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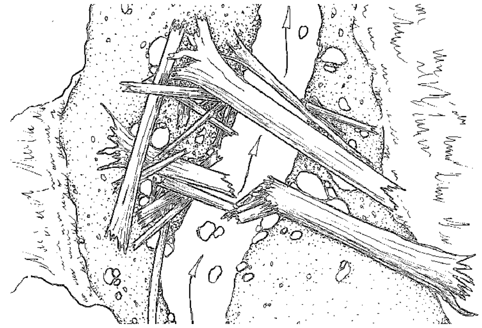

Abundance and Function of Large Woody Debris in Central Sierra Nevada Streams

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Abstract

In 1990 the Stanislaus National Forest surveyed 17 streams to determine the distribution and abundance of large woody debris (LWD). A total of 93 100 m plots were inventoried in mixed conifer and red fir/lodgepole pine forests between 1109 and 2316 m elevation. Plots were in unmanaged, salvaged and second-growth (historically railroad-logged) forests. Unmanaged stands had significantly more large wood and more stable large wood than did second-growth stands. There was no significant differences in the amount of large wood in A, B, or C channel types. Amounts of large wood tended to decrease as stream order increased, with third- and fourth-order streams having more large wood volume than fifth-order streams. Streams in mixed conifer forests did not have significantly different amounts of wood than higher elevation, red fir/lodgepole pine forests. Nearly 30% of the large woody debris was rated as stable, and nearly all wood that formed pools and retained sediment was stable. However, relatively little large woody debris formed pools (2%) or retained sediment (6%). LWD was less abundant on the Stanislaus National Forest than in the Pacific Northwest. Factors influencing LWD in the Sierra Nevada Range may include geomorphology, decay resistance of local tree species, floods, and past management.

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Introduction

The important role of large woody debris (LWD) in streams of forested watersheds is widely recognized (Bisson et al. 1987; Sedell et al. 1988). LWD is integral to structure and functioning of forest stream ecosystems (Harmon et al. 1986; Bisson et al. 1987; Sedell et al. 1988), and influences physical form of the channel, movement and retention of sediment and organic matter, and biological community composition. Importance of LWD in creating and providing habitat for salmonids has also been documented. LWD influences pool formation, pool size and location, deposition of spawning gravels, and cover for fish (Bryant 1983; Bisson et al. 1987; Sedell et al. 1988).

Most studies of LWD in streams have been conducted in the Pacific Northwest (Swanson et al. 1976; Swanson and Lienkaemper 1978; Bilby 1984; Lienkaemper and Swanson 1987; Bilby and Ward 1989) and Alaska (Bryant 1980; Swanson et al. 1984; Murphy and Koski 1989). Information on LWD in streams of the Sierra Nevada Mountains of California is very sparse. One study in Sequoia National Park compared standing crop of LWD in two streams, one with redwood (*Sequoiadendron giganteum*) and one without (S.V. Gregory, unpub. data). The Pacific Southwest Forest and Range Experiment Station is presently studying LWD in streams on the Tahoe and Sierra National Forests (Berg 1992).

We inventoried LWD to provide information on the distribution, abundance, and function of LWD in streams within the Stanislaus National Forest. We sampled stream reaches which, to the greatest extent possible, had not been disturbed by recent fire and logging activity.

Study Area

The Stanislaus National Forest is located on the west slope of the Sierra Nevada Mountains in central California. The Forest ranges in elevation from 335 m to 3528 m. Underlaying most of the Forest is the granite of the Sierra Nevada batholith.

Between approximately 1200 and 2000 m elevation there are mixed conifer forests. Common tree species are ponderosa pine (*Pinus ponderosa*), sugar pine (*Pinus lambertiana*), white fir (*Abies concolor*), Douglas-fir (*Pseudotsuga menziesii*), and incense cedar (*Calocedrus decurrens*). Above 2000 m the forest generally consists of red fir (*Abies magnifica*), Jeffery pine (*Pinus jeffreyii*), white fir, and lodgepole pine (*Pinus contorta*).

From the late 19th century to the 1950's, many mid-elevation (1000-2000 m) timber stands were railroad-logged. Large areas were clear-cut and high-graded; stream courses and riparian areas were not protected. Most of these areas are now forested with second-growth mixed conifer stands. Between the 1960's and the early 1980's many old-growth (>100 years) stands were salvage logged. Salvage contract areas often covered large areas and the amount of removal in any particular site is unknown; however, District timber managers felt that riparian areas were generally not salvaged heavily. Unmanaged stands generally contain old-growth trees and have not been entered for harvest.

Methods

Seventeen streams, in the Stanislaus River and Tuolumne River drainages, were surveyed in 1990. Ninety-three plots were inventoried in streams flowing through mixed conifer forests between 1109 m and 2316 m elevation. Plots were initially selected using maps of stand density (low, medium, and high) adjacent to streams to determine stand condition. After the streams had been surveyed it was determined that stand density maps did not accurately reflect the logging history of the riparian zones, e.g., high stand density could indicate either older, unlogged stands or dense second-growth (historically railroad-logged) stands. The plots were reclassified using field and office information and assigned to one of three new descriptors of stand condition: unmanaged, salvaged, or second-growth. Fifty-seven plots were located in unmanaged riparian areas, 18 plots in salvaged riparian areas, and 18 plots in second-growth riparian areas. Unmanaged plots were those with no stumps in the riparian area. Salvaged plots were either those where stumps were present in limited numbers or those identified by Forest records. No plots were included where extensive logging activity during the past 30 years, as evidenced by adjacent clear cutting or an excessive number of stumps in the riparian zone, was apparent in the riparian area. Second-growth plots were determined using Forest records.

Each plot was 100 m long, with 1-14 plots per stream depending on its length and logging history. Plots were spaced at least 155 m apart on a stream on 7.5 minute quadrangle maps. No plots were located within 155 m of a road crossing or near campgrounds. Stream order at the sample site was determined from 7.5 minute quadrangle maps (Strahler, 1957). Contour crenulations were used to identify first-order streams; we did not rely on only the USGS identified streams. Sites were located in the field and plots were laid out along the thalweg using a string measuring device. Channel type was based on the stream gradient within the plot: "A" channels had gradients of 4-10+%, "B" channels 1.5-4%, and "C" channels 0.1-1.5%.

LWD was defined as all pieces of wood greater than 1 m long and 10 cm in diameter (at the large end). Each piece of wood that met the definition, and was at least partially within the bankfull channel width, was counted and measured. Diameters were taken at each end, with diameter measured at the juncture of the bole and rootwad, if a rootwad was present. Average diameter was calculated from diameters at each end of the piece. Average diameters were grouped by diameter classes: small (10-30 cm), medium (31-60 cm), large (61-90 cm), and very large (>90 cm). LWD was considered stable if it was longer than the mean channel width or was buried at one or both ends (Bryant, 1983). Volume of each piece was calculated using the following formula:

$$\text{Volume} = \frac{\text{pi}\,(D_1^2 + D_2^2)\,L}{8}$$

where D_1 and D_2 are the diameters at each end and L is the length. Volume was calculated only for that portion of LWD which was within the bankfull channel width. Total volume of all pieces of LWD divided by plot area (bankfull channel width X 100 m) yielded volume per unit area (Lienkaemper and Swanson, 1987).

We also noted if the LWD was functioning to create pool habitat or store gravel. LWD formed pool habitat if it created dammed, plunge or scour pools. If the debris was within a pool, but did not appear to be maintaining the pool, it was not considered to be a casual agent. Debris influenced sediment retention if there was an accumulation of sediment upstream or adjacent to it.

This survey was designed as an inventory, it was not designed as an experiment to test for the effects of past management history on

LWD in streams. One-way analysis of variance (ANOVA) was used to test for differences within management history, channel type, and stream order. Since both sample sizes and variances were unequal, a modified Tukey multiple comparison procedure was used to find differences within factors (Kaselman and Rogan, 1978). We used a t-test to find differences between elevations.

Results and Discussion

A total of 1426 pieces of LWD were inventoried. About 60% of all pieces were in the small (10-30 cm) diameter class and another 28% were in the medium (31-60 cm). While the majority of the LWD was less than 30 cm in diameter, these smaller pieces made up little (8%) of the overall volume (Figure 1). The abundance of small diameter pieces of wood in streams has been documented in Alaskan and Appalachian streams (Murphy and Koski, 1989; Flebbe and Dolloff, 1995).

Management History

Of the plots sampled, amounts of LWD differed among management histories. Mean volume of LWD was highest in salvaged plots, unmanaged plots had intermediate amounts, and lowest in second-growth plots (Table 1). Volume of LWD in unmanaged plots was significantly greater than in second-growth plots ($p<0.05$). Variability was high, there were plots in each management category which contained few pieces of LWD. For example, LWD volumes in Bourland Cr., which had only two plots, were 2.13 m^3/ha and 873.2 m^3/ha. Research on other Sierran streams has also shown a clumped distribution of LWD (Berg 1992).

Over 64% of the volume in unmanaged and salvaged plots came from pieces with a diameter greater than 60 cm, with the greatest percentage found in the large (>90 cm) class (Table 2). Medium diameter pieces (31-60 cm) accounted for approximately 50%

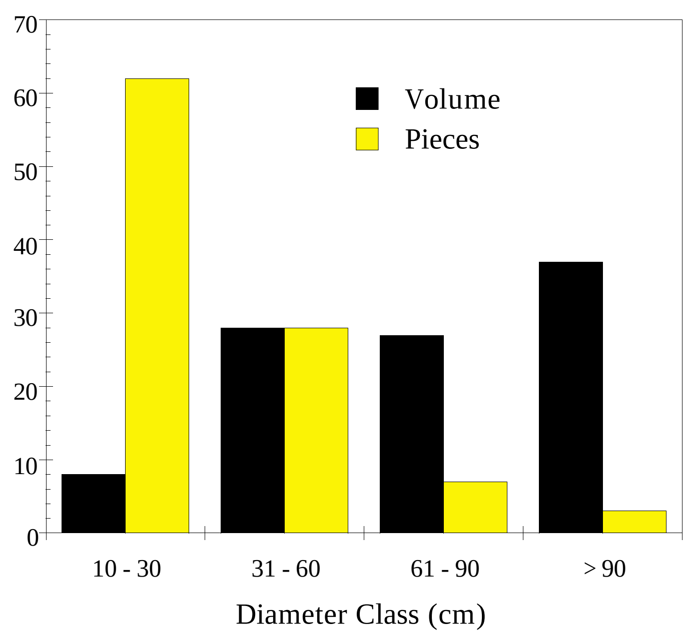

FIGURE 1. Distribution of LWD by percent of total volume and total pieces within four diameter classes in the Stanislaus National Forest, California.

TABLE 1. Distribution of LWD by management history, channel type, stream order, and elevation zone in the Stanislaus National Forest, California. N is the number of plots sampled in each category. Standard deviation is in parentheses. Values with the same lowercase letter are significantly difference (P<0.05).

	Mean volume (m^3/ha)	Mean density (#/100 m)	Mean stable pieces/100 m
Management History			
Unmanaged (N=57)	136 (153)a	17.8 (11.2)b	4.5 (4.1)c
Salvaged (N=18)	205 (290)	13.4 (17.0)	5.4 (7.9)
Second-growth (N=18)	51 (49)a	9.5 (6.7)b	3.1 (2.3)c
Channel Type			
A (N=35)	168 (243.6)	17.0 (13.3)	3.6 (5.2)
B (N=40)	109 (132.6)	13.7 (10.3)	4.5 (4.3)
C (N=18)	116 (114.4)	15.6 (14.0)	5.5 (5.7)
Stream Order			
2nd (N=6)	320 (444)	24.6 (17.7)	11.2 (8.8)
3rd (N=21)	181 (217)a	17.4 (11.6)	5.3 (4.4)
4th (N=53)	115 (111)b	14.8 (12.3)	3.7 (4.4)
5th (N=13)	36 (47.3)ab	9.8 (6.9)	2.4 (2.3)
Elevation Zone			
<2000 m (N=71)	147 (197)	14.7 (11.9)	4.1 (4.5)
>2000 m (N=22)	85 (95)	17.0 (13.0)	5.3 (6.1)

of the volume in second-growth plots. It is likely that many of the larger pieces were removed during railroad logging, have decomposed or been flushed out in the past 50+ years (Bryant 1980; 1985). Flebbe and Dolloff (1995) found smaller LWD pieces in a second-growth Appalachian stream than in old-growth streams. The smaller LWD in second-growth plots is likely due to recruitment from stands that have become established since railroad logging. Larger diameter pieces will not be recruited until the surrounding forest matures (Bryant 1980; Bisson et al. 1987; Andrus et al. 1988; Flebbe and Dolloff 1995).

Plots within unmanaged stands had significantly ($p<0.05$) more pieces and more stable pieces than second-growth plots (Table 1). The smaller pieces found in second-growth plots are more likely to be washed away and less likely to be stable. While salvaged plots had the highest number of stable pieces (Table 1), there were no differences in total or stable pieces between salvaged plots and plots in other management categories.

Due to insufficient sample sizes, we were not able to test for interactions between management history and channel type, stream order, or elevation. The 18 second-growth plots occurred in only three streams, and 16 plots were in two of the streams. Within each stream there may have been interactions between plots for which we did not test.

Channel Type

There were no significant differences ($p<0.05$) in LWD volume, density, or stable pieces between plots in A, B, or C channel types (Table 1). Mean LWD volume in B and C channels (109 m^3/ha and 116 m^3/ha, respectively) were similar and over 30% lower than in A-type channels (168 m^3/ha). Density was

TABLE 2. Distribution of LWD by percent of total volume within four diameter classes in the Stanislaus National Forest, California.

	Diameter class (cm)			
	10-30	31-60	61-90	>90
Unmanaged	8	28	28	36
Salvaged	5	19	28	48
Second-growth	11	51	19	19
Channel Type				
A	6	23	31	40
B	8	30	23	39
C	11	37	26	26
Stream order				
2nd	9	31	16	44
3rd	8	19	27	46
4th	6	30	29	35
5th	15	54	31	0

nearly the same in each channel type. Though not significantly different, the amount of stable LWD seemed to increase as channel gradient decreased (Table 1). Berg (1992) found 70% of the total LWD volume on a 9000 m section of the North Fork American River, also in the Sierras, in low gradient (1-2% slope) channel sections. These low gradient sections made about 25% of the total channel. Low gradient, unconfined channels are typically depositional areas for LWD.

In A and B channels, nearly 40% of LWD volume was in debris pieces with very large diameters (>90 cm). Debris with medium diameters (31-60 cm) contributed 37% of the volume in C-type channels (Table 2). As channel gradient increases, the potential for loss of LWD increases (Harmon et al., 1986; Bisson et al., 1987; Flebbe and Dolloff, 1995). Streamflows in higher gradient channels have potentially higher energy; smaller pieces of LWD are more likely to be transported downstream. This may account for the larger sized pieces in the A and B channels, even though these very large diameter pieces represented only 3% of the total pieces in these channels.

Stream Order

All sections sampled were in second- to fifth-order streams. Generally, LWD volume decreased as stream order increased (Table 1). Plots in third-order and fourth-order streams had significantly higher volumes of wood than plots in fifth-order streams. LWD with very large diameters (>90 cm) provided about 45% of the volume in second- and third-order plots. Only 30% of the volume in fifth-order streams came from wood with diameters over 60 cm, and there were no pieces in the very large (>90 cm) class. Fifty-four percent of the volume in fifth-order streams was found in pieces with medium (31-60 cm) diameters (Table 2). The abundance of large diameter pieces in lower order streams probably reflects the inability of smaller streams to transport large pieces of wood. Contrary to our findings, Ursitti (1990) found that total volume increased with increasing channel width.

There was a tendency for density and number of stable pieces to decrease as stream order increased, however, we found no significant differences in the number of pieces, total or stable, between stream orders (Table 1). Bilby and Ward (1989) studied LWD in second- to fifth-order streams in western Washington; they also found that density decreased as stream size increased. LWD density, in second- to fifth-order Alaskan streams, was related to channel size and hydraulic control (Murphy and Koski 1989). Narrow, steeper channels had more LWD than did wide, unbraided channels. Ursitti (1990) found the number of LWD pieces decreased with increasing channel width. Generally, channel width increases with increasing stream order. As channel width increases, the potential for LWD loss increases (Harmon et al. 1986; Bisson et al. 1987; Flebbe and Dolloff 1995). Larger, wider streams provide fewer obstacles, i.e. opportunities, to anchor debris, and shorter pieces are floated downstream or onto floodplains by floods.

LWD in small second-order streams often consists of pieces that are longer than the bankfull width. Second-order channels tend to be steep and constrained by adjacent hillslopes. Fallen trees into second-order streams tend to be suspended over the channel because the length of the tree exceeds the width of the constrained channel, unless the tree breaks apart in falling (Nakamura and Swanson 1993). The mean length of LWD in second-order plots (5.0 m) was similar to the mean length of LWD in third- to fifth-order plots (4.8, 4.7, 4.6 m, respectively). However, the mean length of LWD in the second-order plots (5.0 m) was only slightly less than the mean bankfull channel width (5.5 m). The mean bankfull widths of the third- to fifth-order plots, 8.8, 11.3, and 10.9 m, respectively, are 1.8 to 2.4 times as wide as the mean LWD length in those plots. This relationship may explain why the mean volume, density, and number of stable pieces in second-order plots were all higher than in third- to fifth-order plots.

Elevation

We examined the data for the effects of elevation because the tree species found at different elevations may have differing resistance to decay. Generally, mixed conifer forests of ponderosa pine, sugar pine, and white fir exist below 2000 m, and red fir or lodgepole pine are dominant above 2000 m. We found no significant differences ($p<0.05$) in LWD volume, density, or number of stable pieces in lower elevation plots versus higher elevation plots (Table 1).

Many of the decay mechanisms that affect decomposition of wood in terrestrial systems are not important factors in streams, particularly if the wood is constantly in the water. For example, microbial activity is restricted to the log surface when wood is continuously wet. Physical abrasion of wood surfaces by flowing water and bedload is a primary agent of decomposition of LWD in streams. However, LWD in stream channels that is alternately wet and dry can be affected by the same decay mechanisms as in terrestrial systems (Harmon et al. 1986; Sedell et al. 1988). Data compiled by Harmon et al. (1986) tends to indicate increasing resistance to decay for: *Abies* sp., ponderosa and Jeffery pine, lodgepole pine, and Douglas-fir, respectively. Only six plots (Big Cr.), all low elevation, occurred in stands dominated by Douglas-fir. The most common species in all of our plots, white fir, ponderosa pine, red fir, and Jeffery pine, all have similar, relatively high rates of decay.

While lodgepole pine is relatively resistant to decay, plots in streams with lodgepole often had lower volumes of LWD (Appendix A and B). The volume of LWD in streams flowing through lodgepole stands may be low because lodgepole trees are usually smaller than either red fir or ponderosa pine.

Geomorphic Functions of LWD

Stable debris influences channel form by retaining sediment and forming pools. Of the 1426 pieces of LWD measured, a total of 409, or 29%, were rated as stable. Stable pieces were larger than unstable pieces. The mean length and diameter of stable pieces was 8.9 m and 40 cm, respectively, while unstable pieces were both shorter (3.0 m) and had smaller diameters (27 cm). Size, including both length and diameter, is an important factor contributing to stability (Bryant 1983; Bilby 1984; Sedell et al. 1988). Some LWD in our study was rated as stable because it met the criteria of being longer than the active channel width; however, these pieces also had small diameters (10-30 cm) and would likely decay quickly (Harmon et al. 1986) and provide little structure to the channel. In our survey, LWD that influenced both pool formation and sediment retention had a mean diameter of 33 cm. Of the 409 pieces identified as stable, only 183 pieces had diameters greater than 30 cm (13%). Berg (1992) found less than 10% of the LWD was stable in two central Sierra Nevada streams.

The role played by LWD in maintaining of pools and retention of sediment is well documented (Bisson 1987; Sedell et al. 1988; Bilby and Ward 1991). Only 29 pieces of LWD, or 2% of all LWD surveyed, were helping to maintain pool habitat (Table 3). Ninety percent of wood forming pools occurred in plots in unmanaged stands. LWD more often formed pools in C and B channel types (14 pieces and 11 pieces, respectively). Nearly fifty percent of the pool-forming LWD occurred in the low gradient plots, even though these represented less than 20% of the total number of plots. All LWD forming pools were found in third- and fourth-order streams.

TABLE 3. Characteristics of LWD which influenced pool formation and sediment retention in streams in the Stanislaus National Forest, California.

	LWD forming pools		LWD retaining sediment	
	Mean diameter at large end (cm)	Number	Mean diameter at large end (cm)	Number
Unmanaged	31	26	29	66
Salvaged	36	2	24	21
Second-growth	67	1	34	5
Channel Type				
A	47	4	44	13
B	31	11	27	28
C	33	14	25	51
Stream Order				
2nd	-	-	50	3
3rd	33	16	29	41
4th	31	13	26	46
5th	-	-	25	2

Ninety-two pieces, or 6% of all LWD surveyed, were retaining sediment (Table 3). About 70% of LWD retaining sediment occurred in unmanaged plots. Only 2 pieces of LWD in second-growth plots retained sediment. More than half of LWD that was storing sediment was in the low-gradient channels and nearly all in third- and fourth-order streams. All LWD that was forming pools was also rated as stable, as were 90 of the 92 LWD pieces that were storing sediment. Of the 29 pieces forming pools, 25 were also storing sediment.

Nakamura and Swanson (1993) studied the relationships between LWD and channel morphology and sediment retention in second- to fifth-order streams in Oregon. LWD in narrow, second-order channels is often suspended above the channel or sticking into the valley floor and has little opportunity to interact with the stream. Channel widening and sediment storage associated with LWD predominately occurs in third- to fifth-order streams where the wider channels allow for more interaction between LWD and the stream. Sediment retention was more often associated with LWD in third- and fourth-order streams. In fifth-order streams, LWD deflects streamflow causing sediment to be stored temporarily along the lateral portions of the channel. Our limited data for Sierra Nevada streams also indicated that sediment retention was associated with LWD in third- and fourth-order streams (Table 3).

LWD played a relatively minor role in the geomorphism of stream channels in the plots we surveyed. In step-pool streams, LWD is most likely to influence pools or sediment accumulation in low gradient reaches where depositional processes occur. Plots in C channels had similar LWD densities as the higher gradient A and B channel plots. We found the majority of debris causing pools or storing sediment were in C channels. Of the 25 pieces of debris that influenced both pool formation and sediment retention, 13 pieces occurred in C channels and 8 pieces occurred in B channels. Berg (1992) found less than 5% of LWD formed pools or stored sediment in two central Sierra streams, and most of these pieces occurred in C channels.

Factors that may be affecting LWD in the Sierras

Geomorphology. Many streams in the central Sierra Nevada mountains are typically high-gradient, step-pool systems, dominated by boulders and cascades. Several plots in our survey were dominated by boulders. In-channel LWD was often laying across the top of boulders and did not appear to interact with stream flow. Other plots in this survey had extensive areas of smooth bedrock or cascades. In moderate to steep gradient streams with boulder and bedrock substrates LWD has little opportunity to influence channel morphology and it is easily flushed out of the channel at high flow.

Floods. Redistribution of LWD by floods is common in medium and high order streams. In the Sierras, rain-on-snow events often cause the largest floods. Recent, major flood events on the Stanislaus National Forest occurred in 1980, 1983, and the largest, in 1986. In 1986, flows high enough to float large pieces of wood occurred at elevations as high as 2100 m in some drainages.

Lienkaemper and Swanson (1987) concluded that most LWD pieces moved by floods were shorter than bankfull width. Pieces longer than the bankfull width, and anchored outside the channel, are long enough to be stable during most flood flows. Debris jams develop when the shorter, floating pieces accumulate against the upstream side of the longer, stable pieces. We observed this effect of flooding on at least one stream, Lily Cr., where several large jams had developed and the channel above the jams contained little LWD. Plots located at jams had large quantities of LWD, while plots between jams had low quantities. Very large floods, like those that occurred in 1986, are capable of transporting even the largest LWD pieces long distances downstream. The impact of these recent flood events on LWD in streams on the Stanislaus National Forest is unknown because no data on LWD had been collected prior to the present survey.

Decay resistance. Sierra Nevada streams, on the average, have lower amounts of LWD than streams in the Coast and Cascade Ranges, Oregon (Table 4). Debris entering streams in the Oregon studies comes from adjacent Douglas-fir/western red cedar (*Thuja plicata*) forests. Douglas-fir and western red cedar are highly resistant to decay and may persist in stream channels for 200 years or more (Sedell et al. 1988). A study done in Sequoia National Park, in the southern Sierra Nevada Range, found LWD volumes similar to those in Oregon (Table 4). One second-order stream in Sequoia National Park had giant sequoia LWD, another species that is very decay resistant. We sampled plots on the Stanislaus National Forest with LWD volumes similar to old-growth Douglas-fir and sequoia forests (Table 4), however, these plots were not common. Mean LWD volume on the Stanislaus National Forest (132 m^3/ha) was more similar to pine forest streams in Idaho (42-120 m^3/ha; Table 4). The relatively low

TABLE 4. Comparison of LWD on the Stanislaus National Forest, California with other streams Idaho, California and Oregon. Sample sizes vary in length.

Site	Age	Sample Size	Stream order	Volume (m^3/ha) mean (range)	Density (#/100m) mean (range)
Stanislaus NF					
All plots	50(?)-100+	93	2-5	132 (0.1-1175)	15 (1-60)
Unmanaged	100+	57	2-5	136 (0.7-1175)	18 (1-50)
Salvaged	100+	18	2-4	205 (2-1175)	13 (1-60)
Second-growth	50-90	18	3-5	51 (0.1-165)	9 (1-24)
Idaho [1]	200	2	-	55 (42-120)	-
So. Sierra Nevada, Calif.[1]	1000	2	2	765 (537-993)	-
Sierra Nevada, Calif.[2]	-	2	-	-	5
Coast Range, Oregon [3]	80-150	9	3-5	190 (86-363)	42 (26-80)
	290-410	6	3-5	382 (258-582)	58 (47-81)
Coast Range, Oregon [4]	80-140	5	2-3	375 (194-584)	61 (37-124)
Cascades, Oregon [5]	400-500	5	2-5	478 (230-750)	-

[1] Harmon, 1986
[2] Berg, 1992
[3] Ursitti, 1990
[4] Heimann, 1988
[5] Lienkaemper and Swanson, 1987

decay resistance of the true fir and pine species in the Sierras may partially explain why LWD appears to have a lesser role in Sierran streams than has been documented elsewhere (Harmon et al. 1986; Bisson et al. 1987; Sedell et al. 1988).

Past management. Historic railroad logging activities appear to have impacted amounts of LWD in stream channels on the Stanislaus National Forest. Plots in second-growth streams had lower volumes of LWD, as well as fewer and smaller pieces, compared to plots in other streams. Second-growth plots also had fewer stable pieces (Table 1).

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Appendix A. Mean LWD volume by stream, Stanislaus National Forest, California.

Stream	Number of Plots	Management History	Mean Volume (m^3/ha)
Smoothwire Cr.	3	Salvaged	607
Campoodle Cr.	1	Salvaged	531
Bourland Cr.	2	Salvaged/Unmanaged	438
Little Rattlesnake Cr.	4	Unmanaged	215
Reynolds Cr.	6	Unmanaged	176
Mill Cr.	10	Salvaged/Unmanaged	164
Clark Fork	6	Unmanaged	148
Big Cr.	6	Unmanaged	148
Lily Cr.	5	Unmanaged	110
Herring Cr.	12	Unmanaged	99
Niagara Cr.	4	Salvaged	93
N. Fk. Tuolumne R.	8	Second-growth	68
Little Reynolds Cr.	4	Second-growth	47
Shoofly Cr.	2	Salvaged	46
Bloods Cr.	5	Unmanaged	34
M. Fk. Tuolumne R.	8	Second-growth	32
Eagle Cr.	7	Unmanaged	32

Appendix B. Characteristics of streams inventoried for LWD on the Stanislaus National Forest, California.

Stream	No. of Plots	Stream Orders	Channel Type[1]	Channel Width (m)	Elevation of Plots (m)	Forest Type[2]
Smoothwire Cr.	3	2nd	A	3-6	1536-1666	MC
Campoodle Cr.	1	4th	B	6	1609	MC
Bourland Cr.	2	3rd	A, B	5-8	1719-1817	MC, RF
Little Rattlesnake Cr.	4	2nd, 3rd	A	8-12	1500-1682	MC
Reynolds Cr.	6	3rd, 4th	A, B, C	5-11	1707-1829	WF, L
Mill Cr.	10	4th	A, B, C	6-8	1670-1939	MC, RF
Clark Fk.	6	3rd, 4th	B, C	9	2085-2134	MC, L
Big Cr.	6	4th, 5th	B	7-8	1256-1305	DF
Lily Cr.	5	4th	C	12	2036	L, RF, J
Herring Cr.	12	3rd, 4th	A, B, C	7-16	1658-2316	MC, L
Niagara Cr.	4	4th	A	6-8	1817-1890	MC
N. Fk. Tuolumne R.	8	4th	B, C	9	1524-1622	MC, WF
Little Reynolds Cr.	4	2nd, 3rd	B	4-8	1853-1939	L, WF
Shoofly Cr.	2	4th	B, C	8	1670-1695	MC
Bloods Cr.	5	4th, 5th	A	11-18	1853-2048	RF, L, J
M. Fk. Tuolumne R.	8	5th	B, C	7-11	1109-1280	MC
Eagle Cr.	7	3rd, 4th	A, B, C	9-16	1817-2256	MC, L

[1] A-channel (4-10% slope), b-channel (1.5-4% slope), c-channel (0.1-1.5% slope)
[2] MC-mixed conifer, RF-red fir, J-Jeffery pine, WF-white fir, L-lodgepole pine, DF-Douglas-fir