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Long-term landscape scale effects of bioenergy extraction on dead wood-dependent species ☆

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ABSTRACT

Dead wood is an important resource for biodiversity, which has often decreased due to forest management. There is an increasing interest in extracting woody residues on clear-cuts for bioenergy production, which will further decrease dead wood amounts. Empirical studies show that such extraction decreases habitat availability for many species at a local scale, but no analyses have been made on long-term effects on population sizes and species persistence in whole landscapes. We investigated how theoretical species that differ in dispersal range, habitat specialization, and commonness are affected by different levels of wood extraction intensity. We also investigated the effect of extracting only slash (branches and tops) compared to both slash and stumps, and the spatial location of the extraction. This was done by simulations of dead wood development and species' colonization–extinction dynamics based on metapopulation theory. The simulations were run for 200 years in an 11 × 11 km managed forest landscape in Sweden. For all species the predicted population sizes decreased, and for six out of eight species the landscape level extinction risks increased with increasing bioenergy extraction. The negative impacts were larger when including stumps compared to extracting slash only. However, rare species declined more strongly with increasing extraction than the common species. Specialists on coarse sun-exposed wood declined more than generalists when stumps were included in the extraction, while the pattern was the opposite when only extracting slash. The population declines continued for up to 200 years before colonizations and extinctions were in equilibrium, and were generally slower for rare compared to common species. Concentrating the extraction to 50% of the landscape had a positive effect on rare and short-dispersing species, which could be assumed to be the most threatened species. Thus, bioenergy extraction is likely to have negative impacts on biodiversity, which are most severe when stumps are extracted at a high intensity throughout the landscape. Even at low levels of stump extraction, species which are already rare and specialized on sun-exposed coarse dead wood may be threatened. Slash extraction has probably less impact, since few species are specialized on fine woody debris. Concentrating the extraction to a subset of forested areas may reduce the negative impact. The apparent direct trade-off between the amount of bioenergy extracted and the remaining amount of dead-wood habitat may require that bioenergy extraction is either limited or further conservation interventions are employed that compensate for anthropogenic habitat loss.

1. Introduction

Habitat loss has been identified as the most important global threat to biodiversity (Fahrig, 2003). Anthropogenic climate change is now interacting with and sometimes compounding the negative impacts of habitat loss on biodiversity, through the additional stressors of rapid environmental change, altered disturbance regimes, and associated changes to species interactions (Brook et al., 2008; Driscoll et al., 2011; Thomas et al., 2004). One way to mitigate climate change is to replace fossil fuels with renewable energy sources. However, this mitigation pathway has the potential to cause further losses of natural habitat, and thus exacerbate the loss of biodiversity (Lindenmayer et al., 2012b; Paterson et al., 2008). A mitigation pathway of particular concern to biodiversity is the rapid expansion of bioenergy production. In agricultural systems, expanding bioenergy crop production has repeatedly been shown to have negative impacts on biodiversity, due to resultant land use change and habitat destruction (e.g. Immerzeel et al., 2014). A related but less studied mitigation

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pathway involves the use of logging residues for bioenergy production. This raises concerns due to its potential to reduce the availability of key forest structures of demonstrated importance to forest biodiversity (Bouget et al., 2012)

Over recent decades the extraction of woody residues for bioenergy production has increasingly occurred on the clear-cuts created by production forestry (Björheden, 2006; Gan and Smith, 2011). This may have negative impacts on forest biodiversity, since dead wood is an important substrate for many species (e.g. Siitonen, 2001; Stokland et al., 2012). In managed boreal forests, the amount of coarse woody debris is typically only a fraction of that in unmanaged forests and often lacks larger diameter size classes (e.g. Fridman and Walheim, 2000; Siitonen, 2001). The loss of large-diameter residues is of particular concern with respect to species associated with coarse dead wood, as these species have already lost substantial proportions of their habitat due to modern forest management (e.g. Stokland et al., 2012). As a response, and due to increasing acknowledgment of the importance of sustaining biodiversity in production forests (Lindenmayer and Franklin, 2002), efforts have been made to increase the availability of dead wood in production forests (Fridman and Walheim, 2000; Lindenmayer et al., 2012a). The extraction of woody residues on clear-cuts for bioenergy production is thus in direct conflict with these past and ongoing efforts. However, the impact of bioenergy extraction on the population persistence of wood-dependent species remains largely unknown, and will differ depending on the composition and intensity of the extraction, and the habitat requirements of the species considered.

Biomass extraction for bioenergy production can involve the removal of tops and branches (slash henceforth), as well as stumps at the time of clear-felling (Dahlberg et al., 2011). In Swedish forests, the extraction of slash is conducted on about 40% of all clear-cuts (Swedish Forestry Agency, 2014), and substantially decreases habitat for many wood-dependent species, despite few species specializing on fine woody debris (Dahlberg et al., 2011). In contrast, stump extraction in Sweden is currently limited to 1–2% of all clear-cuts. This is at least partly due to restrictions placed on stump harvesting by the FSC, which certifies roughly half of the Swedish forest land and has concerns regarding the environmental consequences of this practice. However, the Swedish Forest Agency has concluded that stump extraction on 5–10% of all clear-cuts, if evenly spread across a landscape, should have only minor impacts on biodiversity (Swedish Forestry Agency, 2009).

Stumps on clear-cuts are utilized as habitat for a wide range of wood-dependent organisms (e.g. beetles: Hjältén et al., 2010; lichens: Svensson et al., 2013; fungi: Toivanen et al., 2012), and provide a substrate as important as other types of coarse dead wood for many species (Andersson et al., 2015; Hjältén et al., 2010). Stump extraction therefore has the potential to substantially reduce habitat for many wood-dependent species, especially for species specialized on coarse sun-exposed wood. For example, the populations of almost one quarter of wood-dependent beetle species in a managed forest landscape can be reliant upon clear-cut stumps (Jonsell and Schroeder, 2014). Furthermore, stump extraction has been documented to at least temporarily reduce stand-level biodiversity (Toivanen et al., 2012; Victorsson and Jonsell, 2013), but the long-term effects has been suggested to be rather small (Andersson et al., 2012). However, as logging residue extraction could be applied over extensive areas of production forests (Dahlberg et al., 2011; FAO, 2010), studies evaluating the long-term landscape scale effects of stump and slash extraction on biodiversity are needed (Bouget et al., 2012; Egnell et al., 2007; Riffell et al., 2011).

Determining the long-term potential implications of any form of habitat change on biodiversity (e.g. the effect of bioenergy extraction on wood-dependent species) requires either long-term experiments or the application of predictive models. Due to the relatively recent instigation of bioenergy extraction, long-term data will not be available for landscape scale analyses for several decades. Predictive models can be applied faster, but typically involve single species assessments, requiring substantial knowledge of their habitat and species dynamics, which for most species is lacking. This obstacle can nevertheless be overcome by replacing predictive models for particular species with models built for theoretical species which diverge in key aspects of their life-history and habitat requirements (traits hereafter). The choice of these traits can be based on general knowledge about factors important for explaining species' spatial distributions and colonization–extinction dynamics, such as dispersal ability, habitat specialization and commonness (e.g. Henle et al., 2004).

To predict the population changes of species with different traits in a whole landscape due to the decline and fragmentation of dispersal sources, the theory and methods of metapopulation ecology can be used (e.g. Hanski, 1999; Hanski and Ovaskainen, 2000, 2002). This theory has primarily been developed to address those species specialized on readily defined habitat patches nested within highly fragmented landscapes (Hanski, 1999; Levins, 1969). However, for species inhabiting managed forests, habitat patches are typically not well-defined, and empirical metapopulation studies are therefore difficult to conduct. Nevertheless, also for many forest species their spatial distribution and extinction risk are most likely driven by colonization–extinction processes mainly consistent with metapopulation theory (Ranius et al., 2014a).

The aim of this study was to investigate how wood-dependent species are affected by the extraction of forest residues for bioenergy production in the long term and at the landscape scale. Using theoretical species, we investigated how species which differ in dispersal range, habitat specialization and commonness are affected by different extraction intensities. We also investigated the effect of extracting slash versus the effect of extracting both slash and stumps, and how the spatial location of the extraction (evenly spread out vs. concentrated to 50% of the landscape) alters outcomes. To do so we simulated dead wood development and species' colonization–extinction dynamics over extensive time periods (200 years) in a managed forest landscape under different scenarios of bioenergy extraction.

2. Material and methods

To investigate how wood-dependent species are affected by the extraction of slash and stumps for bioenergy production after final felling, we simulated the availability of dead wood and species' colonization–extinction dynamics over time in a managed forest landscape under different extraction scenarios for species with different traits. First, we describe (i) the model used to simulate species' colonization–extinction dynamics, and (ii) how traits of the model species were chosen. Then we describe (iii) the landscape model and (iv) the bioenergy extraction scenarios.

2.1. Modeling colonization–extinction dynamics

To be able to simulate colonization–extinction dynamics over a whole landscape we simulated the dynamics at the stand level (rather than at the level of single dead wood objects) based on metapopulation theory. The colonization probability was modeled as a function of connectivity to surrounding occupied stands. The connectivity, S, of stand i was modeled as:

$$S_i = \sum_{j=1}^{n} e^{-\alpha d_{ij}} P_j A_j \tag{1}$$