reduce negative effects of forest management on beetles

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ABSTRACT

Decline in biodiversity have increased the interest in alternative forest management approaches. Uneven-aged silviculture has been proposed as a mean to maintain continuity of forest canopy cover, mimic small-scale disturbances and provide a stratified forest structure similar to that of old-growth forests and therefore better maintain species associated with unmanaged forest. We used a large-scale chronosequence study spanning 50 years to study beetle diversity in uneven-aged silviculture compared with both short-term impacts and the longer-term legacy of even-aged silviculture. We compared: (1) even-aged recently clear-felled stand, (2) even-aged recently thinned stand, (3) uneven-aged stands subjected to selective felling with (4) uneven-aged reference stands to evaluate whether abundance, species richness and composition of beetles (Coleoptera) were affected differently by even-aged than by uneven-aged management. We collected 15,147 beetles from 461 species using flight interception traps in 30 stands. Beetle composition was maintained in uneven-aged managed stands; composition did not differ from unmanaged reference stands, the exception being cambium consumers. Both even-aged silviculture treatments (clear-felling and thinning) had different beetle composition compared to the reference stands, indicating that assemblages had yet to recover even 50 years into the rotation. However, beetle composition did not differ between uneven-aged managed and thinned stands. The result supports our prediction that uneven-aged silviculture better maintains beetles assemblages associated with semi-natural mature forest than even-aged silviculture. The greater temporal continuity in selectively felled stands could benefit species dependent of mature or old growth forest since some of the needed habitat qualities are continuously available. Uneven-aged silviculture could therefore serve as an important tool for landscape planning to benefit biodiversity and thus help fulfil environmental commitments. However, uneven-aged silviculture may still alter the forest and should therefore be viewed as an alternative to even-aged silviculture, rather than to set-asides.

1. Introduction

Foresters around the world are struggling to maintain or increase wood production while simultaneously preventing loss of biodiversity (CPF, 2012; Mori and Kitagawa, 2014; Kalonga et al., 2016). Intensive wood production often relies on even-aged silviculture (e.g. clear-felling). However, even-aged silviculture has been linked to severe negative effects on forest biodiversity through a simplification and homogenization of forest structure (Berg et al., 1994; Östlund et al., 1997; Butchart et al., 2010; Paillet et al., 2010; Bernes, 2011). To meet environmental challenges and prevent further loss of biodiversity, alternative forest management approaches based on natural disturbance regimes have been proposed (Pommerening and Murphy, 2004; Drever et al., 2006; Axelsson and Angelstam, 2011).

The underlying hypothesis of natural disturbance-based management (NDBM) is that many aspects of biodiversity can be protected and ecosystem resilience secured if forest management maintains habitats and habitat structure consistent with those found in landscapes dominated by natural disturbances (Drever et al., 2006; Shorohova et al., 2011; Kuuluvainen and Grenfell,

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2012). Unmanaged forest landscapes were formed by disturbances ranging from large stand-replacing fires to small scale disturbances; and were thus often structurally diverse (Kuuluvainen, 2002; Shorohova et al., 2011). High-severity fires, insect outbreaks and storm events have historically created highly variable landscapes where patches of mature forests are interspersed with early successional habitats, with large quantities of standing and downed deadwood. In boreal Fennoscandia, stand-replacing disturbances have been historically less widespread compared to boreal North America (Franklin, 2007). In this region, smaller-scale disturbances that cause single-tree or localized mortality may also have played a large role in forming the forest (Ohlson and Tryterud, 1999; Kuuluvainen, 2002). These smaller-scale disturbances maintained stratified old-growth uneven-aged forests with a continuous forest cover and high deadwood volumes.

With increasing conversion to even-aged forests, forest species associated with older, heterogeneous forest habitats are often restricted to smaller remnants of uneven-aged forest. Semi-natural forests that have eluded clear-felling are important refuges for those old-growth favoured species as well as a source of biodiversity for more intensively managed surrounding stands (Berg et al., 1994; Gustafsson et al., 2004; Stenbacka et al., 2010; Hjälten et al., 2012; Johansson et al., 2016). Biological legacies such as dead wood, old trees and microclimatic conditions remaining within those semi-natural forests yield a structure resembling that found in natural small scale disturbance forest. The rationale for uneven-aged silviculture is that, by mimicking small-scale disturbance, a continuously forested stand with uneven-aged tree structure, stratified canopy and stable microclimate would be retained. Retention of these habitat qualities within the managed stand is expected to maintain associated biodiversity (Kuuluvainen et al., 2012). Uneven-aged silviculture may therefore provide an opportunity to combine biodiversity and production, and preserve temporal continuity of forests within the managed landscape by avoiding clear-felling. However, maintaining structures and processes important for biodiversity while meeting timber management goals is an act of balance (Franklin, 2007) and it is crucial to evaluate how uneven-aged silviculture methods affect forest species assemblages.

Beetles constitute a significant portion of forest biodiversity and perform important ecological functions, including dead wood decomposition and nutrient cycling (Grove, 2002). Beetles are also sensitive to silviculture and can thus be good indicators of forest habitat quality (Siitonen, 2001; Martikainen and Kouki, 2003; Paillet et al., 2010; Stenbacka et al., 2010; Boucher et al., 2012). Approximately 20% of the Swedish beetles are red-listed, and forest harvesting has been reported to be one of the main negative influencing factors (Westling, 2015), indicating vulnerability to current management practice. Saproxylic beetles, i.e. beetles that are associated with deadwood for part or all of their life cycle, are among the most sensitive to the impacts of even-aged silviculture (Siitonen et al., 2000). Beetle diversity is known to increase with increasing structural complexity of the stand, such as numbers of microhabitats, higher tree species diversity and deadwood diversity (Esseen et al., 1997; Siitonen, 2001; Bouget et al., 2013; Gibb et al., 2013). Forests with historically limited management support a higher abundance of species preferring natural substrates such as large spruce logs in shaded conditions than managed forests (Martikainen et al., 1996). The differences between unmanaged and managed forest are most pronounced immediately following clear-felling, when a large proportion of the natural substrates have been removed (Niemela, 1997; Gibb et al., 2006a; Paillet et al., 2010). Uneven-aged silviculture has potential to maintain some of those important substrates and is therefore likely to benefit the associated beetles.

Initial evaluations of uneven-aged silviculture have shown that mature or late-successional forest characteristics and species assemblages are better maintained than in even-aged stands (Koivula, 2002a; Kuuluvainen et al., 2012). While informative, most of these studies reflect changes in composition over timescales less than 15 years (Atlegrim and Sjöberg, 1996a,b; Siira-Pietikainen and Haimi, 2009). Here we present a large-scale chronosequence management study that spans over 50 years to compare the long-term impacts of uneven and even-aged silviculture on beetle (Coleoptera) composition. In our study we evaluate how beetle composition differed between uneven-aged silviculture compared to early and late stages of even-aged silviculture, and compared to unmanaged forest.

We expected that uneven-aged silviculture would result in stands which resembled unmanaged forests in terms of species richness, abundance and beetle composition and would therefore from a conservation perspective be an improvement compared to current silviculture. Directly following clear-felling, we expected that compared with unmanaged stands, species richness and abundance of saproxylic beetles would be reduced and beetle composition altered by favouring open-habitat and generalist species. We anticipated that these effects would become less apparent with time, as overstory stand structure is re-established. However we expected that beetle composition in older, even-aged stands that have undergone clear-felling and commercial thinning still differed compared to unmanaged forest and uneven-aged managed forest.

2. Methods

2.1. Study area

Our study area was located in the boreal forest of central Sweden (Fig. 1), in the counties of Jämtland and Medelpad (63.0–62.3 N, 15.2–16.4 W). The forest cover in those counties is about 77% (Nilsson and Cory, 2016). Annual temperature in the region averages 2 °C and yearly precipitation is ~600 mm (SMHI, 2013). Experimental stands were dominated by Norway spruce (*Picea abies* (L.) Karst) (>70% of the volume) mixed with birch (*Betula pendula* Roth. and *B.pubescens* Ehrh) and a smaller component of Scots pine (*Pinus sylvestris* L), aspen *(Populus tremula* L) and willow (*Salix caprea* L). Ground vegetation was mainly composed of bilberry (*Vaccinium myrtillus* L.) and low herbs. Experimental stands varied from 2 to 16 ha in size (mean = 8 ha) and elevation from 247 to 480 m above sea level (mean = 375 masl).

2.2. Experimental design

The study was designed as a randomized incomplete block experiment comparing (1) recently (2–14 year prior to the study) clear-felled stands that were uneven-aged prior to harvesting but became even-aged as a direct consequence of clear-felling ('Clear-felling'); (2) older, even-aged stands regenerated after clear-felling 50–60 years ago that recently (2–14 year prior to the study) have undergone commercial thinning ('Thinning'); (3) mature stands originating from uneven-aged, stratified stands which have recently (2–15 year prior to the study) undergone uneven-aged silviculture ('Selective felling') and (4) mature stands originating from uneven-aged, stratified stands without recent history (~50 year) of management ('Reference'). The stands evenly distributed in the landscape and not closer than 1000 m apart (Fig. 1, Table 1).

The most used uneven-aged silviculture method for spruce forests in Sweden is single tree selection felling (hereafter 'selective felling'), where single large-diameter trees are harvested and a