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Biofuel harvests, coarse woody debris, and biodiversity – A meta-analysis

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ABSTRACT

Forest harvest operations often produce large amounts of harvest residue which typically becomes fine (foliage, small limbs and trees) and coarse woody debris (snags and downed logs). If removed at harvest, residual biomass has potential to be a local energy source and to produce marketable biofuel feedstock. But, CWD in particular serves critical life-history functions (e.g., breeding, foraging, basking) for a variety of organisms. Unfortunately, little is known about how forest biodiversity would respond to large scale removal of harvest residues. We calculated 745 biodiversity effect sizes from 26 studies involving manipulations of CWD (i.e., removed or added downed woody debris and/or snags). Diversity and abundance of both cavity- and open-nesting birds were substantially and consistently lower in treatments with lower amounts of downed CWD and/or standing snags, as was biomass of invertebrates. However, cumulative effect sizes for other taxa were not as large, were based on fewer studies, and varied among manipulation types. Little is currently known about biodiversity response to harvest of fine woody debris. Predicting the effects of biomass harvests on forest biodiversity is uncertain at best until more is known about how operational harvests actually change fine and coarse woody debris levels over long time periods. Pilot biomass harvests report post-harvest changes in CWD levels much smaller than the experimental changes involved in the studies we analyzed. Thus, operational biomass harvests may not change CWD levels enough to appreciably influence forest biodiversity, especially when following biomass harvest guidelines that require leaving a portion of harvest residues. Multi-scale studies can help reduce this uncertainty by investigating how biodiversity responses scale from the small scale of manipulative experiments (i.e., 10-ha plots) to operational forest management and how biodiversity response to CWD levels might vary at different spatial and temporal scales and in different landscape contexts.

1. Introduction

Traditional forest harvest operations often produce large amounts of woody residue consisting of tree-tops, limbs, slash, foliage, and felled non-crop trees and small-diameter trees that cannot be sold at value great enough to justify the costs of removing it from the site. However, harvesting (i.e., removing) could become economically feasible because these residues have potential to help meet increasing demand for biofuel and allow the forest industry to participate in the emerging economic market for biomass feedstocks.

Forest harvest residues include growing stock volume cut or knocked down during harvest, low-quality commercial trees, dead wood and non-commercial tree species typically left at the harvest site (Gan and Smith, 2006). Coarse woody debris (CWD) has been defined various ways and some consider it to include both down wood and standing snags (e.g., Loeb, 1999). In this review, we will distinguish between snags and down coarse woody debris (DCWD). We consider *snags* to be standing dead trees ≥1.8 m in height and ≥10.2 cm diameter at breast height (dbh) following Thomas et al. (1979), although others may use slightly different girth and height criteria. We consider *down coarse woody debris* (DCWD) to be downed dead wood such as logs, stumps, piles of limbs and other woody material of a minimum size found on the forest floor. Although no universally recognized size criteria exist (Jones et al., 2009), most studies we reviewed defined CWD as >10 cm in dbh and >60 cm in length. We define *fine woody debris* (FWD) as down, dead woody material <10 cm in dbh or <60 cm in length.

Although pilot and experimental biomass harvests have been conducted across North America (Arnosti et al., 2008; Evans and Finkral, 2009), little is known about the response of forest biodiversity to removal of forest harvest residues. A primary mechanism for biodiversity response would likely occur through changes in the

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Table 1
Summary of manipulative studies used for meta-analysis of effects of coarse woody debris manipulations on biodiversity.

Study	Location	Forest type	Taxa	Effect sizes[a]
Caine and Marion (1991)	Florida	Slash Pine	Birds	1, 2, 12, 0
Castro and Wise (2010)	Kentucky	Mixed Hardwood	Invertebrates	3, 19, 0, 0
Haggard and Gaines (2001)	Washington	Ponderosa Pine	Birds	0, 0, 13, 0
Hanula et al. (2006)	S. Carolina	Loblolly Pine	Invertebrates	4, 13, 0, 0
Horn and Hanula (2008)	S. Carolina	Loblolly Pine	Invertebrates	0, 1, 0, 9
Hutto and Gallo (2006)	Montana	Ponderosa Pine	Birds	0, 1, 17, 0
Koivula and Schmiegelow (2007)	Alberta	Boreal Mixedwoods	Birds	0, 1, 2, 0
Loeb (1999)	S. Carolina	Longleaf Pine	Mammals	1, 1, 11, 0
Lohr et al. (2002), Summer	S. Carolina	Loblolly Pine	Birds	4, 14, 58, 0
Lohr et al. (2002), Winter	S. Carolina	Loblolly Pine	Birds	4, 13, 56, 0
McPeek et al. (1987), Summer	Kentucky	Mixed Hardwoods	Birds	0, 0, 6, 0
McPeek et al. (1987), Winter	Kentucky	Mixed Hardwoods	Birds	0, 0, 6, 0
Morissette et al. (2002)	Saskatchewan	Boreal Mixedwood	Birds	0, 0, 10, 0
Morissette et al. (2002)	Saskatchewan	Jack Pine	Birds	0, 0, 20, 0
Moseley et al. (2005)	S. Carolina	Loblolly Pine	Invertebrates	0, 36, 0, 0
Moseley et al. (2008)	S. Carolina	Loblolly Pine	Mammals	0, 0, 9, 0
Osbourne and Anderson (2002)	West Virginia	Mixed Hardwoods	Mammals	8, 2, 10, 0
Owens et al. (2008), Phase I	S. Carolinaa	Loblolly Pine	Reptiles Amphibians	12, 18, 30, 0
Owens et al. (2008), Phase II	S. Carolina	Loblolly Pine	Reptiles Amphibians	12, 18, 33, 0
Saab et al. (2007)	Idaho	Ponderosa Pine	Birds	0, 0, 7, 0
Schwab et al. (2006)	Labrador	Boreal Mixedwood	Birds	1, 1, 6, 0
Stepnisky (2003), Summer	Alberta	Boreal Mixedwood	Birds	0, 3, 0, 0
Stepnisky (2003), Winter	Alberta	Boreal Mixedwood	Birds	0, 4, 0, 0
Todd and Andrews (2008)	S. Carolina	Loblolly Pine	Reptile	0, 0, 2, 0
Todd et al. (2008)	S. Carolina	Loblolly Pine	Invertebrate	0, 0, 1, 0
Ulyshen and Hanula (2009)	S. Carolina	Loblolly Pine	Invertebrates	80, 150, 0, 0

[a] Number of effect sizes from each study for diversity, guild abundance, species abundance, and biomass, respectively.

amount of snags, down coarse woody debris and fine woody debris. Harvest residues may represent a substantial input of DCWD. Thus, removal of harvest residues may impact amount of DCWD present during years following the biomass harvest.

Although detailed information about biodiversity response to harvest residue removals has not been collected, the importance of DCWD and snags to cavity-nesting birds and other wildlife has long been recognized (Harmon et al., 1986; Freedman et al., 1996; Russell et al., 2004; Jones et al., 2009). As a result, some research efforts have experimentally manipulated levels of snags and DCWD in a way that closely mimics changes likely to occur from biomass harvests. To summarize biodiversity response to removal of snags and DCWD, we reviewed the literature and conducted a meta-analysis of experimental studies.

2. Methodology

We reviewed the literature for papers that compared biodiversity responses to experimental manipulations of downed coarse woody debris and/or snags. Diversity responses included diversity metrics (i.e., species richness, diversity or evenness), abundance of taxa or groups of species (guilds), and single-species abundance estimates. We included responses of birds, mammals, reptiles, amphibians and invertebrates. We included both manipulative experiments and management experiments where harvested areas were compared to appropriate unharvested controls. We included studies of salvage logging – harvest of merchantable residues after large forest fires to recover economic value of wood – because it is a viable management option in forests in western North America. Additionally, demand for woody biomass may increase the frequency (and intensity) of salvage logging. Also, salvage logging mimics – to a certain extent – CWD manipulations likely to occur in biomass harvests, especially post-disturbance. Salvage logging experiments reduce standing dead biomass similar to what might occur when non-crop trees are removed at harvest and potentially reduce the future stock of snags.

We used Wildlife & Ecology Worldwide, USDA Forest Service TreeSearch and Google Scholar databases to search for relevant studies. We searched article abstracts using combinations of forestry terms (coarse woody debris, fine woody debris, snags, harvest residue, slash, salvage logging) and biodiversity terms (biodiversity, diversity, richness, wildlife, birds, avian, amphibians, reptiles, invertebrates, insects and mammals). We supplemented searches by examining bibliographies of articles for additional references.

We found 26 studies suitable for use in a meta-analysis (provided sample size and standard deviations for biodiversity responses) with the following experimental manipulations: removal of DCWD, addition of DCWD, snag removal (including salvage logging), snag addition and removal of both snags and DCWD (Table 1). These studies provided 745 individual effects sizes (Table 1). Because responses to habitat manipulations can vary greatly among taxa and among species within a taxon, we considered different biodiversity measures (e.g., diversity, abundance, richness) from the same study to be independent effects (Bender et al., 1998). For birds, we also considered studies that presented analysis of breeding and winter bird responses as separate "studies" because the behavior, habitat requirements and composition of bird communities can be very different during those two seasons. When studies presented comparisons in different types of forest, we similarly treated these as separate experiments because species' responses can vary among different forest types. When studies presented results of two separate experiments on the same study areas, but separated in time, we also treated those as independent experiments. When studies presented comparisons for a metric in consecutive years, we calculated the overall mean effect and standard deviation using the pooled variance. Some studies compared more than one treatment to the same control (e.g., Lohr et al., 2002), so these effect sizes would not be independent because they included data from the same control sites. To account for this, we conducted meta-analysis for each taxon across all manipulations and separately for each type of manipulation (see Table 1). Because of the number of studies and effects sizes available for birds, we were able to do additional meta-analysis by season and by nesting strategy (strong excavator, weak excavator, secondary cavity nester, and non-cavity nester following Martin et al. (2004)).