RESEARCH NOTE

Woody Debris as a Component of Ecological Diversity in Thinned and Unthinned Northern Hardwood Forests

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ABSTRACT: We examined the effects of management on coarse woody debris, both standing and downed, in thinned and unthinned northern hardwood forests in upper Michigan. The unthinned conditions included old growth and second growth, while the thinned conditions included both even- and uneven-aged management. The structural features analyzed were stem diameter, density, basal area, and height of snags and live trees, as well as volume, diameter, and decay state of downed woody debris (DWD). As measured by these features, the relative structural complexity among the forest conditions was generally old growth > uneven-aged > second growth ~ even-aged. Although snag density was highest in second-growth forests, old growth had the highest snag basal area. Old growth also had the largest volume of DWD, second growth and even-aged had the least, and uneven-aged had an intermediate value. Unlike old growth, other treatments lacked large diameter (> 40 cm) snags and DWD. If prescriptions are changed to allow for the creation of larger snags and DWD, particularly those > 60 cm in diameter, stands can be managed to more closely resemble these structural aspects of old-growth forests.

Index terms: diversity, northern hardwoods, forest management, structure, complexity, Michigan

INTRODUCTION

From an ecological perspective, dead wood is as important as live wood. Dead trees and downed woody debris represent a substantial accumulation of energy, carbon, and nutrients in many forest ecosystems (Tyrrell et al. 1998). Dead wood and the humus that it forms are the source of soil organic matter that influences a wide array of physical, chemical, and biological properties and processes. For a northern hardwood ecosystem in New England, approximately 90 percent of the nitrogen occurred in the soil organic matter, while less than 1 percent existed as available nitrogen in the soil and the remaining 9 or 10 percent occurred in the vegetation (Bormann et al. 1977). Soil microorganisms rely on soil organic matter as an energy source (Fisk et al. 2002). The release or mineralization of nutrients from organic materials by soil microorganisms provides a large share of the nutrients required for plant growth. In addition, organic matter influences soil aggregate formation, which in turn affects a number of physical and chemical soil properties (e.g., aeration, drainage, and available water content of the soil). When present in a variety of sizes and conditions, dead trees add structural diversity to the forest (Crow et al. 2002), and their value as critical habitat for organisms large and small is well documented (Bull and Meslow 1977, Brown et al. 1982, Raphael and White 1984, Rosenberg et al. 1988, Crow et al. 1994).

Downed woody debris and snag dynamics differ between thinned and unthinned forests (Tyrrell and Crow 1994a, Siitonen et al. 2000). Traditional silvicultural practices focus on retaining and growing commercial species and on removing culls as well as trees susceptible to mortality. These practices can result in a loss of species richness and a loss of structural and functional diversity (Noss and Cooperrider 1994). In even-aged thinned forests, most commercial-size trees are harvested at some point during the rotation. Although removal causes an input of downed woody debris from slash, these inputs are usually smaller in diameter and less than those produced in natural forests due to more complete utilization of timber resources (Peet and Christensen 1987, Sturtevant et al. 1997). Smaller materials decompose rapidly, reducing their importance for nutrient retention and wildlife habitat. Under management, thinning reduces competition and mortality (Siitonen et al. 2000), which are creators of snags in the forest. Tree growth, tree death, and canopy gap formation continue as forests age, but harvesting truncates forest development, thus limiting the accumulation of large dead trees (Hansen et al. 1991, Tyrrell and Crow 1994b).

In our study, we compared the formation of snags and downed woody debris under four conditions: even- and uneven-aged forests of northern hardwoods managed for timber, unthinned old-growth, and unthinned second-growth forests. The two unthinned conditions provide baselines for the managed conditions. The purpose was to determine how thinning in northern hardwood forests impacts the formation of snags and downed woody debris by measuring (1) snag density, basal area, mean diameter, and height distribution, and (2) downed woody debris diameter, volume, density, and decay class.

METHODS

Study Sites

We studied northern hardwood forests in the western Upper Peninsula of Michigan within the Watersmeet and Iron River Ranger Districts of the Ottawa National Forest (Crow et al. 2002). The forests are dominated by sugar maple (*Acer saccharum* Marsh.), with other common tree species including yellow birch (*Betula alleghaniensis* Britton), basswood (*Tilia americana* L.), eastern hemlock (*Tsuga canadensis* (L.) Carr.), and ironwood (*Ostrya virginiana* (Mill.) Koch). To minimize variation in the physical environment, all study sites were located on Ecological Landtype Phases (ELTP) 38B and 38C, which were nested within a single ecosystem classification unit, Sub-subsection IX.3.2 (Winegar Moraine; coarse-textured ice-stagnation moraines with numerous kettle lakes; northern hardwood forests; bogs) (Albert 1995). ELTP 38B occurs on gently sloping moraines with a slope of 1 to 6 percent and has Acer-Tsuga-Dryopteris as the dominant habitat type. ELTP 38C is the same except it has slightly greater slopes. Three sites were established for each forest condition: unthinned old growth (OG), unthinned second growth (SG), thinned even-aged (EA), and thinned uneven-aged (UEA).

Forest History and Stand Descriptions

Our study was established in 1994. The six thinned stands in the study had been last entered for timber harvesting in the late 1980s and early 1990s. The cutting prescriptions for these forests were obtained from records maintained by the Ottawa National Forest. For UEA forests, the guidelines called for reductions in stand basal area by 7.5 to 8.0 m^2ha^{-1} in trees > 12 cm DBH using individual tree selection. The first trees to be removed were those considered high risk and likely to die before the next entry and those that had obvious defects that would reduce their commercial value. The creation of canopy gaps was recommended to promote tree regeneration. For EA, forests were thinned to about 90 percent crown cover. The goal was to leave 150 to 180 dominant and co-dominant crop trees per hectare. The trees removed in the thinning to create this density of remaining trees were high-risk, cull, and subcanopy trees. Under EA management, forests are generally thinned several times prior to the final harvest (a clear-cut). In our EA study sites, only the initial thinning had occurred and the final overstory removal had not yet taken place.

In addition to these instructions, general guidelines were applied to all of the thinned forests, including the retention of eastern hemlock and northern white-cedar (*Thuja occidentalis* L.). Sugar maple and yellow birch > 50 cm DBH were generally harvested. The retention of an average of 5 to 10 wildlife (cavity) trees ha^{-1} was also recommended.

In OG forests, canopy trees ranging in age between 200 and 300 years dominated the forest, although a wide variety of tree ages and sizes were measured in the subcanopy (Crow et al. 2002). The diameter distribution for live trees in the UEA treatment resembled that of old growth except for the > 60 cm DBH class, which was missing in the thinned forests. Mean DBH, stem density, and basal area for old growth can be compared to that for the other forest conditions in Table 1.

The unthinned SG forests originated after commercial clearcutting between 1915 and 1920, and they have had limited or no disturbance since their harvest. Trees 60 to 80 years old dominate these forests with occasional residual trees ranging from 120 to 200 years in age; mean age is 71 years (Table 1). The EA forests resembled the unthinned SG in terms of tree diameter distributions. The average live tree basal area for unthinned SG forests was 31 m^2ha^{-1} (Table 1).

For the UEA forests, the mean live tree age was 110 years and the trees ranged from the mid 30's to greater than 200 years. Although the EA forests had a similar range of tree ages, their mean live tree age was lower (74 years). The thinned treatments had similar live tree basal areas, although the live tree densities differed (Table 1).

Table 1. Structural characteristics of live trees for the four conditions studied. Means are based on three replications. Number of tree species is summed among the three replications.

	Unthinned		Thinned	
Characteristic[a]	Old growth	Second growth	Uneven-aged	Even-aged
Mean stand age (years)	175	71	110	74
Number of tree species	16	16	11	13
Mean DBH (cm), live trees[b]	11.6 (0.79)	16.7 (0.80)	12.4 (0.80)	17.4 (0.82)
Mean density (stems ha^{-1})	1124	969	911	707
Mean basal area (m^2ha^{-1})	34	31	23.4	24.3

a Includes woody vegetation > 1.5 cm DBH.
b Standard deviations are included in parentheses.

UEA had larger numbers of small trees compared to EA.

Snag and Downed Woody Debris Measurement

Ten 1/12-ha plots were randomly established in each study area to measure snags with a DBH > 1.5 cm. Total height was measured on all of the snags within 3 of the 10 plots per stand, while DBH and tree species were recorded for all snags in all plots. To quantify the downed woody debris, we used a line intersect method (Van Wagner 1968, 1982). The sample line is actually a vertical plane in which a series of circular cross-sectional areas are collected at the intersections between the line and downed woody debris. We measured the diameter of all downed woody debris ≥ 2 cm in diameter that intersected three 120-m transects established in each sites. The 120-m transects were formed in the shape of equilateral triangles, with 40 meter sides, to avoid bias associated with the non-random orientation of downed woody debris (Van Wagner 1968). Starting points and angle of orientation for the triangles were randomly chosen for each triangle. All of the debris sampled was assigned to a decay class from I (recent or least decomposed with leaves present, bark intact, wood sound, current-year twigs present, and the form round) to V (very decayed with leaves absent, bark detached or absent, wood punky, branches absent, and form oval or collapsed) based on classifications from Sollins (1982) and Tyrrell and Crow (1994b). We converted diameter of downed woody debris to volume using $V = (\pi^2/8L)\sum d^2$, where V is volume of wood per unit area, d is the diameter of downed woody debris at the intersection of the sample line, and L is the length of the sample line (Van Wagner 1968).

Statistical Analyses

A one-way analysis of variance (ANOVA) with one random effect was used to determine if there was a statistically significant difference between forest types in terms of mean diameter of downed woody debris and snags and in terms of mean height of snags. Statistical analyses were performed using the general linear models procedure in SAS (SAS Institute Inc. 1999).

RESULTS

Snag Basal Area and Size-Class Distribution

Total basal area of snags was highest in OG with almost triple the amount found in the thinned forests (Figure 1). SG, UEA, and EA had similar percentages of total basal area in snags (Table 2). The consideration of snag basal area by diameter classes reveals very different patterns among forest conditions (Figure 1). OG averaged only 6 percent of the total snag basal area in the < 30 cm DBH class, compared to 57 percent for SG and 43 percent for EA (Table 2). Likewise, OG had the highest

Table 2. Structural characteristics of snags by forest condition. Means with the same letter are not significantly different at P = 0.05.

	Unthinned		Thinned	
Characteristic[a]	Old growth	Second growth	Uneven-aged	Even-aged
Total no. of snags	266	549	347	208
Number of species	13	12	8	10
Mean DBH (cm)[b]	14.3a (1.15)	10.7ab (0.98)	7.8b (1.07)	14.3a (1.23)
Density (stems ha^{-1})	106.8	219.6	140	87.2
Snag size distribution				
1.5-10 cm	76.8	141	119.6	49.2
10.1-30 cm	11.6	67.2	11.6	29.6
30.1-45 cm	4.8	9.6	4	5.6
45.1-60 cm	4.8	1.2	3.6	2.4
> 60 cm	8.8	0.4	1.2	0.4
Mean height (m)[b]	5.9ab	7.4b	5.0a	7.0ab
	(4.6)	(4.5)	(2.7)	(3.8)
Basal area snags (m^2ha^{-1})	5.7	3.4	2.2	2.4
% of total basal area	14.3	9.8	9.6	8.9
% basal area snags				
< 30 cm	5.7	57.1	22.1	43.2
30-45 cm	9.5	31.3	19	27.1
> 45 cm	84.9	11.6	58.8	27.7

a Includes woody vegetation > 1.5 cm DBH for snag characteristics.
b Standard deviations are in parentheses.

percentages of total snag basal area in the > 45 cm diameter class, while EA and SG had the lowest percentages in this size class. OG was the only forest condition with a large amount of basal area in snags with a diameter > 60 cm – seven times the basal area found in the next highest forest condition (Figure 1).

Snag Density and Diameter Distribution

SG had the highest snag density with > 200 snags ha^{-1}, and EA had the lowest density among the forests with an average of 87 snags ha^{-1} (Table 2). OG had nearly triple the average number of large snags (> 45 cm) measured in UEA and nearly five times the average number found in EA. OG also had more snags > 60 cm DBH. UEA was the only other forest type with a significant density of snags larger than 60 cm, with an average of 1.2 per hectare (Table 2). Snags larger than 60 cm were largely absent from the EA forests. OG and EA had similar mean snag DBH's. These diameters, however, were not significantly different from the SG mean snag DBH (Table 2, OG-SG P = 0.152, EA-SG P = 0.2169), nor was SG mean snag DBH significantly different from that for UEA (UEA-SG P = 0.4791).

Snag Height Distributions (> 10 cm DBH)

SG had the highest mean snag height followed by EA, OG, and UEA, in that order (Table 2). On a relative basis, OG, EA, and UEA each had more snags in the lower height classes compared to the SG forests (Figure 2). Overall, OG had a wide distribution of snag heights, with heights evenly distributed among the diameter classes, and large snags (> 30 cm DBH) present in each height class. UEA had an even distribution with snags in all height classes from 1 to18 m tall and large snags (> 30 cm DBH) in all height classes except one. EA had snags in height classes from 1 to 21 m, with 10.1 to 30 cm DBH snags making up most snags 1 to 12 m tall (Figure 2).

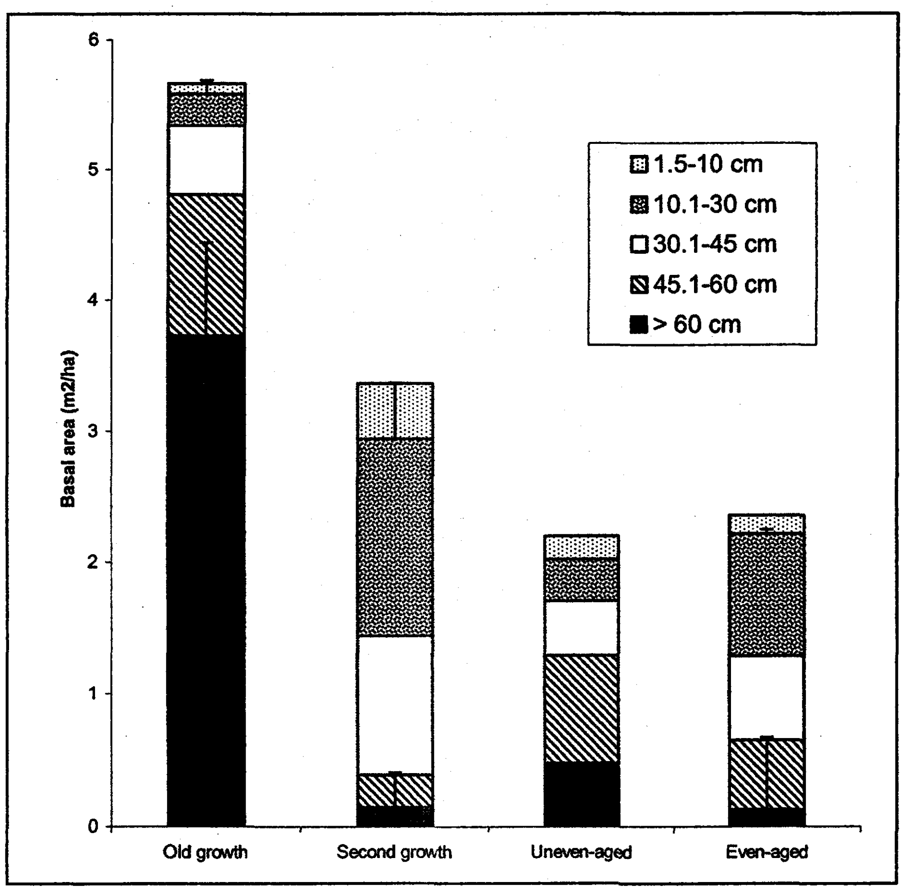

Figure 1. Snag basal area distribution by diameter size classes for thinned and unthinned northern hardwood forests. Top error bars show one standard deviation for all snags in the 10.1 to 30 cm diameter breast height (dbh) class and the bottom error bars are for snags > 60 cm dbh.

Downed Woody Debris Volume Distributions

OG had the highest average volume of downed woody debris, with 1.5 times more volume than UEA and 2.5 times more volume than SG and EA (Table 3). For OG, large volumes in the 20.1 to 40 cm and 40.1 to 60 cm DBH classes account for most of the difference among forest conditions (Figure 3).

Differences were also found in the distributions of downed woody debris among decay classes (Table 3). Surprisingly, OG had the lowest percent of volume in advanced stages of decay (decay class V) but had the highest percentages in classes III and IV. All forest types studied had small percentages in decay class I.

Downed Woody Debris Size Distributions and Densities

OG had the highest mean downed woody debris diameter of all the forest types, with an average of 1.3 times larger mean diameter than the next closest mean diameter recorded in the UEA (Table 3). The mean diameter for OG downed woody debris was significantly different from that for all of the other forest conditions (P < 0.0001 for all comparisons). EA had the highest downed woody debris density while OG had the lowest. SG and UEA had similar densities. OG had nearly two times the amount in the > 40 cm classes than UEA; SG and EA had almost no downed woody debris larger than 40 cm. OG and UEA had similar volumes of downed woody debris with diameters > 60 cm, with OG still averaging the highest volumes (Figure 3).

DISCUSSION

The primary purpose of most silviculture systems is to enhance forest productivity by controlling stand density and obtaining adequate regeneration of desired species following harvest. The emphasis is on manipulating the composition and structure of the forest to produce commodities. Silvicultural guides call for harvesting trees at risk of mortality (e.g., the residual *Populus grandidentata* and *P. tremuloides* in the second-growth, sugar maple forests in our study areas), trees of poor quality (cull trees in forestry terminology), and larger, commercial-size trees (trees ≥ 25 cm DBH). Although commercial harvesting may result in an abundance of fine organic litter on the soil surface in the short term, thinned northern hardwood forests generally have lower volumes in snags and downed woody debris compared to unthinned old growth forests (Gore and Patterson 1985, Tyrrell and Crow 1994a, Goodburn and Lorimer 1998). Also, small woody debris produced during timber harvesting tends to decompose rapidly (Harmon et al. 1986, Gore and Patterson 1985).

Thinned and unthinned northern hardwoods in our study differed in their amount, size, and condition of dead wood. Not surprisingly, old growth had greater basal areas and volumes of dead wood than thinned hardwood forests. Likewise, thinned forests had a higher proportion of volume and basal area of snags in smaller diameter size-classes compared to OG forests. The highest volumes of downed woody debris were measured in OG, as would be expected, since no timber was harvested and natural mortality was allowed to occur. The volume of downed woody debris in the thinned forests was intermediate between that measured in the OG and that in the unthinned SG forests.

Because the thinning regimes implemented in our study had been conducted for less than 10 years, we present an initial comparison among forest types. Indeed, Tyrrell and Crow (1994b) estimated that it would take > 350 years for hemlock-hardwood forests in the Lake States to accumulate > 65 m^3ha^{-1} of downed woody debris distributed among all decay classes. If forest development were allowed to proceed in SG, however, they should eventually accumulate snag and downed woody debris volumes and size classes comparable to OG. Hardt and Swank (1997) found a convergence for most of the structural characteristics they examined (snag and log abundance, mean diameter and volumes) between maturing SG and OG in their study of southern Appalachian forests. If forest density is controlled through thinning, the time for developing OG characteristics might be reduced by increasing growth rates on the residual trees (Singer and Lorimer 1997, Tappeiner et al. 1997). For example, Singer and Lorimer (1997) found that heavy thinning could increase basal area growth by 70 to 100 percent in SG northern hardwood forests.

We found significant differences in dead

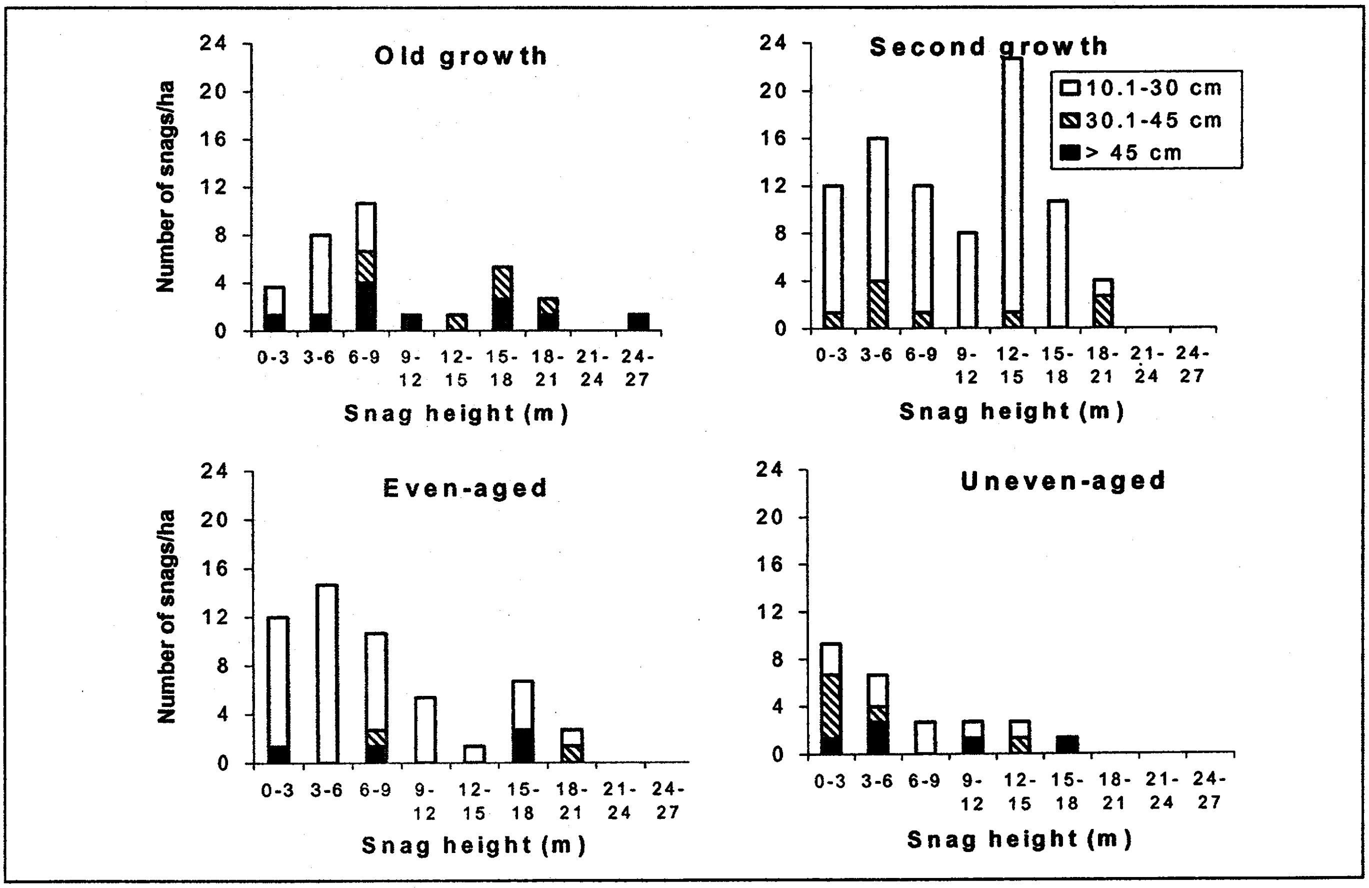

Figure 2. Height distribution of snags for thinned and unthinned northern hardwood forests in the Ottawa National Forest, Upper Peninsula, Michigan.

Table 3. Number, volume, distribution by decay class and size class for downed woody debris (DWD) by forest condition. Means are based on three replications. Letters denote means that are not significantly different at P = 0.05.

	Unthinned		Thinned	
Characteristic[a]	Old growth	Second growth	Uneven-aged	Even-aged
Mean no. of DWD pieces sampled per stand[b]	241.7 (35.4)	301.7 (96.3)	283.3 (30.7)	366.0 (71.9)
Mean diameter (cm)[b]	9.6	5.7ab	7.6	6.2b
	(11.9)	(6.2)	(9)	(4.7)
Mean no. DWD pieces				
2-10 cm	182.7	270.3	234.3	324.7
10.1-20 cm	26	32.3	29	34
20.1-40 cm	23.3	5.7	15.7	6.7
40.1-60 cm	7.7	1	3.3	0.7
> 60 cm	1.7	0.3	1.3	0
Mean total volume per stand ($m^3 ha^{-1}$) [b]	120.5 (9.1)	46.5 (13.4)	84.1 (1.4)	47.4 (2.9)
Decay class of fallen wood (% of volume)[c]				
I	0.3	2.1	4.7	0.2
II	11.2	25.5	17.2	35
III	46.2	27.6	24.1	32.1
IV	31.2	19.5	27.6	19.4
V	11.2	25.1	26.4	12.9

a Includes all DWD pieces 2 cm and larger.
b Standard deviations are in parentheses.
c I = recent to V = very decayed.

wood between thinned and unthinned northern hardwood forests. Goodburn and Lorimer (1998) reported similar results when comparing dead wood in OG, SG, and UEA northern hardwoods. They also reported snag density, volume of snags, and downed woody debris in UEA hardwood forests to be intermediate between that for SG and OG forests, and they found that the most significant difference between thinned and unthinned forests was in the large diameter snags and fallen wood. In their study, UEA forests averaged about 4 large snags ha^{-1}, which was only 21 percent of that measured in their OG forests. Both studies illustrate the importance of unmanaged natural areas as baselines for comparing with managed forest conditions.

SUMMARY

Thinning affects the structure of northern hardwood forests. Because management for timber removes large trees before they die naturally, thinned forests in our study had few large diameter coarse woody debris pieces, either standing or downed. In general, old growth was on the high end in terms of the amounts of all the attributes measured, except for total snag and downed woody debris densities (Table 4). Intermediate values were seen in the uneven-aged with unthinned second-growth and even-aged treatments generally having the lowest values (Table 4).

Large snags and the presence of large down woody debris (> 40 cm DBH) are two structural attributes common to old-growth northern hardwoods in the Lake States that should be developed as part of standard guides for managed forests. Although the loss of trees to mortality may seem wasteful from a utilization perspective, the functional importance of these structural elements to long-term productivity justifies their inclusion in managed forest ecosystems.

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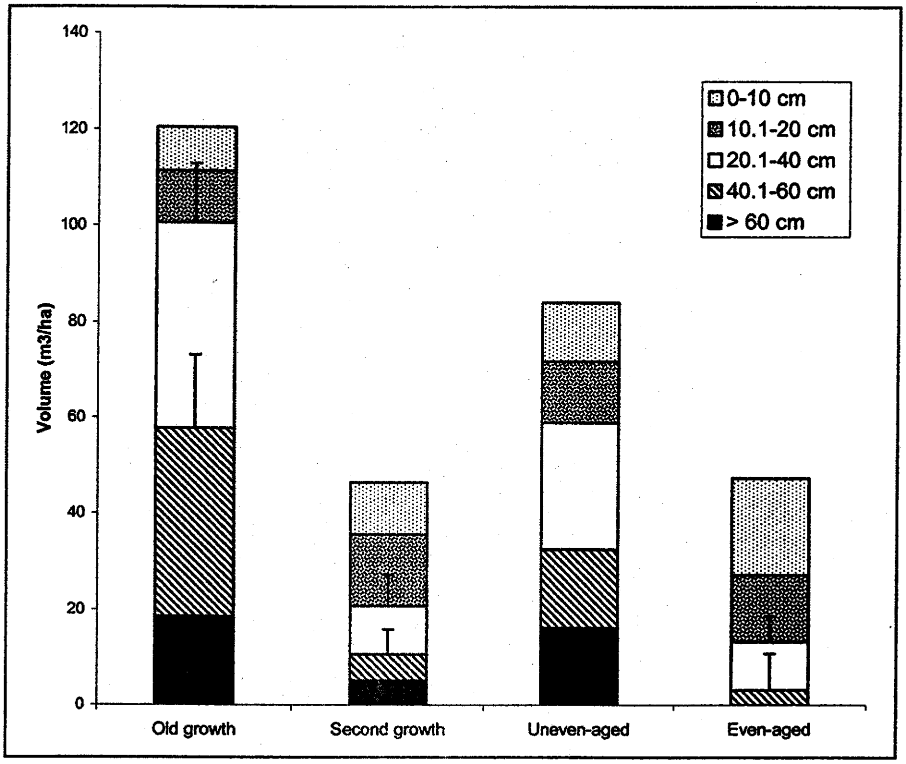

Figure 3. Volume and size distribution of downed woody debris by diameter classes for thinned and unthinned northern hardwood forests. Top error bars show one standard deviation for downed woody debris in the 20.1 to 40 cm diameter class and bottom error bars are for 40.1to 60 cm diameter class.

landscape. Her interests include restoring hydrology and a more natural fire regime to the Aspen Parklands.

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Table 4. A relative comparison among thinned and unthinned northern hardwood forests where high indicates the highest amount of the item present and low indicates the lowest present.

	Unthinned		Thinned	
	Old growth	Second growth	Uneven-aged	Even-aged
Snag species	High	High	Medium	Medium-High
Live tree species	High	High	Medium	Medium
Mean snag dbh	High	Medium-High	Low	High
Mean live tree dbh	Medium	High	Medium	High
Snag density	Low	High	Medium	Low
Live tree density	High	Medium	Medium	Low
Presence of large snags				
> 45 cm	High	Low	Medium	Low
> 60 cm	High	Low	Low	Low
Mean snag height	Medium	High	Medium	High
Basal area of snags	High	Medium	Low-Medium	Low-Medium
Basal area of live trees	High	High	Medium	Medium
DWD density	Medium-Low	Medium-High	Medium	High
Mean DWD diameter	High	Low	Medium	Low
Presence of large DWD				
> 40 cm	High	Low	Medium	Low
> 60 cm	High	Low	High	
Volume of DWD	High	Low	Medium	Low
Mean age of stand	High	Low	Medium	Low

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