# DEAD WOOD: GEOMORPHIC EFFECTS OF COARSE WOODY DEBRIS IN HEADWATER STREAMS, GREAT SMOKY MOUNTAINS

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**ABSTRACT—Coarse woody debris (CWD) is an important component of headwater streams. This study compares the distribution, residence time, and geomorphic function of CWD between two headwater streams, one located in an area of the Great Smoky Mountains that was logged 80 years ago and the other in an old growth forest zone. Coarse woody debris channel obstructions are more frequent along the old growth-area stream (3.0 per 100 m) compared with the logged-area stream (1.4 per 100 m). Differences in CWD frequency and size between the two reaches have important consequences for observed variations in channel morphology and sediment storage. Coarse woody debris stores approximately 25 times more sediment along the old growth reach than along the logged-area reach. In addition, variations in channel width and longitudinal profile are more closely tied with variations in CWD frequency along the old growth stream. The greatest effect of CWD on channel morphology occurs where debris slides have delivered multiple trees to headwater streams creating 'log jams.' One log jam consists of over 50 trees and stores ~1200 $m^3$ of sand and gravel. Future investigations should focus on monitoring sediment release from large log jams since such releases may dramatically affect downstream channel morphology and basin sediment yield.**

Coarse woody debris (CWD) has been recognized as an important component of headwater streams (Harmon et al., 1986). Coarse woody debris controls organic matter transport (Bilby, 1981), promotes sediment storage (Megahan, 1982), and causes channel bank erosion (Keller et al., 1995). Disturbances such as logging and mass wasting affect the rate at which CWD is delivered to streams. Spies et al. (1988) and Hedman et al. (1996) showed that CWD production is greater in old growth forests compared to younger-aged stands. In the Great Smoky Mountains, Silsbee and Larson (1983) found that CWD was larger in diameter in old growth-area streams than in logged-area streams. Landslides scour hollows and deposit large pulses of CWD into headwater streams, which may remain in place for decades (Pearce and Watson, 1983; Perkins, 1989)

While several studies have highlighted the function of CWD in maintaining aquatic habitat in the southern Appalachians (Coulston and Maughan, 1983; Fleebe and Dolloff, 1995; Hilderbrand et al., 1998), little is known about the effects of CWD on channel morphology and sediment storage in the region. Moreover, estimates of in-stream residence time for CWD have rarely been reported for southern Appalachian streams. Since the magnitude of channel change associated with CWD is dependent upon the volume and size of CWD delivered to streams, differences in channel morphology should exist between streams with different disturbance histories. This paper compares the distribution, residence time, and geomorphic effects of CWD along headwater streams in logged and old growth areas of the Great Smoky Mountains. The formation of large log jams by debris slides is also discussed.

## SITE DESCRIPTION AND METHODS

Coarse woody debris (woody material > 0.1 m in diameter) that blocks the bankfull channel was mapped along 500-meter reaches of the Road Prong and Huskey Branch watersheds (Fig. 1). Both reaches are steep (channel slope ~0.10), boulder/bedrock-dominated streams bordered by steep valley walls. The Huskey Branch watershed (2.0 $km^2$) was heavily logged and burned as late as the 1920s, before designation of the area as a national park. At present, the dominant tree species of the Huskey Branch watershed are American beech (*Fagus grandifolia*) and yellow poplar (*Liriodendron tulipifera*). The Road Prong watershed (1.8 $km^2$) is covered by old growth forest with dominant species being red spruce (*Picea rubens*) and yellow birch (*Betula alleghaniensis*).

In order to evaluate the effects of CWD on channel morphology, bankfull channel dimensions were measured at 20 m intervals and 1 m upstream from all CWD obstructions. The volume of sediment (all sizes) stored behind CWD was measured by probing the depth through sediment to bedrock in the channel with a steel rod. Channel bed particle size was evaluated along Road Prong using the Wolman (1954) method. Finally, the minimum residence time of CWD in streams was found by determining the age of sprouts growing on fallen or 'nurse' logs (Swanson and Lienkaemper, 1978). I used an increment borer to core sprouts growing on in-stream CWD and then counted annual rings on these cores to determine the minimum residence time of CWD.

## RESULTS AND DISCUSSION

Coarse woody debris obstructions are more frequent along Road Prong (3.0 per 100 m) than along Huskey Branch (1.4 per 100 m) (Table 1). 'Complex' CWD obstructions, those consisting of > 5 logs, are common along Road Prong, but absent on Huskey Branch. Ninety-three percent of the CWD along Road Prong

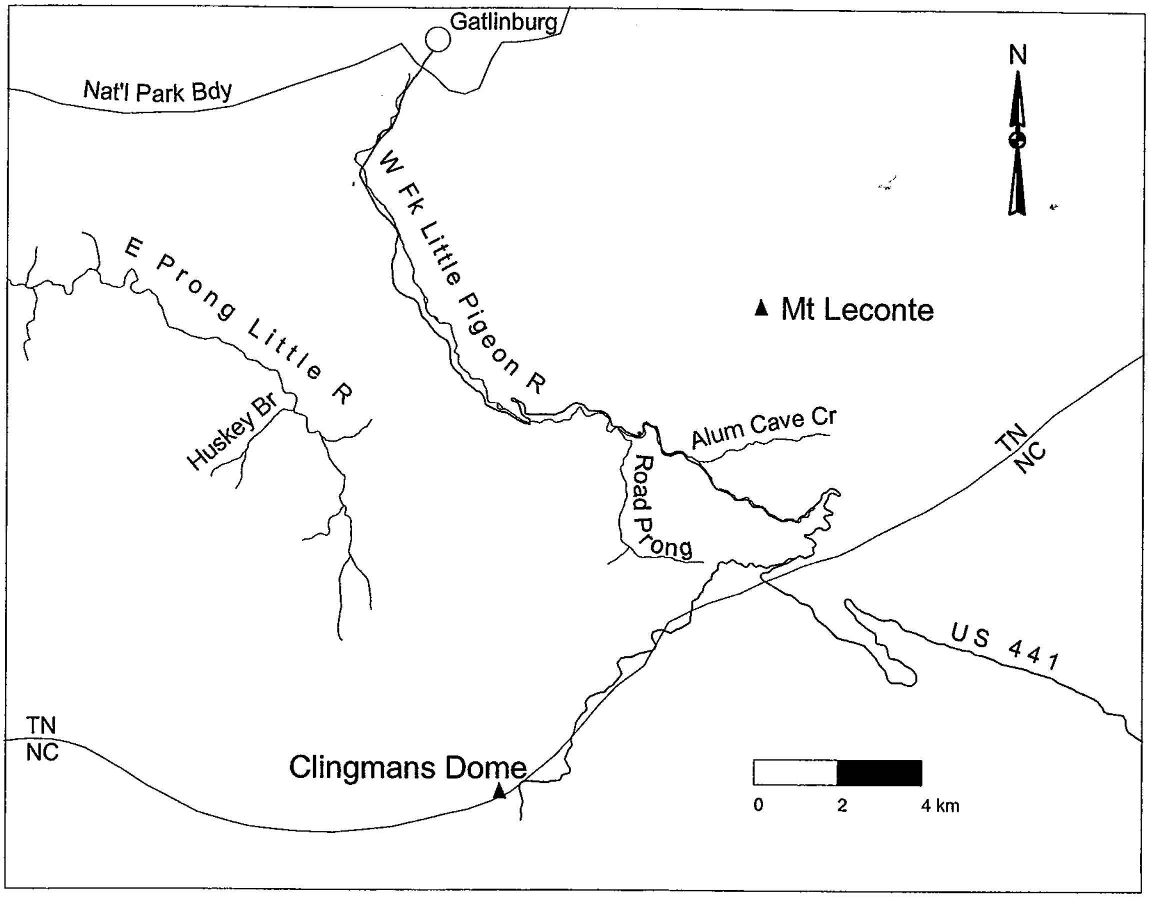


FIG. 1. Map of study area showing location of study reaches within Great Smoky Mountains National Park.

consisted of whole trees, while only 35 percent of CWD obstructions along Huskey Branch were whole trees. The higher frequency and greater size of CWD obstructions along Road Prong support the idea of Spies et al. (1988) that old growth forests produce larger volumes of CWD than younger aged forests. Differences in CWD frequency also may be related to forest type, however, data relating CWD production and tree species are limited. The frequency of CWD has implications for channel morphology and sediment storage along the study reaches. On both reaches channel cross-sections located 1 m upstream from CWD tend to be wider and shallower than reach-average cross-sections. However, the effect of CWD on channel dimensions is more pronounced along Road Prong (Fig. 2 and 3). Thus, variations in channel width are, in part, controlled by flow diversion and bank

TABLE 1. Summary data from study streams. The Huskey Branch watershed was logged in the 1920s. The Road Prong watershed is in an old growth forest zone.

| Stream | Avg. bankfull width (m) | Avg. bankfull width at CWD[a] (m) | # of CWD obstructions per 100 m | # of complex CWD obstructions[b] | Percent of CWD formed by whole trees | Total sediment stored by CWD ($m^3$) | Average volume of sediment stored per CWD obstruction ($m^3$) | Percent of reach vertical drop controlled by CWD |
|---|---|---|---|---|---|---|---|---|
| Huskey Branch (2.0 $km^2$) | 4.6* | 6.5* | 1.4 | 0 | 35 | 14* | 2* | 3 |
| Road Prong (1.8 $km^2$) | 7.2* | 9.9* | 3.0 | 5 | 93 | 318* | 21* | 26 |

* There was a significant difference ($P < 0.05$) between study reaches.
[a] CWD is coarse woody debris.
[b] Complex CWD obstructions consist of >5 logs.

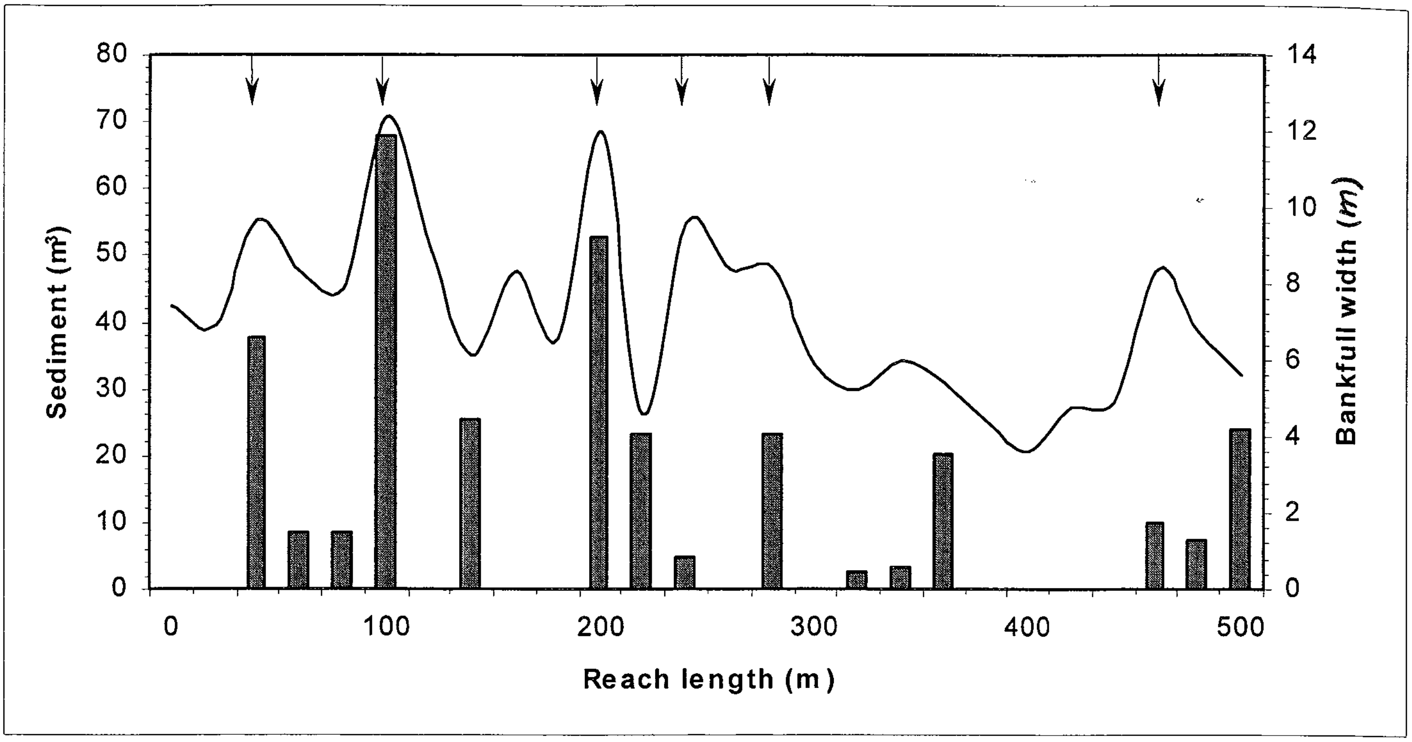


FIG. 2. Bankfull channel width (line) and sediment storage associated with coarse woody debris (CWD) (bars) along Road Prong (old growth). Arrows indicate locations along reach of channel-blocking CWD accumulations.

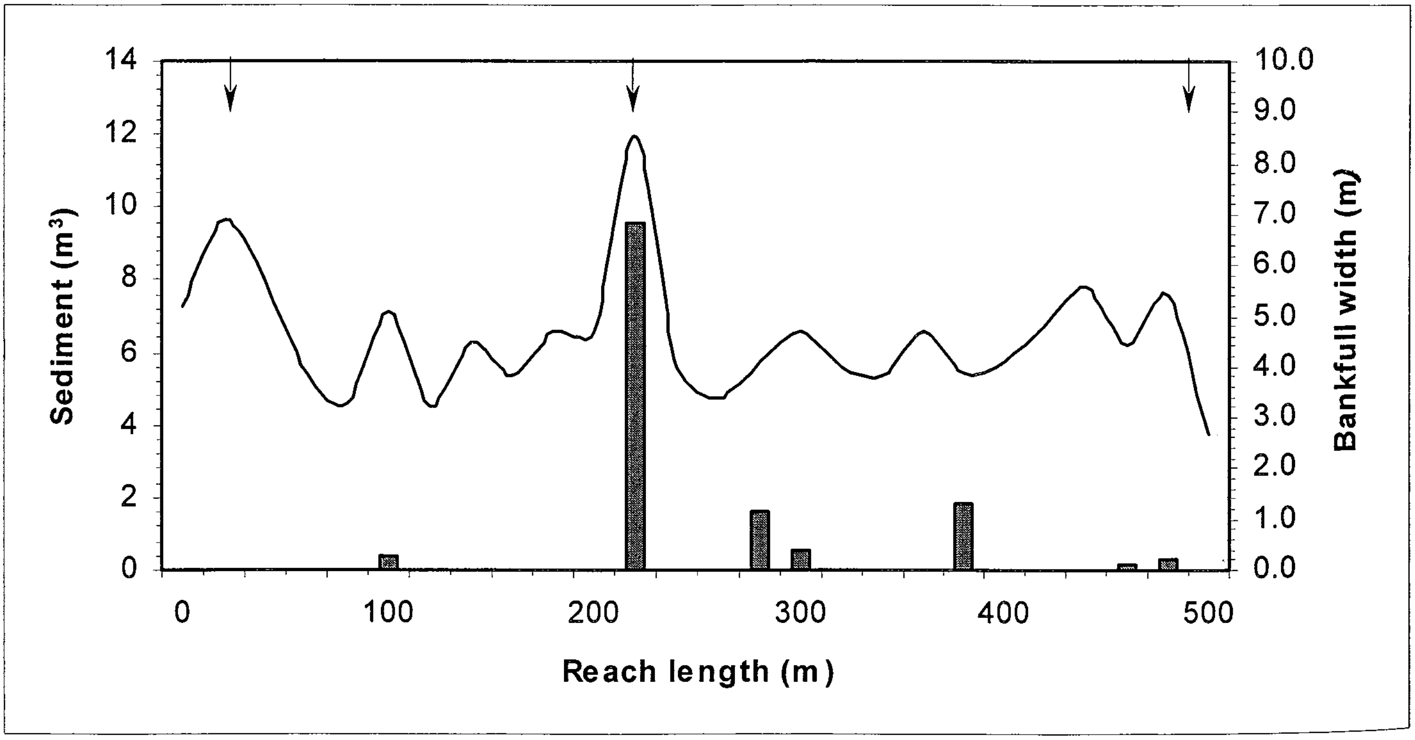


FIG. 3. Bankfull channel width (line) and sediment storage associated with coarse woody debris (CWD) (bars) along Huskey Branch (logged). Arrows indicate locations along reach of channel-blocking CWD accumulations.

FIG. 4. Eighty-five-year old yellow birch growing on log step along Alum Cave Creek. Age of tree is used as a minimum residence time for the log step. Pole for scale is 2 m in length; vertical drop over log step is approximately 1 m.

erosion caused by CWD. Sediment deposition upstream from CWD may lead to the formation of a hydraulic jump, or 'log step' (Marston, 1982) (Fig. 4). Along both reaches, vertical drop over individual log steps ranged from 0.3 to 1.4 m. Log step vertical drop accounts for 26 percent and 3 percent of the total reach vertical drop along the Road Prong and Huskey Branch stream reaches, respectively.

Direct measurement of sediment stored behind CWD obstructions reveals that 15 CWD obstructions store a total of 318 $m^3$ of sediment along Road Prong. In contrast, 7 CWD obstructions store only 14 $m^3$ of sediment along Huskey Branch (Fig. 2 and 3). The median grain size of CWD-stored sediment along Road Prong is 47 mm while the reach average median grain size is 126 mm. Thus, CWD appears to provide refuges for relatively fine sediment along a reach dominated by coarse bedload. The geomorphic effectiveness of CWD is dependent upon its residence time in streams. Along Huskey Branch, no CWD obstructions supported sprouts that could be dated. Five CWD obstructions along Road Prong yielded minimum establishment dates ranging from 23–96 years before present (ybp) (average = 67 ybp). The lack of older, stable CWD along Huskey Branch appears to be the result of logging operations that effectively 'cleaned' streams of CWD (Lambert, 1958). Although logging in the Huskey Branch watershed ended nearly 80 years ago, CWD loading still has not recovered to levels typical of streams in old growth areas. Residence time estimates for CWD along Road Prong are similar to those reported for old growth forests in Oregon (10–108 years) (Swanson and Lienkaemper, 1978), but less than those reported for streams in redwood forests in California (> 200 years) (Keller et al., 1995).

The most dramatic effects of CWD occur where debris slides form large channel-blocking 'log jams.' In 1995, a debris slide scoured a first-order tributary of Road Prong depositing more than fifty trees into the main channel upstream from the study reach (Fig. 5). In 2001, approximately 1200 $m^3$ of sand and gravel remained in storage behind this log jam. A comparison between photographs taken in 1995 and field observations made in 2001 indicates that little sediment had been removed from the log jam since its formation. Since steep valley walls prohibit the channel from bypassing the log jam, most of the sediment will not be available for transport until the log jam is breached or decays. The log jam forms a slackwater pool about 40 m in length along a stream that previously had an average slope of 0.10. Another log jam on nearby Alum Cave Creek (Fig. 1) is larger and apparently older than the Road Prong log jam. It consists of over 100 trees and stores approximately 2800 $m^3$ of sand, gravel, and organic material. Based on the age of sprouts, I estimated the minimum residence time of this log jam to be 23 years. However, several trees that anchor the log jam are over 100 years old, suggesting a residence time longer than 23 years. Debris slides occurred in the Alum Cave Creek basin in 1942, 1951, 1974, 1984, 1993, and 1995 (Bogucki, 1970; Ryan, 1989). Thus, the residence time of this log jam is several times greater than the recurrence interval of debris slides, suggesting that this site is undergoing long-term aggradation. In addition, logs within the jam are in various stages of decay, suggesting that more CWD has been added to the log jam over time.

FIG. 5. Log jam formed in 1995 by debris slide on Road Prong upstream from study reach. Over 50 trees store approximately 1200 $m^3$ of sediment at this site. This photo was taken in 1999.

CONCLUSION—Results from this study indicate that early 20th-century logging in the Great Smoky Mountains has current implications for CWD loading and channel morphology along some streams. Along Road Prong (old growth), CWD obstructions are more numerous and have longer residence times than along Huskey Branch (logged). Despite an end to logging in the Huskey Branch watershed almost 80 years ago, levels of in-stream CWD have yet to return to pre-logging levels. Different amounts of CWD in these two stream reaches are reflected in differences in sediment storage and channel morphology. Variation in channel width appears to be more closely tied to the occurrence of CWD along Road Prong, where CWD is larger and more stable. Moreover, CWD is an effective sediment buffer along Road Prong, storing almost 25 times more sediment than it does on Huskey Branch.

Log jams formed by debris slides store extremely large volumes of sediment, the future release of which is likely to affect channel morphology in downstream reaches and may increase basin sediment yield. However, due to valley configuration, significant sediment release is not likely until log jams decay. Thus sediment release from CWD-storage sites is controlled, in part, by processes unrelated to the fluvial system and may not necessarily be initiated by peak discharges. While little is known about decay rates of in-stream CWD, dendrochronologic evidence from this study demonstrates that CWD can remain intact in streams for several decades. Periodic monitoring of CWD integrity may be useful in predicting future sediment releases from log jams.

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