Logging Residue Volumes and Characteristics following Integrated Roundwood and Energy-Wood Whole-Tree Harvesting in Central Maine

Julia I. Briedis, Jeremy S. Wilson, Jeffrey G. Benjamin, and Robert G. Wagner

ABSTRACT

Integrated roundwood and energy-wood whole-tree, partial harvesting has become common in Maine over the past decade, yet there is limited information about the volume and characteristics of logging residues left behind on such harvest sites. To better inform forest managers about the downed woody material remaining after whole-tree partial harvesting, we measured downed wood volume and characteristics on 12 harvested sites in central Maine using line intersect sampling. All sites were harvested using mechanical systems (feller-bunchers and grapple skidders) within a year prior to sampling. The mean volume of downed wood across all sites was 726 ± 57 ft^3/ac (±SE), 47% of which was residue generated by the harvest. The variability of residue volumes was higher within sites (coefficients of variation between 36 and 69%) than between sites (coefficient of variation, 27%). Coarse woody material between 3 and 6 in. in diameter at the large end dominated the postharvest debris, while logs greater than 10 in. in diameter were scarce. The majority of harvest-generated downed wood was in decay class 1, whereas preharvest debris consisted of mostly decay classes 2, 3, and 4. The volumes of downed wood remaining on the study sites were within the range of volumes found on other managed sites of similar forest types. However, further research is necessary to assess whether these amounts and characteristics are adequate for long-term maintenance of ecological processes.

Keywords: biomass, coarse woody material, fine woody material

Logging residue is a byproduct of timber harvesting operations that includes mostly tree tops and branches in addition to cull trees, small stems, and deadwood (Maine Forest Service 2008a). In the past, this residue has been considered waste material. In recent years, however, the reemergence of the bioenergy industry has revived the market for these residues, and demand for this material is likely to increase with increasing oil prices and government policies seeking renewable and carbon-neutral energy sources. U.S. forests are projected to provide one-third of the billion-ton biomass feedstock needed for the emerging bioenergy and bioproducts industry (Perlack et al. 2005). Northeastern forests, and especially those in the state of Maine, have been identified by the Department of Energy's National Renewable Energy Laboratory as having some of the highest forest residue availability in the country (National Renewable Energy Laboratory 2009). Maine is the most forested state in the country (89%) and currently accounts for more than half of the wood harvested in the Northeastern region (New York, Vermont, New Hampshire, and Maine) (North East State Foresters Association 2007a, 2007b). Thus, Maine will be an important contributor of woody biomass to the growing bioenergy industry.

Logging residue is commonly extracted from the forest through integrated roundwood and energy-wood (woody biomass) whole-tree harvesting. This method involves skidding the entire aboveground portion of the tree to the landing where it is limbed, topped, and bucked into roundwood products. Because of the high efficiency of whole-tree harvesting, it has become a common harvest method in Maine. When biomass is an integrated part of the harvest, the tops and limbs are chipped at the landing and sold as energy wood; otherwise, the residues are returned back to the harvest block or left in piles on the landing. Integrating residue removal with a conventional roundwood harvest requires no additional steps for the retrieval of logging residues, which is one reason for its widespread use in Maine as a system of energy-wood extraction.

Concerns about the environmental consequences of removing too much material from the forest arose in the 1970s and 1980s, when whole-tree clearcutting was a common practice (Boyle and Ek 1972, Weetman and Webber 1972, Freedman et al. 1981). Several studies conducted in red spruce (*Picea rubens* Sarg.)–balsam fir (*Abies balsamea* [L.] Mill.) forests found there to be 30–40% more total biomass removed from whole-tree clearcut sites than from conventional stem-only clearcuts where residue remained in the forest (Freedman et al. 1981, Smith 1984). Even though partial harvesting has taken the place of clearcutting in Maine as the dominant harvesting practice (Maine Forest Service 2008b), concerns remain that whole-tree harvesting may not be leaving enough logging residue in the woods.

Woody material plays an important role in forested landscapes by supplying a variety of ecosystem functions, including nutrient cycling, providing wildlife habitat, acting as a carbon sink, mitigating soil erosion, and providing a substrate for seedling establishment (Harmon et al. 1986). It is vital for all of these functions that an adequate amount of downed wood of all sizes and decay stages

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Table 1. Descriptive characteristics of the whole-tree harvested study sites. Presented are site number, preharvest forest type, treatment type, site acreage, date of harvest, number of plots installed per site, and basal area per acre harvested from each site (mean ± 1 SE).

Site	Forest type[a]	Treatment[b]	Size (ac)	Harvest date	No. of plots	BA[c] harvested (ft^2/ac)
1	S	OSR	53	Spring 2008	27	57.0 ± 8.0
2	HS	Partial	55	Winter 2008	38	72.6 ± 7.1
3	H	Partial	21	Winter 2008	12	66.7 ± 9.3
4	H	Partial	67	Winter 2008	37	55.7 ± 6.1
5	H	Partial	58	Winter 2008	32	59.4 ± 6.0
6	S	OSR	37	Summer 2007	26	58.5 ± 7.9
7	HS	OSR	47	Summer 2007	25	68.8 ± 7.2
8	S	OSR	50	Summer 2007	30	64.7 ± 9.0
9	H	OSR	159	Summer 2007	27	64.4 ± 6.5
10	S	OSR	21	Winter 2008	9	171.1 ± 12.1
11	SH	OSR	29	Winter 2008	14	90.0 ± 12.4
12	HS	Partial	96	Winter 2008	20	52.0 ± 7.9

[a] S, ≥75% BA softwood; SH, >50% and <75% BA softwood; HS, >50% and < 75% BA hardwood; H, ≥75% BA hardwood.
[b] OSR, overstory removal.
[c] BA, basal area.

remains on the harvest block. Foliage and small branches contain a disproportionate amount of a tree's essential nutrients (Smith et al. 1986, Hendrickson et al. 1989). The cycling of nutrients back into the soil when these materials decay is, therefore, a critical process for maintaining site productivity. In addition, small woody material plays an important role in shielding bare soil from erosive forces (Patric 1978), thereby protecting the quality of local waterways. Wildlife use downed logs for a variety of purposes, including forage, refuge, and travel, for which they require a wide spectrum of log sizes and decay stages (Hagan and Grove 1999). Large logs in particular have been shown to be important for some species of small mammals, amphibians, and insects (Carey and Johnson 1995, Strojny 2004, Thomas et al. 2009). When logging residues are removed from harvest blocks for bioenergy, it is possible that some of these ecosystem values are compromised.

Quantifying the volume and characteristics of postharvest logging residue is a vital part of assessing whether enough downed wood is remaining on whole-tree harvested sites. Some studies have calculated the volume and/or weight of woody material on whole-tree clearcut sites in the Northeast (Smith et al. 1986, Pedlar et al. 2002). However, no known studies have quantified the volume of residue remaining on whole-tree, partially harvested sites. Because partial harvests make up over 95% of harvests in Maine (Maine Forest Service 2008b), and whole-tree harvesting with an integrated energy-wood component is increasingly common, it is critical that forest managers understand the amount and type of residue being left behind on these sites. The objectives of this study were, therefore, to determine the volume and characteristics of woody material remaining on sites where integrated roundwood and energy-wood whole-tree partial harvesting had occurred.

Methods

Twelve harvested sites in central Maine were sampled during the summer of 2008. All sites were managed by a single company and whole-tree harvested using a feller buncher and grapple skidder within a year of being sampled. Five different logging contractors performed the harvest operations on the 12 sites. In addition to roundwood, energy wood was recovered as an integrated component of all harvests. A chipper was used to fragment the energy wood at all sites except for site 2, where a grinder was used. Harvest treatments varied, yet basal area removals were relatively consistent between sites, with the exception of site 10 (Table 1). Five sites were softwood forest types dominated by eastern white pine (*Pinus strobus* L.), balsam fir, red spruce, northern white-cedar (*Thuja occidentalis* L.), and eastern hemlock (*Tsuga Canadensis* [L.] Carr.). The remaining seven sites were hardwood forest types dominated by red maple (*Acer rubrum* L.), paper birch (*Betula papyrifera* Marsh.), yellow birch (*Betula alleghaniensis* Britt.), big-toothed aspen (*Populus grandidentata* Michx.), sugar maple (*Acer saccharum* Marsh.), and American beech (*Fagus grandifolia* Ehrh.). The terrain was similar on all sites, with slopes of 0–10%.

The line intersect method (Van Wagner 1968) was used to sample both downed coarse woody material (CWM) and fine woody material (FWM). Sample points were systematically located on a grid with 200- or 230-ft spacing depending on the size of the site. Sampling was conducted throughout the entire site except within the two largest sites (sites 9 and 12), where a random portion was sampled and extrapolated to the whole site. The transect layout was modified from that of Grushecky et al. (2006), with two 100-ft transects emanating from each point center. The azimuth of the first transect was determined randomly, with the second transect at a 90° angle to the first. CWM (≥3 in. in diameter and ≥3 ft long) was tallied if its longitudinal midpoint crossed the line transect. Large and small end diameters (down to 3 in.), length (between measured diameters), species, and decay class were recorded for all tallied pieces. FWM (≥0.5 and <3.0 in. in diameter and ≥1 ft long) was recorded if the piece intersected the 20 ft of transect furthest away from point center. Midpoint diameter, species, decay class, and length were recorded for FWM pieces. For both CWM and FWM, species was identified where possible; otherwise, the piece was categorized as either hardwood or softwood. Waddell's (2002) five decay stage classification scheme was used to indicate extent of decay, with decay class 1 indicating least decayed and decay class 5 indicating most decayed.

Downed wood pieces were also classified by their relation to skid trails and to the harvest. The location of a piece where it intersected with the transect was used to determine whether the piece was labeled as being in or out of a skid trail. Skid trails were defined as the area between outer wheel rut edges. Material that was evidently not created by the harvest or had obviously not fallen since the harvest was deemed preharvest material. Pieces that were clearly left by the harvest, such as those with freshly cut or broken-off faces, were labeled as harvest-generated. Trees that evidently blew down after the harvest were excluded from this category. The postharvest material included the harvest-generated material and the preharvest material, as well as blowdowns that fell after the harvest (of which there were few). One potential source of bias may be inaccurately categorized woody material, such as debris of decay class 1 that fell immediately prior to the harvest.

CWM volume was calculated using Fraver et al.'s (2007) conic-paraboloid equation that assumes the piece to be between the shape of a cone and a second-order paraboloid. The volume of FWM was calculated using Huber's formula that assumes the shape of a paraboloid frustum (Husch et al. 2003).

Residual overstory trees and stumps were also tallied at each point. The dbh, species, and height of all tally trees (≥4.5 in. dbh) within a 10 basal area factor (BAF) variable radius plot around point center were measured. Cut stumps from the most recent harvest were tallied using a 20 BAF prism. The diameter, distance to the stump, and species of all tally stumps were recorded. The dbh of harvested trees was estimated using a species-specific stump diameter to dbh conversion equation (Wharton 1984). The estimated dbh was used to exclude harvested trees that would have fallen outside the 20 BAF plot.

Results

Downed Woody Material Volumes

Total downed wood volumes within the whole-tree harvested sites were variable, with coefficients of variation ranging between 36 and 69%. Likewise, total debris volumes were variable between sites with some statistically significant differences (Tukey's honestly significant difference test; $\alpha = 0.05$). Site 10, in particular, had a relatively high volume of downed wood compared with other sites, which was likely due to the high basal area that was harvested on this site (Table 1), as well as its poorly drained terrain requiring more logging residue to be left on trails for the prevention of deep rutting. The coefficient of variation of average downed wood volumes between sites was 27%, but with the exclusion of site 10 it was reduced to 19%.

The total volume of postharvest debris, including both the coarse and fine wood, averaged 726 ± 57 ft^3/ac (± SE) across all sites (Fig. 1), with a range of 477 to 1,211 ft^3/ac. CWM made up an average of 72 ± 2% of the total postharvest downed wood volume. FWM contributed between one-fifth and one-third of the total volume of downed wood, much of which was located in skid trails. Of all harvest-generated downed wood, between 16 and 50% was located within skid trails. Across all sites, skid trails covered an average area of 15.1 ± 1.3%.

Harvest-generated debris made up between 26 and 63% of the total volume of downed wood, averaging 47% across all sites. Preharvest volumes of downed wood, therefore, made up 37 to 74% of all debris, ranging from 216 to 573 ft^3/ac and averaging 381 ± 32 ft^3/ac (Fig. 1). FWM consisted of an average of 44% of the harvest-generated material, whereas it was only 15% of the preharvest residue.

Downed Woody Material Characteristics

American beech made up 25% of the CWM volume that existed on the sites before the harvests and 18% of the debris volume generated during the harvests. Twenty percent of the downed wood was unidentifiable at the species level; however, of those that could be identified, balsam fir and red spruce, respectively, had the next most consistently high CWM volumes across all sites. Northern white cedar was also a major contributor to the overall log volume; however, this was strongly influenced by its abundance on site 10. The most common hardwood CWM species after American beech were big-toothed aspen, paper birch, and sugar maple.

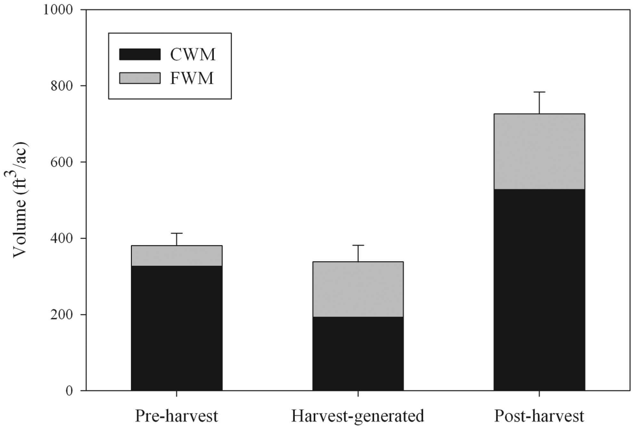

Figure 1. Average volume of downed wood on the study sites categorized as debris existing preharvest, debris generated during the harvest operation (harvest-generated), and all postharvest debris (preharvest plus harvest-generated and material blown down after harvest). Error bars represent 1 standard error of the total mean volume in each category.

When measured as the number of logs per acre, the diameter distribution of CWM (large-end diameter) was skewed substantially toward the smallest diameter class. Of the total average of 364 ± 29 logs/ac of CWM, 282 ± 25 logs/ac were in the 3–6-in. size class (78% of all CWM), and only 2 ± 1 logs/ac were in the 15+ in. size class (0.5% of all CWM) (Figure 2a). The most abundant log size on postharvest sites was 4 in. in diameter at the large end. The proportion of CWM in the smallest size class was greater in the harvest-generated (84%) than in the preharvest downed wood (71%). In the 7–10-in. class, preharvest CWM was nearly double the percentage of harvest-generated CWM. The average log length of CWM across all sites was 9.6 ± 0.3 ft. When measured by volume, CWM in the 3–6-in. and 7–10-in. large-end diameter classes had similar average volumes of 199 ± 19 ft^3/ac and 206 ± 21 ft^3/ac, respectively (Figure 2b). There was an average of 46 ± 10 ft^3/ac of CWM of the largest size class left on the study sites, which represents 9% of the total CWM volume.

The majority of the harvest-generated debris volume was in decay class 1 (67.3%) (Figure 3). Conversely, most of the volume of the preharvest CWM was in decay classes 2, 3, and 4. Of all postharvest material, there were nearly equal volumes of CWM in decay classes 1, 2, and 3. An average of only 1.7% of the total postharvest logs/acre was in decay class 5.

Discussion

The volume of downed woody material remaining on the harvested sites in this study was highly variable within each site. This within-site variability is not unique to whole-tree harvested sites (Remington 1986, Jordan et al. 2004, Grushecky et al. 2006); rather, it seems to be the heterogeneous nature of downed wood to be scattered irregularly throughout both managed and unmanaged stands (Harmon et al. 1986). One factor that makes residue particularly clumpy and irregular on whole-tree harvest blocks is the placement of residue back into skid trails to mitigate rutting of wet areas

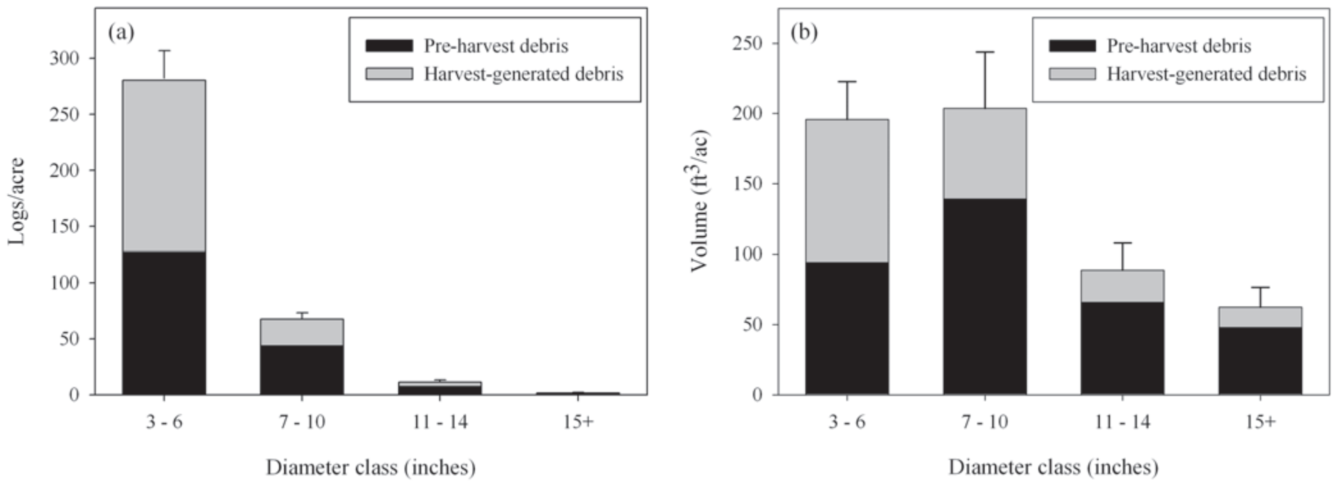

Figure 2. Average logs per acre (a) and log volume (ft^3/ac) (b) by 4-in. size classes (large end diameter) across all study sites. Represented in each size class are debris that existed preharvest and debris that was generated during the harvest operation. Error bars represent 1 standard error of the total in each diameter class.

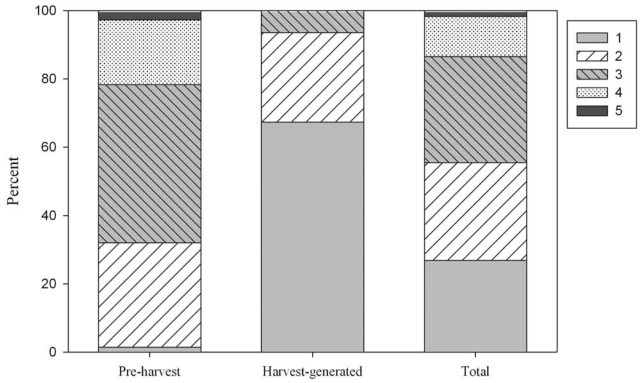

Figure 3. Average percentage of CWM volume in each decay class across all study sites for preharvest debris, harvest-generated debris, and total postharvest debris (preharvest debris plus harvest-generated debris and postharvest blowdowns). Decay class 1 signifies least decayed, and decay class 5 signifies most decayed.

(Maine Forest Service 2004), a practice encouraged by foresters even when energy wood is a harvest component. Species patchiness and stand density inconsistencies were also likely contributors to the observed within-site CWM volume disparities.

This study's total average CWM volume (528 ± 50 ft^3/ac) and average volume of only the harvest-generated CWM (193 ± 33 ft^3/ac) are similar to those reported in several other studies of recent partial harvests. A West Virginia study that sampled 70 recently harvested sites had an average CWM volume of 624 ft^3/ac (Grushecky et al. 2006) and a study from Vermont that measured only harvest-generated debris reported an average of 264 ft^3/ac of CWM (Remington 1986). Studies of recently harvested clearcuts, however, reported CWM volumes two to three times greater than those reported in this study (McCarthy and Bailey 1994, Pedlar et al. 2002), illustrating that results from whole-tree partial harvests and whole-tree clearcuts may not be comparable.

Studies from old-growth forests in temperate and boreal forest ecosystems have reported downed wood volumes from 1,988 ft^3/ac (139 m^3/ha) in a northern hardwood forest in New York (McGee et al. 1999) down to 429 ft^3/ac (30 m^3/ha) in a mixed-oak forest in Ohio (Goebel and Hix 1996). Differences in forest type, disturbance history, and sampling methods could be factors that explain the variability of the old-growth CWM volumes. Pedlar et al. (2002) reported CWM volumes from mature, managed stands in Ontario, Canada, that are within the higher ranges of temperate old-growth forests; however, many managed stands have volumes within the range of 157 ft^3/ac (11 m^3/ha) (Sittonen et al. 2000) to 872 ft^3/ac (61 m^3/ha) (McGee et al. 1999), including the volumes presented in this study. Old-growth CWM volumes are described here to provide context to our findings; they are not intended as target levels for the future management of sites such as those sampled in this study.

It is well documented that downed woody material volumes increase immediately following harvest activity (Gore and Patterson 1986, McCarthy and Bailey 1994, Hardt and Swank 1997). As is evident from the 96% increase in debris from preharvest volumes presented here, integrated roundwood and energy-wood whole-tree harvests are no exception. The smallest diameter logs (3–6 in. at the large end), however, comprised the majority of the harvest-generated CWM, similar to the findings of other studies in recently harvested stands (Gore and Patterson 1986, Remington 1986, McCarthy and Bailey 1994). An average of 31% of the volume of harvest-generated material was located in skid trails, where it can be important for mitigating erosion, but where its benefits to wildlife and future stand productivity may be limited. The scarcity of logs greater than 15 in. (large-end diameter), shown in Figure 2a, is likely the result of past management practices that removed the potential for future inputs of large logs through harvesting trees once they were financially mature.

Wildlife species whose habitat requirements depend on large-diameter logs could be negatively affected in the Northeast if the lack of large logs on the harvested sites in this study is shown to be indicative of other, similarly harvested sites throughout the region. A study of eastern red-backed salamanders (*Plethodon cinereus*) in central Maine found that the salamanders are more likely to use large-diameter logs in harvested gaps than logs of smaller diameters (Strojny 2004). Similarly, in the same region of Maine, the abundance and species richness of 15 click beetle species in CWM were found to be positively related to downed log diameters (Thomas et al. 2009). Furthermore, Thomas et al. (2009) reported that nine of the beetle species were reliant on the presence of large logs, whereas none were reliant on small-diameter material. Studies from other regions have observed similar dependencies on large logs for many insect species (Torgersen and Bull 1995, Grove 2002) and small mammals (Carey and Johnson 1995). Large logs may be preferred or critical habitat for numerous wildlife species because of their persistence in the environment (Elliott 2008) and the diversity of microhabitats within an individual log (Grove 2002).

Small debris, of which there is an apparent ample supply on recently harvested sites, also provide essential forest values. Fine woody debris mitigates erosion of exposed soil in trails and provides habitat for wildlife, but most critically, it plays a role in nutrient cycling. For many tree species in this region, concentrations of nitrogen, potassium, magnesium, phosphorous, and calcium are higher in the branches and foliage than in the tree stems (Young and Carpenter 1967, Freedman et al. 1981, Smith et al. 1986). Within the aboveground portion of red spruce and balsam fir trees, between 35 and 74% of the abovementioned macronutrients has been found to be contained within the tree crown (Freedman et al. 1981, Smith et al. 1986). Thus, small-diameter logging debris can provide an important source of nutrients when left on harvest sites.

Unlike larger woody debris, the small debris is not a long-lasting feature, as it usually decays rapidly (Harmon et al. 1986). In the Northeast, the small-diameter logging slash may be completely decayed in 20–50 years (Spaulding and Hansbrough 1944, Gore and Patterson 1986, Vanderwel et al. 2008). Given that harvest entries generally occur in intensively managed stands every 15–25 years in this region, it is likely that by the time of the recent harvest, much CWM from the preceding harvest has reached mid- to late stages of decay (McGee et al. 1999). Developing young and vigorous stands naturally contribute small amounts of CWM to the forest floor (Spies and Cline 1988) because they normally have less coarse wood that is subject to breakage (Smith 1984) and support less overall biomass than older stands (Gore and Patterson 1986). Therefore, the high abundance of decay classes 2, 3, and 4 of preharvest CWM in this study was likely a combination of decayed residue from the previous harvest and natural accumulations of dead and dying diseased American beech. This preharvest decay distribution of CWM was altered by the high inputs of decay class 1 material during the recent harvesting activity, resulting in a postharvest decay distribution dominated by the earlier decay stages (Figure 3). Such a shift has been documented in other studies following major disturbances, such as a harvesting (Gore and Patterson 1986, Fraver et al. 2002, Pedlar et al. 2002).

Conclusions

Stem-only harvests, by nature, retain more logging residue on site; however, this study demonstrated that a considerable volume of residue remained even on whole-tree harvested sites, as was evident by the near doubling of preharvest debris volumes from the harvests. This research was designed and presented as a descriptive study, yet a future study that quantifies downed wood remaining on stem-only harvest sites in Maine could provide valuable results for a comparison of the two systems. As has been found in other managed stands, much of the residual CWM from the sites in this study was of the smallest diameter class with a clear lack of large-diameter material. Although it is understood that residual logging debris is beneficial to forest health, further research is needed to determine whether the amounts and types of residue left after whole-tree partial harvests in central Maine and elsewhere are enough to support healthy ecosystem functioning and site productivity or whether more extraction is warranted.

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