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Substrate specific restoration promotes saproxylic beetle diversity in boreal forest set-asides

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A B S T R A C T

In many parts of the boreal biome intensive forest management has resulted in profound changes in forest structure, tree species composition and dead wood availability, and by so negatively effecting forest biodiversity. Restoration of degraded forest habitats is therefore of high priority, both internationally and nationally. Consequently, it is of uttermost importance to develop cost-efficient restoration methods. We have therefore initiated a cost neutral ecological restoration experiment aimed at increasing the variety and volume of dead wood in voluntary set-asides (as part of the FSC certification requirements) by mimicking the two natural disturbances, forest fire and small scale gap dynamics. We studied how tree species and substrate type, i.e. the way in which a tree was killed (cut, girdled, tipped over or cut to produce a high stump), affect species composition, abundance and species richness of saproxylic beetles. We found that species composition differed between tree species in burned as well as gap-cut stands, and that tree posture, i.e. standing or downed trees, also affected species composition in gap-cut stands. In addition, abundance and species richness differed between tree species in gap-cut stands, generally being higher in spruce than in pine and birch. Based on our results we recommend a wider practice of dead wood creation involving a multitude of tree species and tree postures, through mimicking natural disturbances in the management of boreal forests. Furthermore, we suggest that voluntary set-asides provide an excellent opportunity for restoration as they are wide spread and already available in the forest landscape. Restoration cost can therefore be kept at a minimum or totally avoided as in this study.

1. Introduction

Habitat loss and degradation are recognized as two main causes of declining biodiversity on a global scale (Heinrichs et al., 2016). In many parts of the boreal biomes the introduction and practise of rotation forestry has replaced natural disturbance regimes formerly present (Esseen et al., 1997; Lindenmayer et al., 2006; Kuuluvainen, 2009). Disturbances such as forest fires and death of single or groups of trees, which create gaps in the canopy, were once the main drivers behind the structure and composition of these forests (Esseen et al., 1997; Angelstam and Kuuluvainen, 2004; Kuuluvainen and Aakala, 2011). Formerly complex forest ecosystems with considerable variations in habitat type, including vertical structure, tree species composition, age distribution, and dead wood dynamics, have often been transformed into simplified forest habitat (Esseen et al., 1997; Kuuluvainen, 2009). These are often even aged, single species cohorts of planted trees supporting low levels of dead wood (Kuuluvainen, 2009; Brumelis et al., 2011). Consequently the volume of dead wood has decreased due to biomass extraction and at the same time dead wood diversity has decreased (Siitonen, 2001; Jonsson et al., 2005; Stokland et al., 2012).

Saproxylic species, i.e. dead wood dependent species (Stokland et al., 2012); have evolved under conditions with a great variety of dead wood present in the forest landscape. Hence, different species have adapted to utilize differing qualities of dead wood; manifested through dependencies on certain tree species, diameter intervals, substrate types, e.g., standing or downed wood (Ulyshen and Hanula, 2009; Toivanen and Kotiaho, 2010; Stokland et al., 2012), and different stages of decomposition (Lee et al., 2014), as well as in which environment the dead wood substrates are located, e.g. in shade or sun exposed positions (Lindhe et al., 2005). Considering that saproxylic organisms constitute a large proportion of the species present in boreal forest (Grove, 2002; Gibb et al., 2006; Boucher et al., 2012), reductions in dead wood availability have had profound negative effects on boreal biodiversity (Siitonen, 2001; Grove, 2002; Jonsson et al., 2005; Rassi et al., 2010; Stokland et al., 2012; Gärdenfors, 2015). Ultimately expressed by the high proportion of saproxylic species included in many national red-lists of threatened species (Rassi et al., 2010; Gärdenfors, 2015).

Through legal demands and conservation schemes such as the Forest

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Stewardship Council (FSC) and the Programme for the Endorsement of Forest Certification (PEFC), today's forest industry is encouraged to practise a variety of conservation measures improving conditions for biodiversity (Johansson et al., 2013). In boreal regions these measures include: setting forest stands aside from ordinary forestry, leaving buffer zones of trees alongside wetlands and water bodies, leaving snags and logs on clear cuts, and also actively creating dead wood in connection to final harvesting (Gustafsson et al., 2012; Johansson et al., 2013); often high stumps of spruce (*Picea abies*). Prescribed burning of clear-cuts and to some extent standing forests are also included in the FSC-standards for boreal Fennoscandia (Johansson et al., 2013).

However, these efforts do not seem to suffice in restoring biodiversity and we are still witnessing biodiversity losses in boreal ecosystems (Rassi et al., 2010; Johansson et al., 2013; Gärdenfors, 2015). It has therefore been suggested that a more proactive dead wood management is needed to reverse the present negative trend (Shorohova et al., 2011). Lindenmayer et al (2006) propose that ecological restoration is best practiced by mimicking natural disturbances. In boreal settings, Kuuluvainen (2002) and Shorohova et al. (2011) suggest that such practice should include restoration burning of standing forests and mimicking gap scale dynamics. By planning such restoration actions carefully and taking into account the need for a great diversity of different dead wood substrates, both concerning tree species and mortality factor, it should be possible to cater for as many dead wood associated species as possible (Ulyshen and Hanula, 2009; Toivanen and Kotiaho, 2010; Hjältén et al., 2012; Stokland et al., 2012).

The aim of this study was therefore to evaluate if the different dead wood substrates, including three tree species and four substrate types, results in differing saproxylic beetle communities reproducing within the dead wood substrates created during restoration burning as well as artificial gap creation. We therefore address the following questions:

- Does tree species, i.e. spruce (*Picea abies*), pine (*Pinus sylvestris*) or birch (*Betula pubescens* and *B. pendula*) affect the abundance, species richness and composition of saproxylic beetle communities emerging from trees killed during restoration burning?
- Does tree species and substrate type, i.e. if the trees are i) cut at the base and left as logs, ii) tipped over and left as logs, iii) girdled and left standing or iv) cut 3–5 m above ground and left as a high stumps; affect the abundance, species richness and composition of saproxylic beetle communities emerging from dead wood substrates created in gap cut stands?

2. Materials and methods

The study was conducted in the middle and northern boreal zones (Ahti et al., 1968) of northern Sweden (Fig. 1; 63° 23' N to 64° 30' N and 17° 37' E to 21° 20' E). Sixteen voluntary set asides that have never been clear cut, were similar in tree species composition, tree age, field layer vegetation and standing tree volume were included in the study (for details see Hjältén et al. (2017)). Selection was based on a combination of stand data provided by the land host (Holmen AB) and field visits. Stand size varied between 4.3 and 21.6 ha. All stands were dominated by Norway spruce (*Picea abies*) and/or Scots pine (*Pinus sylvestris*). Deciduous trees such as downy birch (*Betula pubescens*), silver birch (*B. pendula*), aspen (*Populus tremula*) and goat willow (*Salix caprea*) were scattered throughout the stands.

Restoration treatments were applied during the early spring and summer of 2011. Six of the stands were subjected to restoration burning and ten stands were subjected to artificial gap creation. In the six stands assigned for restoration burning 5–35% of the trees were cut during the early spring of 2011. This increased solar radiation, and thereby allowed the forest floor to dry up quicker after snow melt. Except for approximately 5 m^3/ha of the cut trees that were left at site as fuel, the remaining trees were removed to cover costs for restoration. In stands selected for artificial gap creation standard harvesters were used to

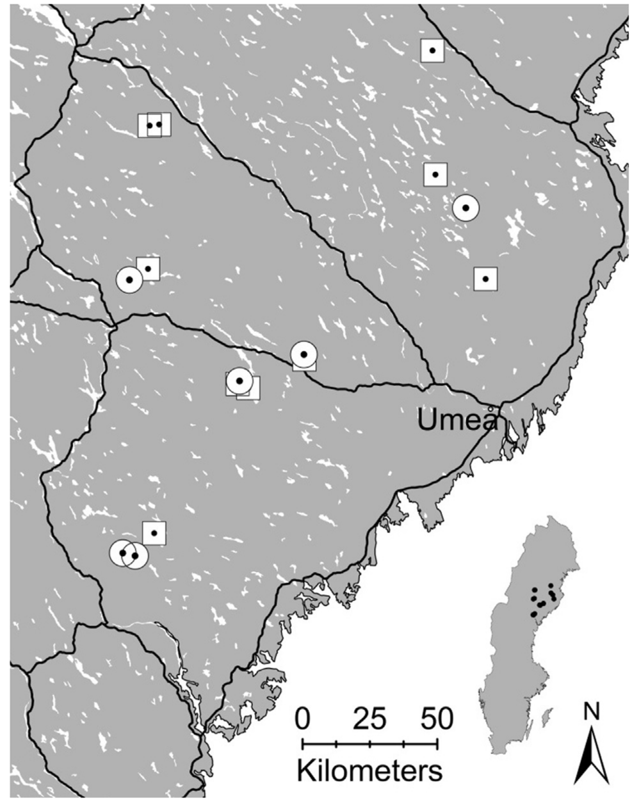

Fig. 1. Map of study area. Circles = burned stands; squares = gap-cut stands.

create six canopy gaps 20 m in diameter per hectare. In every second gap, dead wood substrates were created by killing trees with a standard harvester in four different ways; namely (i) cutting the tree at the base and leaving the log, (ii) simulated windfall by pushing the tree over (with the harvester), thus exposing the root the tree, (iii) girdling trees by removing bark at a height of 4–6 m above ground and (iv) creating 3–5 m tall high-stumps by cutting the trees at this height. Due to the scarcity of deciduous trees in the stands the only way of creating dead wood of birch was by cutting them at the base and leaving the remaining tree as a log. For the two coniferous species all four methods were used. In the remaining gaps all trees were removed to cover costs for restoration.

2.1. Beetle sampling

Beetles were sampled using eclector traps which give a representative sample of the beetles hatching from a certain piece of wood (Okland, 1996; Schiegg, 2001; Alinvi et al., 2006). Each eclector trap consisted of a black plastic mesh wrapped around the trunk of each sampled tree. Traps were attached to the trunk of the sampled trees with plastic straps at the bottom and top end of each trap, approximately 40 cm apart. The enclosed volume of each trap was calculated as a cylinder based on the diameter of the tree trunk and the length of the trap. Foam rubber was used to insure that there were no gaps between the mesh and tree trunk at the two ends of the trap. Three to four metal wires separated the mesh from the trunk of the tree allowing insects emerging from the bark to make their way to the only light source available: a semi-transparent plastic bottle filled to 1/3 with a 50–50 mixture of propylene glycol and water. A small amount of detergent was added to the glycol-water solution breaking surface tension (see Andersson et al. (2015) for illustration). The traps were set up during the first week of June, and collected during the last week of September in 2013.

Sampling was conducted on a total of 12 different substrate types