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Defining stump harvesting retention targets required to maintain saproxylic beetle biodiversity ☆

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ABSTRACT

Stumps comprise up to 80% of the residual deadwood following clear cutting and are a significant source of biomass for bioenergetic applications. However, stump harvesting may pose significant conservation risks for saproxylic organisms that occur in residual deadwood. To define retention targets for stump harvesting operations, we compared abundance and species richness of saproxylic beetles within individual stumps as well as species accumulation curves in replicated pairs of clear cuts with and without stump harvesting in northern Sweden. Using 20 stands, we sampled 1049 stumps using eclector traps and collected 9821 beetles representing 253 species with known saproxylic biology. Nineteen of these species were red-listed in Sweden. We hypothesized that individual stumps left following stump harvesting would contain higher densities and species richness than in clear cuts without stump removal due to crowding of beetles into increasingly limited habitats. However, we found no difference in density or richness within individual stumps between control clear cuts and stumped stands. We also compared species richness between control and stumped treatments using rarefaction within individual stands and across all stands and found no difference. As with density and richness, beetle composition at the stand-level did not differ between control and stumped stands. Thus, the density of surrounding stumps within a stand had very little effect on beetle assemblages in residual stumps. We estimated the effect of stump harvest on species richness at the stand level by combining all samples and extrapolating a rarefaction curve derived from the landscape-level species pool to an accumulated sample volume of 48 m^3 which corresponds to the total volume of stumps on average-sized clear cuts in Northern Sweden. Using this curve, we compared differences in species richness in average-sized clear cuts with 100% (48 m^3) and 25% (12 m^3) stump retention and found that stump harvest resulted in a 26% (95% C.I. 7–41%) loss of species. While the absolute scaling of the landscape-derived rarefaction does not reflect species loss at the stand-level because the combined curve reflects all rare species in the landscape, the relative species loss derived from this curve may serve as credible benchmark for species loss at the stand level following current stump harvesting practices. This benchmark may be further calibrated with additional information on number of singleton species and estimates of maximum species richness.

1. Introduction

The desire to offset fossil fuel consumption with renewable sources such as forest biomass has spurred interest in the recovery of additional logging residues such as stumps in Fennoscandia (Björheden, 2006). Slash and stumps in combinations with other wood fuels could theoretically provide 40 TW h of energy in Sweden by 2020, which is more than twice the industry use of fossil fuels (Oljekommissionen, 2006). The demand for renewable energy has led to extensive implementation of stump harvesting throughout Finland (Hakkila, 2004) as cited in Walmsley and Godbold (2010) and significant trials within Sweden which are estimated to provide ca. 2 TW h in the near future (Skogsstyrelsen, 2009). However, in Finland and Sweden, coarse deadwood has already been greatly reduced through sustained, intensive harvest (Siitonen, 2001; Stenbacka et al., 2010) and stumps now comprise much of the deadwood (Eräjää, 2010, Rabinowitsch-Jokinen and Vanha-Majamaa, 2010). For saproxylic organisms that rely on dead and decaying wood to complete their life cycle, many of which are currently red-listed (Nieto and Alexander, 2010; Gärdenfors, 2015), stumps may serve an important habitat legacy in intensively

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managed stands (Hedgren, 2007; Caruso and Rudolphi, 2009; Hjältén et al., 2010; Jonsell and Hansson, 2011; Jonsell and Schroeder, 2014). Thus stump harvesting can be viewed as an important ecological trade-off that pits long-term potential benefits of climate mitigation strategies against short-term (Geijer et al., 2014) or long-term (Johansson et al., 2016) impacts of biodiversity loss.

Although stumps have been identified as an important substrate for saproxylic organisms (beetles: (Jonsell and Schroeder, 2014); lichens: (Svensson et al., 2016)), we have limited understanding on how stump harvest might influence these species. Recent empirical studies have suggested that in the short term, stump harvesting may have limited, negative impacts on saproxylic species. Within individual stumps, Victorsson and Jonsell (2012) found no differences in saproxylic beetle density between control clear cuts and stump removal plots suggesting that initially following stump harvesting beetles are not crowding into residual stumps. This suggests that the total number of beetles will be proportional to the number of stumps left within the stand and beetle abundance (and presumably species richness) will be lower at the stand-level (Victorsson and Jonsell, 2012). Using the same experiment, these authors demonstrated that species richness of saproxylic beetles was marginally lower in stands where stumps had been removed (Victorsson and Jonsell, 2013). These authors also demonstrated that piles of harvested stumps left to dry at the edge of stands served as ecological traps attracting 4 species in relatively high densities (Victorsson and Jonsell, 2013). However, when longer-term impacts of stump harvesting were evaluated on saproxylic beetle assemblages at the stand-level using flight intercept traps, few differences in species composition, species richness or relative abundance were observed 21–28 years post harvest (Andersson et al., 2012). Together, these studies provide initial benchmarks defining a potential range of impacts caused by stump harvesting. However elaboration of more clearly defined retention targets for stump harvesting requires additional information that quantifies biodiversity impacts as a function of stump biomass removed.

Here we evaluated the effect of stump harvest on saproxylic beetles at both the scale of individual residual stumps and at the stand level. We hypothesized that stump harvesting would initially lead to greater densities of both individuals and species within individual stumps at sites immediately or soon after stumps had been removed due to reduced dead wood availability. We also hypothesized that overall species richness at stand level would be lower following stump harvesting and that species composition following stump harvest would represent a subset of assemblages found in stands where stumps had been retained. We also compared species accumulation curves based on emergence patterns of saproxylic beetles between clear cuts where stumps were removed or retained to define retention targets for stump harvesting operations.

2. Methods

2.1. Study sites

We collected beetles from 20 clear cuts in northern Sweden where half of the clear cuts had been stump harvested and half had been left as controls (Fig. 1). Control and stump harvested clear-cuts were paired based on proximity and harvest date and were treated as 10 replicated experimental blocks. In stump removal clear-cuts, ca. 25% of the stumps were retained according to current recommendations. Stumps were harvested randomly thoughout stands within 1-year of clear cutting. Stumps were harvested using a Pallari hydraulic head consisting of opposing blades which is used to first shear and then pull out the entire stump (Karlsson, 2007). Size of clear cuts, month and year of clearcutting and spatial distance between paired sites within each block are reported in Table 1. Prior to harvesting the stands were all dominated by Norway spruce (*Picea abies* (L.) Karst.). The surrounding forest mainly constituted of managed stands dominated by Norway spruce and Scots pine (*Pinus sylvestris* L.) in various age classes. In both control and stumped sites, most individual stumps had volumes less than 0.02 m^3 (Fig. 2). In control sites 88% of the stumps were less than 0.02 m^3 and the largest stumps did not surpass 0.05 m^3. In stumped sites 83% of the residual stumps were less than 0.02 m^3 but the range of volumes were greater than control sites with a small proportion (less than 1%) of stumps exceeding 0.05 m^3.

2.2. Sampling

We collected beetles using eclector traps that covered the exposed portion of spruce stumps above the roots (Fig. 3). Each eclector consisted of a mesh bag (ca. 1.5 $\times$ 1.5 m) fitted with a support wire that allowed emerging insects to reach a collection bottle filled to 1/3 with 50% propylene glycol (diluted with water) and a small quantity of detergent to break the surface tension. Eclector traps were attached to stumps at soil level using plastic polystrapping placed over the mesh and a thin foam strip used to prevent insects from escaping through furrows in the bark. Traps were set between 2013-05-29 and 2013-06-10 and collected between 2013-09-11 and 2013-09-24 (between 2 and 3.5 years after overstory trees had been removed and stump harvesting occurred). All beetle specimens were identified to species by Stig Lundberg and Jacek Hilszczanski. Within each experimental block, we randomly placed 60 eclector traps on stumps in control clear cuts and 60 eclector traps on residual stumps in stump harvested plots. In total we deployed 1200 eclector traps and recovered 1049 samples following trap losses.

2.3. Data treatment

We limited our analysis to species that could be characterized as facultatively or obligatorily saproxylic based on an extensive review of existing literature on life history of both adult and larval stages according to Speight (1989) and the saproxylic database (Anonymous, 2007) to which species confined to the northern part of Sweden were added (Hilszczanski, J., Pettersson R. and Lundberg S., pers. comm.). Species were assigned to functional groups if either larvae or adult could be confidently described as (i) predators, (ii) fungivores, or (iii) cambium and wood feeders. Eighteen species had life stages that were a combination of these three principal functional groups and were defined as predator-fungivore (11 species), fungivore-cambium/wood feeder (6 species), predator-cambium wood-feeder (1 species). Species with both larval and adult life stages other than these three principal functional groups were grouped as ‘other’.

We evaluated whether stump harvesting would lead to greater beetle abundance or beetle species richness within stumps using non-linear least squares regression. Both abundance and species richness were characterized as a function of stump volume for each treatment. We selected non-linear least squares regression and a Michaelis–Menten model for our analysis because linear and generalized linear models consistently overestimated both beetle abundance and richness in larger stumps and visual inspection of data clearly suggests a non-linear relationship between both beetle abundance and richness and individual stump volume. The Michaelis–Menten model fits an asymptotic curve using a parameter (V_m) to determine the maximum value for the asymptote and a second parameter to determine one-half of the maximum value, referred to as the Michaelis parameter (K). Non-linear