LARGE WOODY DEBRIS IN A SECOND-GROWTH CENTRAL APPALACHIAN HARDWOOD STAND: VOLUME, COMPOSITION, AND DYNAMICS

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ABSTRACT.—We estimated the volume of large woody debris in a second-growth stand and evaluated the importance of periodic windstorms as disturbances in creating large woody debris. This research was conducted on a reference watershed (Watershed 4) on the Fernow Experimental Forest in West Virginia. The 38-ha stand on Watershed 4 was clearcut around 1911 and has been undisturbed by management activities since that time. Down dead wood (DDW) was sampled in 1999 and identified by species and decay class. The contributions from two windstorms, in 1993 and 1998, were quantified at the same time. Total volume of DDW in Watershed 4 was 69.7 m^3 ha^{-1}, a value equal to or greater than those reported for old growth in central/eastern hardwood forests. The most frequent and the largest volume of DDW was chestnut, followed by sugar maple. Standing dead trees (snags) provided another 41.4 m^3 ha^{-1} of large woody debris. Of the DDW contributed by the windstorms, the largest volume was American beech. The two windstorms were found to contribute approximately 3.5 m^3 ha^{-1} of DDW each. Using these data and other stand characteristics, the stand on Watershed 4 was compared with old growth stands, and implications for management discussed.

Coarse woody debris (CWD), which includes both down dead wood (DDW) and standing dead trees (snags), plays many important ecological functions in forests: providing wildlife habitat (Loeb 1996, Hagan and Grove 1999, Loeb 1999, Menzel and others 1999), creating niches for regeneration of various plant species, and cycling nutrients (Boddy 1983, Harmon and others 1986, Fisk and others 2002), among others. Despite the importance of CWD, the quantity and dynamics have been documented for only a few forest ecosystems in the U.S., and most often in old growth forests (Spies and others 1988, Tyrrell and Crow 1994, Jenkins and Parker 1997). Only recently has the effect of forest management on CWD received attention in the Appalachians (Hardt and Swank 1997). CWD dynamics in central Appalachian hardwood forests, most of which are second-growth, naturally regenerated stands, are not well documented.

In forests throughout the central Appalachians, numerous root mounds of varying ages are obvious. The source of these mounds, some of which are quite old, is not well known, but many mounds are believed to be due to infrequent but severe local windstorms. Romme and Martin (1982) characterized gap production in an old-growth mixed mesophytic forest in Kentucky and identified local, high intensity windstorms as a potentially significant contributor to CWD inputs. However, inputs of CWD were not quantified. For this paper, we measured density, volume, and composition of CWD in a 90-year-old second-growth hardwood stand in the central Appalachians of West Virginia and estimated the inputs of DDW from two localized severe windstorms. We also discuss stand characteristics in term of management implications.

SITE DESCRIPTION AND METHODS

Watershed 4 (38.73 ha) is a reference watershed with an ESE aspect located on the Fernow Experimental Forest, Tucker County, WV (latitude 39º 04′ N, longitude 79º 41′ W). Topography is rugged and elevations ranges from 737 to 853 m on Watershed 4, with slopes ranging from 10 to 60 percent. The old-growth stand was harvested around 1911, leaving some residual trees that were inaccessible or of lower

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value, such as sugar maple, black birch, beech, and hickory. The stand regenerated naturally. Some standing dead American chestnut trees were removed in the 1930s and 1940s (mostly pole-sized). Otherwise there has been no harvesting in this stand since the original harvest. This watershed has been well characterized as part of long-term hydrometeorological studies on the Fernow watershed (Adams and others 1994). Red oak site index 50 ranges from 64 to 81.

In March 1993, a significant winter storm with high winds moved through the area. Within the Monongahela National Forest, an estimated 116 ha of timber was blown over and required salvage logging (Linda White, USDA Forest Service, personal communication). Similar damage was estimated to have occurred on private land adjacent to the National Forest. Significant blowdown was observed on Watershed 4 and another nearby research watershed. Windblown trees on Watershed 4 were cut off at the stump for safety reasons. Where the logs lay across the road at the top of the watershed, they were removed. Otherwise, logs remained where they fell. Another similar storm in April 1998 also resulted in a considerable amount of blowdown and partially uprooted trees on Watershed 4 and the surrounding area. Once again, trees only were removed from Watershed 4 from roads or if they presented a safety hazard.

During September 1998, DDW was measured on Watershed 4 using the transect intersect method (Harmon and Sexton 1996). To achieve a 20 percent precision in our samples (per Martin 1976, Pickford and Hazard 1978), thirty 100-m transects were randomly located within Watershed 4. Along each transect, all DDW larger than 10.2 cm diameter and longer than 1 m was tallied. Species, small and large diameters, length, and wood decay class were recorded for each intersection. Decay classes ranged from 1 to 3, with decay class 1 being the least decayed and decay class 3 being the most advanced stage of decay. (See Adams and Owens [2001] for a more detailed definition of these decay classes.)

Windstorm origin (1993 or 1998) also was noted for every piece of DDW encountered when possible. Other specific wind events could not be identified and all other DDW was classified as "pre-1993". Volume was calculated using the formulae of Van Wagner (1968) and summed for the area. The number of intersections also was summed. The Importance Value was calculated as the sum of the relative volume and relative number of intersections, divided by 2. Standing dead wood (snags) and overstory characteristics also were measured as part of a 100 percent cruise in 2001. Decay class was not assessed for standing dead wood.

RESULTS

Twenty-two species of trees were identified as DDW (table 1). The most commonly encountered species of DDW was American chestnut (for scientific names see table 1). The second most abundant species, based on importance values, was sugar maple, followed by northern red oak.

American chestnut also represented the largest volume of DDW (fig. 1). Sugar maple and northern red oak made up the second and third largest volume of DDW, followed by black locust and American beech. Black cherry also was present in significant amounts. The largest diameter recorded for DDW was a 96.5 cm (38 inches) sugar maple. Total DDW volume for the stand was estimated at 69.7 m^3 ha^{-1}. Overall, 27.9 percent of the DDW was in decay class 1 (least decayed), 40.8 percent in decay class 2, and 31.2 percent in decay class 3 (table 2).

There was an average of 48 standing dead snags per hectare, with a basal area of 5.2 m^2 ha^{-1} and a volume of 41.4 m^3 ha^{-1}. Snags represented 37 percent of total CWD (DDW and standing dead combined), and approximately 16 percent of the standing live volume. Northern red oak was the dominant snag species (of 24 species), followed by sugar maple, black cherry, and black locust. Sixty-nine percent of the standing dead was less than 35.6 cm in diameter and 50 percent was 20.5 cm or less in diameter. The snag with the largest diameter at breast height (dbh) was a 107 cm sugar maple.

Twenty-five species of live overstory trees were recorded. The dominant overstory species on Watershed 4 was northern red oak. Red oak trees were relatively abundant and larger in volume. On the other hand, sugar maple and red maple were abundant but generally smaller in diameter than the northern red oak. Black locust, which is ranked high in the importance values for DDW, is ranked fairly low in overstory importance. The relative importance values for DDW, standing dead, and overstory trees are shown in figure 2. Stand density (stems >10 cm dbh) was 292 trees ha^{-1} with 9.7 trees ha^{-1} having diameters greater than 75 cm dbh. Overstory basal area was 33.3 m^2 ha^{-1}, and estimated volume of 263.8 m^3 ha^{-1}. Stand summary values are shown in table 3.

Table 1.—*Scientific and common names, importance values, and wood decay resistance of tree species represented by down dead wood (DDW) on Fernow Experimental Forest, WV*

Tree Species	Common Name	Relative Importance	Decay resistance[1]
Castanea dentata (Marsh.)Borkh.	American chestnut	.155	High
Acer saccharum Marsh.	Sugar maple	.133	Low
Quercus rubra L.	Northern red oak	.113	Low
Robinia pseudoacacia L.	Black locust	.075	High
Fagus grandifolia Ehrh.	American beech	.074	Low
Prunus serotina Ehrh.	Black cherry	.070	High
Quercus prinus L.	Chestnut oak	.062	High
Betula lenta L.	Sweet birch	.055	Low
Magnolia acuminata L.	Cucumber magnolia	.055	Low
Sassafras albidum (Nutt.) Ness	Sassafras	.051	High
Acer rubrum L.	Red maple	.045	Low
Quercus alba L.	White oak	.042	High
Fraxinus americana L.	White ash	.023	Low
Liriodendron tulipifera L.	Yellow-poplar	.017	Low
Carya cordiformis (Wangehn.)K.Koch	Bitternut hickory	.005	Low
Carya ovata (Mill.) K.Koch	Shagbark hickory	.005	Low
Betula lutea L.	Yellow birch	.004	Low
Oxydendrum arboreum (L.) DC.	Sourwood	.004	Not estimated
Magnolia fraseri Walt.	Fraser magnolia	.003	Low
Tilia americana L.	American basswood	.002	Low
Nyssa sylvatica Marsh.	Black gum	.002	Not estimated
Cornus florida L.	Flowering dogwood	.002	Not estimated

[1] **Based on heartwood decay groupings in Wood Handbook (Forest Products Laboratory 1987).**

In the 1993 and 1998 storms, 6 and 7 species of trees, respectively, were blown over in each storm, with American beech being the most frequent species of DDW created (fig. 3). The two windstorms contributed approximately the same amount of coarse woody debris, about 3 to 3.5 m^3 ha^{-1}. Input from these two storms amounted to approximately 9 percent of the volume of DDW measured on the watershed. Most (88.5 percent) of the dead wood from trees that fell in 1998 was in decay class 1.

More than two-thirds of the trees that fell in 1993 were in decay class 2 (68.5 percent) and the rest (31.5 percent) in decay class 1. None of the trees that fell in 1993 or 1998 were in decay class 3. The more common tree species that fell in 1993 included American beech, sugar maple,

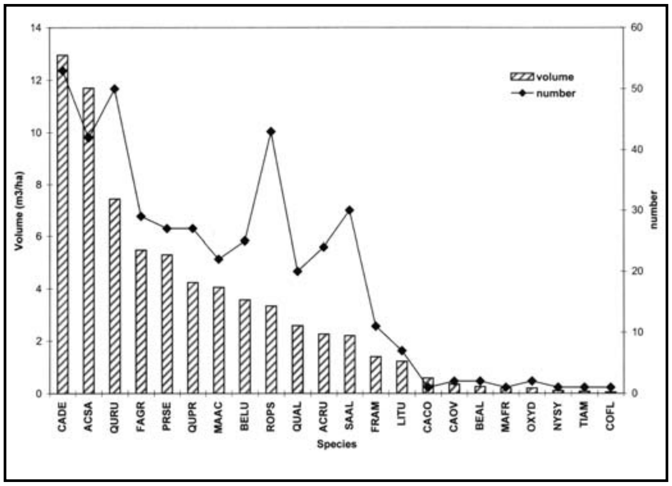

Figure 1.—*Volume and number of down dead wood (DDW) on Watershed 4, Fernow Experimental Forest, WV, by tree species. Species is indicated by the first two letters of their genus and species, except for Oxydendrum (OXYD). See table 1 for genus and species names.*

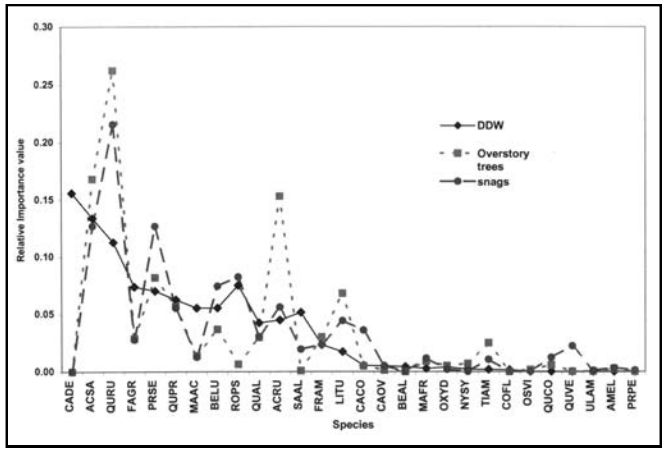

Figure 2.—*Comparison of Importance Values (see Methods for calculation) of down dead wood (DDW), standing dead snags, and live overstory trees, by species, Watershed 4, Fernow Experimental Forest, WV. Species is indicated by the first two letters of their genus and species, except for Oxydendrum (OXDY) and Amelanchier (AMEL). See table 1 for genus and species names.*

Table 2.—*Frequency (percent) of DDW by decay class and time of fall, Watershed 4, Fernow Experimental Forest, WV*

Data set/year	Decay class 1	Decay class 2	Decay class 3
All DDW/years	27.9	40.8	31.2
1998 Storm	88.5	11.5	0
1993 Storm	31.5	68.5	0
Pre-1993 DDW	24.8	40.7	34.41

Table 3.—*Summary of live and dead wood characteristics, Watershed 4, Fernow Experimental Forest, WV*

	Volume (m^3 ha^{-1})	Density (n ha^{-1})	Richness	Evenness	Shannon-Wiener Index (H')
Canopy	263.8	292	25	0.716	2.304
Standing dead	41.4	48	25	0.798	2.568
DDW	69.7	11	22	0.843	2.605

and yellow poplar, while the primary species that fell in 1998 were American beech, red maple, and cucumber magnolia. Species that were found only in the older DDW (did not fall in 1993 or 1998) included American chestnut, sweet birch, hickory, chestnut oak, sassafras, and black locust (fig. 4).

DISCUSSION

CWD composition is clearly a function of several interacting factors: presence in the overstory, disturbance, tree size, and longevity/resistance to decay. For example, distribution of DDW by species generally reflected living stem species composition, with two exceptions: American chestnut and black locust. Both are important DDW, but not in the overstory. Chestnut no longer exists as a canopy species, therefore its presence reflects its previous abundance and great resistance to decay. Black locust is commonly represented among DDW and snags (fig. 2), but much less so in the overstory. Black locust is a shade-intolerant early successional species and short-lived (approx. 40-50 years; Strode 1977). Therefore, it is perhaps not surprising to see it less important in a 90-year-old overstory. Because of the high decay resistance of black locust wood, however, it remains important for snags and DDW for a longer time than almost all other species.

Although red maple is important in the overstory, it is not particularly so for snags or DDW. American beech has low decay resistance, and its relative importance as DDW is probably due to repeated inputs of large decadent branches or tops, such as in the two windstorms recorded here. All three components of the stand have

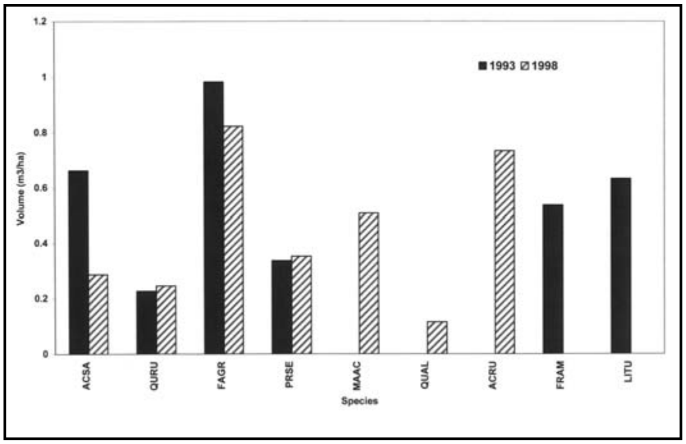

Figure 3.—*Volume of down dead wood delivered from two windstorms, in 1993 and 1998, by tree species. Species is indicated by the first two letters of their genus and species. See table 1 for genus and species names*.

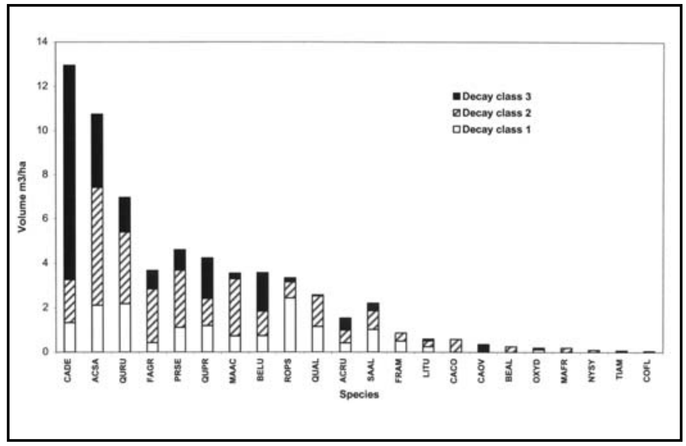

Figure 4.—*Volume of pre-1993 down dead wood (see Methods for definitions) by species and decay class. Species is indicated by the first two letters of their genus and species. See table 1 for genus and species names.*

relatively high species diversity (table 3). In addition to the differences highlighted above, there are a few noncommercial or rare species that are not present as snags or DDW, due to their relative rarity and smaller size.

The two windstorms each contributed about 5 percent of the DDW present at the time of the survey. Although these types of storm are believed to be uncommon, they obviously can contribute significant amounts to the DDW loading in a stand (Spetich and others 1999), and may be an important contributor of DDW to such stands. The distribution among decay classes for these two age groups varies with the age of DDW (the length of time on the ground). However, the two storms did not significantly alter the distribution among classes in total: pre-1993 and total values of DDW distributions among decay classes are approximately the same (table 2). This suggests that these events, while apparently periodic and severe, do not significantly change the longer-term equilibrium of DDW. Hardt and Swank (1997) suggested that near-even distribution of DDW among decay classes provided evidence of regular inputs, as from gap-phase dynamics. The slightly greater volume in decay class 2 would suggest that a pulse of DDW inputs had occurred relatively recently in the past, perhaps as a result of windstorms.

We did not expect that American chestnut would be the dominant form of DDW on Watershed 4. American chestnut previously made up 25 to 50 percent of the overstory in some of these forests (Weitzman 1949), but was nearly wiped out in the 1920s and 1930s by the chestnut blight (*Cryphonectria parasitica*). Although still present in stands today as sprouts (usually less than 15 cm dbh) American chestnut seldom reaches maturity before blight kills the stems. American chestnut wood was widely prized for its durability and it is among the most decay resistant species in the eastern United States (table 1). Most (69 percent) of the American chestnut that was recorded on Watershed 4 was in decay class 3, the most decayed. The largest American chestnut log remaining was 63.5 cm in diameter and the average chestnut log diameter was about 25 cm, suggesting most of the chestnut DDW represents remnants of trees that died at least 60 years ago.

The volume of DDW on Watershed 4 seems high compared to values reported for second growth forests in the Central Hardwood region. Within the Missouri Ozark Forest Ecosystem Project (Shifley and others 1998), DDW volume ranged from 8 to 30 m^3 ha^{-1} for second-growth stands up to 60 years old. DDW volume ranged from 14 to 84 m^3 ha^{-1} in a chronosequence of silvicultural openings in southern Indiana forests (Jenkins and Parker 1997), with the youngest stands (less than 20 years) having greater volumes of DDW than older stands, and the lowest volume (14.71 m^3 ha^{-1}) in the 80 to 100-year-old stands. In a similar assessment in the Southern Appalachians, DDW volume ranged from 22.4 m^3 ha^{-1} to 91.4 m^3 ha^{-1}, with both highest and lowest volumes in the youngest stands (Hardt and Swank 1997).

The volume of DDW on Watershed 4 approaches values reported for old-growth stands. Spetich (1995) noted a total down-wood volume of 74.2 m^3 ha^{-1} in an old-growth forest remnant in southern Indiana. Tyrrell and others (1998) report values ranging from 20.8 to 68.4 m^3 ha^{-1} for mesic and wet-mesic old-growth sites, predominantly in the Midwest, whereas values for old-growth western mesophytic and mixed mesophytic forests range from 66 to 410 m^3 ha^{-1} (Greenberg and others 1997). Some of these mesophytic stands included large American chestnut DDW and snags, particularly those in the southern Appalachians. In an old-growth forest in eastern Kentucky, Muller and Liu (1991) reported a CWD volume of 66.3 m^3 ha^{-1}, of which 11 percent was American chestnut.

Overstory characteristics also fall within the range reported for old-growth forests. The density of snags on Watershed 4 (48.25 trees ha^{-1}) falls within the range published by Tyrrell and others (1998) of 13 to 168 trees per hectare, snag basal area values ranging from 1.3 to 6.8 m^2 ha^{-1}, and snag volumes ranging from 1.8 to 74.8 m^3 ha^{-1}. Values for western and mixed mesophytic forest include 10 to 70 snags per hectare (Greenberg and others 1997). Live stand basal area for Watershed 4 also falls within the range summarized by Tyrrell and others (1998), although stand basal area usually recovers more quickly from disturbance than other stand characteristics (Clebsch and Busing 1989). Martin (1992) suggested at least seven trees per hectare greater than 75 cm dbh is indicative of old growth, while Greenberg and others (1997) report a range from 8.5 to 44.3 trees >75 cm dbh per ha.

On Watershed 4, there are 9.7 trees per ha with a dbh greater than 75 cm. The largest live tree diameter recorded on Watershed 4 was a 122 cm (48 in.) northern red oak, falling within the range (55-127 cm) recorded for black oaks in mesic and wet-mesic northern oak stands (Tyrrell and others 1998). For mixed mesophytic stands, Greenberg and others (1997) list a range of maximum diameters from 104 to 195 cm, but does not include any oak species. Finally, the overstory diversity is high, meeting some of the criteria proposed by Martin (1992) for canopy community composition for old-growth, mixed mesophytic forests: 1) 20 species or more, and 2) evenness of 0.50 or greater. The Shannon-Wiener Index (H') for Watershed 4 is slightly less than the 3.0 proposed by Martin (1992). Although some characteristics, including stand age, do not match all the definitions developed by various scientists, we believe that this second-growth stand has many structural characteristics of old-growth stands.

IMPLICATIONS

Many believe that old-growth forests take several hundred years to develop in parts of the eastern United States and the only way to increase old growth is to leave areas of potential old growth undisturbed for several hundred years. However, the stand on Watershed 4 has developed many of the structural characteristics of an old-growth forest in less than 100 years. Thus, by considering the development of Watershed 4, we may be able to develop some guidelines and management ideas for encouraging old-growth attributes in secondary stands.

Although Watershed 4 is designated as a reference watershed, it is not free from disturbance. Cut in 1911, residual trees of lower value species, or those less accessible, were left behind. These included species like sugar maple, black birch, beech, and hickory, which were not considered merchantable at that time. In a 1933 report on the area that was to become the Fernow Experimental Forest, the forester estimated that "a few hundred feet of beech, birch, and maple" were left after logging in 1911 (Trimble 1977). It was also noted that there were dense stands of American chestnut sprouts, attesting to its importance in the developing stand.

Chestnut blight was undoubtedly a serious disturbance because stands in the area often contained 25 percent by volume of chestnut (Weitzman 1949). The major loss of chestnut in this area occurred in the late 1920s. Loss of such a significant overstory component in such a short time span may have acted to release other species in the young stand, perhaps favoring oak, which perhaps eventually lead to dominance of northern red oak in this stand. Repeated windstorms, such as the two documented in this study, would have created large, infrequent contributions of large woody debris and created larger, multi-tree gaps in the canopy.

Is it possible to use intensive forest management to mimic these processes in Watershed 4, to create "functional old growth," defined here as stands that provide the structure, habitat, and processes found in true old growth, in less than 100 years? True old growth is rare in the central Appalachians and stands are very small and isolated. Although there are as yet no documented old-growth obligate wildlife species in the region, there are many species such as Virginia northern flying squirrel (*Glaucomys sabrinus*), cerulean warbler (*Dendroica cerulea*), and pileated woodpecker (*Dryocopus pileatus*), which exhibit a preference for old-growth habitat attributes. Old growth is clearly lacking in representation in the central Appalachian landscape. To create desirable old-growth structural attributes such as those needed for the aforementioned wildlife, we propose, using Watershed 4 as a case study, to consider how to develop functional old-growth attributes in 100 years rather than in 300-plus years.

We propose that the following intensive forest management can be used to mimic the milestones mentioned:

1) Very heavy cutting and removal of valuable timber but with scattered older residuals would provide the greatest probability of regenerating a diverse stand of trees, including shade-intolerant species. It will be important to leave only some minimal level of residual stocking (e.g., 2 m^2 ha^{-1} of basal area) in order to ensure the establishment and development of a diverse stand containing a high proportion of intolerant species (Miller and Kochenderfer 1998). Such a cut may prove to be particularly advantageous in regenerating stands that have suffered repeated high-grading, as has been commonly practiced in the Appalachians. Note that in many locations in the eastern United States, controlling white-tailed deer (*Odocoileus virginianus*) herbivory might be necessary, however, to ensure successful diverse regeneration.
2) At approximately 10 years of age, conduct a precommercial crop tree release of intolerants, and particularly where present, northern red oak. This will be necessary to ensure its development among faster growing intolerant species. It is important to remove sufficient stems to provide release of intolerant co-dominant/intermediate trees.
3) At approximately 20 years of age, conduct another precommercial crop tree release of northern red oak and other selected crop trees. Leaving the wood on the ground would provide another source of CWD.
4) Repeated thinning or patch clearcuts would provide additional CWD and release intolerants.

Another approach might be to create small clearcuts to regenerate intolerant species in order to maintain diversity, with designated portions of stands in sensitive areas (e.g., riparian zones) to be left completely unmanaged. In many cases, cutting and leaving all fiberwood and other low value trees on site would have a minimal economical impact on harvesting revenues (J.N. Kochenderfer, unpublished data).

This proposal is based on a single case study, and thus should not be inferred for wide-spread application. Rather, we urge careful consideration of these ideas and site-specific evaluation. Further research and evaluation is clearly called for. It is important, however, to begin to consider ways that we can intensively manage our important hardwood forests for a variety of desired future conditions, and to think “outside the box” in doing so.

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