PRELIMINARY OBSERVATIONS ON THE TRANSPORTATION OF LARGE WOODY ORGANIC DEBRIS IN BURNED AND UNBURNED HEADWATER STREAMS, TONTO NATIONAL FOREST, ARIZONA

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There are no published data on the transportation or accumulation of large woody debris (LWD) within aquatic ecosystems of the southwestern United States. The information available on LWD in the Southwest includes a review of the role and reduction of LWD in "hot desert" streams in the Southwest from a historical perspective (Minckley and Rinne 1985). Heede (1985) examined channel adjustments to the removal of log steps in two streams in the White Mountains of Arizona. In Wyoming and Colorado where climates are more similar to the Southwest than the Pacific northwestern states, Young (1994) examined the movement and characteristics of stream-borne coarse woody debris in adjacent burned and undisturbed watersheds in Wyoming. Richmond and Fausch (in press) studied the characteristics and function of large woody debris in mountain streams of northern Colorado.

Most of the published literature available on LWD comes from the Pacific Northwest and eastern United States. Information on LWD accumulation and transport, however, is not directly comparable with the Southwest because of meteorological, hydrological, and vegetation differences. Studies have examined the role of LWD in the following ways: (a) creating and providing fish habitat, protection from predation, and rearing areas for under-yearling salmonids (Bryant 1983; Bisson et al. 1982; Andrus et al. 1988; Murphy et al. 1984; Angermeier and Karr 1984); (b) storing sediment within a stream system (Klein et al. 1987); (c) providing stability or causing instability in the bed and banks of channels (Keller and Swanson 1979; Smith et al. 1993; Cherry and Beschta 1989); (d) as a source for decomposition products supplying the stream system with nutrients (Bilby and Likens 1980; Bilby 1981); and (e) as a food source and habitat for aquatic invertebrates and microorganisms (Cummins 1974, 1975; Sedell et al. 1975; Triska and Sedell 1975). This research is quite valuable for understanding processes and functions of LWD in northwestern and eastern streams. However, because of the varied climate and hydrologic regimes in the Southwest, research is needed on LWD dynamics and processes in the Southwest.

The Dude Fire, the largest and costliest fire in Arizona history, occurred below the Mogollon Rim on the Tonto National Forest as a result of a lightning strike on June 25th, 1990. The fire burned rapidly and ultimately consumed over 28,000 acres of forest type vegetation, destroyed over 50 homes, claimed six lives, and cost several million dollars of damage. The watersheds of three major permanent-flowing streams (Dude, Bonita, and Ellison creeks) were burned. The fire burned at a high intensity over 60 percent of the landscape, with the remaining 40 percent divided equally between medium and low intensity (personal comm., Grant Loomis, Tonto National Forest). Because of the severity of the burn, a large percentage of the undercover and overstory vegetation was destroyed and the soil became hydrophobic.

After the fire large amounts of dead trees were extant in riparian areas and land managers from the Tonto National Forest were concerned that debris accumulations would form. These, in turn, could wash out bridges and culvert crossings, and result in flooding of summer homes on Bonita and Ellison creeks. To mitigate the possible damage, larger trees were cut into smaller pieces on several creeks to facilitate flushing the pieces through the system more quickly and avoid debris jam formations. The question arises, "What is the best management practice with large woody organic debris in an area that

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has been impacted by a wildfire?"

Because of the lack of information and the question of debris jam formation, we began a study with two primary objectives: (a) to examine the relative transportation of differing sizes of hardwood and conifer LWD in four Southwestern watersheds—three burned and one unburned—and (b) to delineate the accumulation, composition, and movement of LWD in existing debris jams. This paper will only report on preliminary results of the first objective and future study methods for examining the second objective. Ultimately, data collected from this study will aid in the management of watersheds before and after wildfires in the Southwest.

Study Area

From July 6 to 10, 1990, runoff from initial, low-intensity monsoon rains, mixed with 5–10 cm of ash on the hillslopes and riparian areas, caused "slurry flows" down the study stream channels. As the monsoon intensity increased, stream discharge was in a flood state on July 10/11th and continued intermittently for 2 weeks. Prefire base flows in the study creeks averaged 0.1 m^3/sec during the July–September monsoon season, compared with base flows of approximately 10.6 m^3/sec during the early July flows in 1990 after the fire (Rinne in press).

In 1990 and 1991, water discharge was relatively high during both winter and summer months. During February–March 1993, 150–200-year flood events occurred on all drainages affected by the fire and others, such as Pine Creek 15 km to the west. These events eroded streambanks and transported both large (>1 m in length, >10 cm in width) and small (<1 m in length) woody organic debris. Since the large flows in 1993, precipitation and runoff have been relatively low and LWD pieces and accumulations have been basically static, except for movement of tagged LWD pieces on Dude Creek during flows in late August 1994 and in February 1995.

Presently, dead and decomposing trees subject to wind and weather continue to break and fall within the three burned drainages. In addition, trees have been uprooted because of a combination of loss of root systems, winds, and streamflow. In the process of breaking, falling, and uprooting, increasing amounts of LWD and sediment are entering the active stream channel.

Four sites were selected for the study: one study reach (1,500 m) each on Pine, Dude, Bonita, and Ellison creeks. Before the fire, the principal vegetation types in the overstory were ponderosa pine, juniper, and oak. The shrub overstory included three species of Arizona chaparral. The riparian vegetation was predominantly Arizona alder, Arizona walnut, bigtoothed maple, and Arizona sycamore. To date, riparian vegetation, as well as ground cover within the drainage basins, is partially reestablished.

Methods and Materials

From autumn 1993 through summer 1994, field work and data collection consisted of labeling, mapping, and description of LWD along each creek. Seventy-seven pieces were located and marked on Pine, 127 on Bonita, 114 pieces on Dude, and 150 pieces on Ellison. The number of pieces marked depended on both the availability of LWD and the goal of marking 150 pieces per creek. We selected LWD pieces of varying length and width marked within study sections on all creeks. By definition, a piece of woody debris had to be at least 10 cm in width at one end, and at least 1 m in length (Platts et al. 1987). The volume of pieces can ultimately be calculated by using the formula for the volume of a cylinder:

$$V = \frac{\pi \cdot (\text{diameter 1} + \text{diameter 2}) \cdot \text{length}}{8}$$

The marking procedure was from downstream to upstream within the 1500 m linear reaches on each stream channel. A 60 cm wooden stake was set on the banks adjacent to the stream channels every 50 m and a 152 cm fence post at every 100 m. To indicate cumulative distance, fence posts were enumerated with a 5 cm circular, stamped aluminum tag; wooden stakes were labeled with a permanent marker.

Initially, to assess movement of LWD, each piece of wood was labeled with a 5 cm tag similar to those affixed to fence posts. Each piece of LWD has a unique, sequential number within that stream. Determining the initial location was necessary for calculation of downstream movement. Accordingly, a linear distance (made by laser or tape measurement), as well as a compass reading, from the metal tag to a labeled wooden stake or fence post was used to fix the initial location of each piece. Ultimately, all tagged pieces will be located in reference to the distance from the nearest stake on the bank, along the thalweg of the wetted channel. Visual observation and a metal detector are used to locate the

LWD pieces that have moved.

Each piece of LWD was classified as either hardwood or conifer. In this study, the relative distance traveled and the longevity of a hardwood versus a conifer LWD piece will be examined and delimited.

Because this study is programmed to last for 10 years, pieces of LWD that will not conceivably decompose or reduce in size more than 50 percent were chosen. The relative ages of the pieces were determined by (a) the percentage of bark present, (b) the degree of bark attachment on the LWD, and (c) the presence or absence of branches remaining.

Platts et al. (1987) was used to describe the position of each piece of LWD relative to the streambank: (a) complete bridge, (b) collapsed bridge, (c) ramp, and (d) drift (Figure 1). A complete bridge includes pieces that are suspended over the channel from one bank to the other at bankfull discharge. A collapsed bridge includes pieces that were once a complete bridge, but have broken and collapsed into the stream channel. Pieces of LWD with one side leaning on the bank and one side extended into the stream channel are included in the ramp category. Finally, the drift category comprises pieces that are lying within the channel.

The orientation of the most right side of the LWD piece relative to the right bank was spray painted or marked with a small metal tag. The positions of the LWD pieces relative to the stream channel were also recorded. Facing upstream, right bank, mid-channel, and left bank designations were assigned to pieces by dividing the stream bankfull width into thirds.

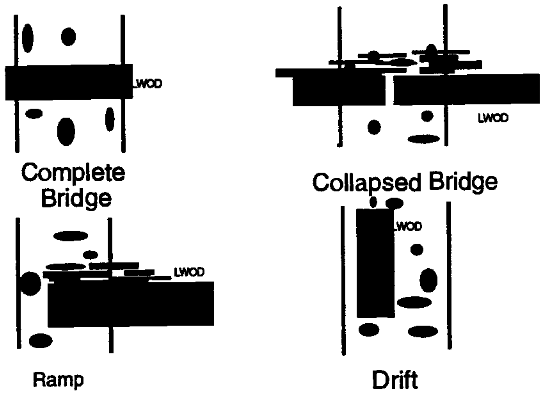

Figure 1. The Movement of LWD in Dude Creek in August 1994.

The last factor examined was the effect of the large woody debris pieces on the stream morphology. We determined whether a pool was created due to the presence of the piece, if sediment was being stored behind or in front of the piece, if the flow was being deflected by the piece or if it could be in higher flows, if other small woody debris or large woody debris was being stored behind the piece, and if there was no effect from the woody debris piece. A diagram was drawn for each piece of LWD. Diagrams indicate the direction of flow, the location of the piece in relation to the wetted channel, the bankfull discharge, bends in the channel, other pieces of LWD, debris jams, trees, and rocks.

In November of 1994, pressure transmitters coupled to data loggers were installed on each of the study creeks. Cross sections were surveyed and flow rating curves are being created.

Results

In August of 1994, flows approximating 90 m^3/sec occurred in Dude Creek and transported some LWD pieces a distance of 1500 m. No movement was detected on the other creeks. As a result of August flows on Dude Creek, 27 LWD pieces moved, while 8 pieces only shifted in position. Most pieces (15) moved less than 100 m; 8 pieces shifted in position only. Seven pieces moved 100–500 m, 3 pieces moved from 500–1000 m, and 2 moved greater than 1000 m.

A two-sample analysis (t-test) indicated a significant difference in the distance moved between pieces in the 1–2 m length class versus those in the greater than 6 m length class (Table 1). However, comparisons of movement between the 1–2 m length class versus the 4–5.9 m length class, and the 2–3.9 m length class versus the greater than 6 m length class, were not significantly different.

From the February 1995 flows on the study creeks, we have neither completed checking the streams for LWD movement nor calculated peak storm discharge measurements. On Pine Creek, we have examined 16 pieces for movement. Of these, 38 percent of the pieces could not be located, 56 percent did not move, and only 6 percent of the pieces did move (Table 2).

On Ellison Creek, we examined 101 pieces: 26 percent could not be located, 34 percent did not move, and 40 percent of the located pieces moved. On Dude Creek, out of the 74 pieces examined, 11 percent were not located, 77 percent of the pieces did not move, and 12 percent of the located pieces moved. Bonita Creek has not been checked yet for movement.

Table 1. Analysis of the movement of LWD by size class on Dude Creek, summer 1994.

Comparison of Size Classes			Significance	
1–2 meters (4)	vs.	>6 meters (9)	0.02	Significant
1–2 meters (4)	vs.	4–5.9 meters (5)	0.16	Not Significant
2–3.9 meters (17)	vs.	> 6 meters (9)	0.08	Not Significant

Table 2. The movement of LWD as a result of winter (Feb. 1995) flows on two burned and one unburned watershed.

Streams Surveyed	Pieces Moved/ Not Located	Pieces Did Not Move	Pieces Moved/ Located
Pine (16)	38%	56%	6%
Ellison (101)	26%	34%	40%
Dude (74)	11%	77%	12%

Discussion

Based on the 35 pieces that moved on Dude Creek during the August 1994 flows, the two-sample analysis suggests that the length of LWD pieces is not the only factor influencing distance transported. Other factors that influence the transportation of LWD include the size of the piece, and the configuration and position in relation to the stream channel, flow, and other pieces and obstructions. The flows necessary to move a piece, channel configuration and morphology, and the instream obstructions (e.g. boulders, other LWD, standing trees, channel banks, bend in the channel, culverts) that may impede transport also affect mobility of LWD. Because of the complexity of factors affecting the transportation of singular LWD pieces and the need to understand debris jam formation and dissolution processes and dynamics, we will focus on the remainder of these components. Nevertheless, we will continue to monitor the movement of the large woody debris pieces already marked, their orientation before and after movement, and what obstructions have effected their movement.

Future Data Collection

To examine and monitor the movement and accumulation of LWD on burned and unburned channels, we need to first understand the variation in the quantity of LWD in undisturbed riparian stream systems in the Southwest and the processes involved in the transportation and accumulation. Next we need to examine burned channels to see the differences between each channel before comparing them together and then to the unburned system. To gain a baseline understanding of the location, size, quantity, movement, and debris jam formations of LWD pieces in southwestern riparian areas we will survey additional creeks within the region below the Mogollon Rim to define the natural variability of LWD in these stream channels.

Ultimately the question is, "What is the best management practice with the large accumulation of LWD after a wildfire?" This study is planned to continue for 10 years. Results of this study will provide an understanding of the transport and accumulation of LWD in the Southwest, as well as the effects of fire on these processes. Conceivably, this knowledge will enable managers to develop the best management practices in and along aquatic-riparian ecosystems before and after fires.

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