

Large Woody Debris Budgets in the Caspar Creek Experimental Watersheds¹

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Abstract

Monitoring of large woody debris (LWD) in the two mainstem channels of the Caspar Creek Experimental Watersheds since 1998, combined with older data from other work in the watersheds, gives estimates of channel wood input rates, survival, and outputs in intermediate-sized channels in coastal redwood forests. Input rates from standing trees for the two reaches over a 15 year period varied from a high of 28 m³/km/yr in the North Fork (in 1995) to a low of 0.12 m³/km/yr in the South Fork (from 2000 to 2002). Rates in the South Fork, where a second-growth forest was selectively logged in the 1970s, have consistently been lower than those in the North Fork, where partial clearcutting in the 1990s left buffer strips along the channel. Since 2004, inputs in both reaches have been between 2 and 8 m³/km/yr and are dominated by inputs from snags. More than 90 percent of the volume of conifer pieces that entered the channel in 1995 was still present in 2010; alder pieces from that period are mostly gone. Wood budgets demonstrate the contrast in wood volumes between the two channels and the importance of stored wood in the system.

Key words: in-stream wood, wood budgets, large woody debris, buffer strips

Introduction

An important aspect of sustainable forest management is maintaining adequate levels and types of large woody debris (LWD) in stream channels. Because LWD inputs are often episodic and pieces can persist for decades in the channel, an LWD budgeting approach can be a useful tool to estimate long-term effects of management activities, but such budgets are limited by the reliability of the estimates used for inputs, survival, and outputs. In the Caspar Creek Experimental Watersheds, an influx of LWD in the North Fork channel in 1995 created an opportunity to monitor piece persistence in that channel and to compare input and survival rates between the North and South Fork channels, which are adjacent to stands with contrasting forest management histories.

There is a large body of literature on LWD volumes in stream channels, but few studies have documented LWD dynamics over time (Wohl et. al. 2010). At Caspar Creek, O'Connor and Ziemer (1989) sampled LWD in the North Fork channel, and Surfleet and Ziemer (1989) sampled wood in both the North Fork and South Fork channels shortly after the North Fork logging. The current study differs from earlier Caspar studies by using monitoring of all large pieces within defined reaches to understand what causes changes in volume over time.

¹ This paper was presented at the redwood science symposium: coast redwood forests in a changing California. June 21-23, 2011, University of California, Santa Cruz.

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Methods

The study area is in the Caspar Creek Experimental Watersheds, Jackson Demonstration State Forest, Mendocino County, California. Stream-adjacent stands are dominated by coast redwood (*Sequoia sempervirens*), Douglas-fir (*Pseudotsuga menziesii*), grand fir (*Abies grandis*), and, in the South Fork, red alder (*Alnus rubra*). Both watersheds were clearcut, with channel clearing, in the 1860s through the early 1900s. Selective logging (with stream-adjacent roads) in the South Fork in the early 1970s removed about 2/3 of the standing volume. A series of small clearcuts with partially cut buffers along the mainstem channel removed approximately 45 percent of the volume in the North Fork watershed upstream of the XYZ tributary between 1989 and 1991 (Henry 1998). Some wood was removed from South Fork channels during logging. Buffer strips prevented as much wood from entering the North Fork channel during logging as had entered during South Fork logging, and any that did enter remained there rather than being yarded out. Some pieces, particularly in the North Fork, have been cut to maintain access trails for streamflow studies.

The North and South Fork watersheds have weir ponds at the downstream ends. The study reaches are along the mainstem channels upstream of these ponds, and, in the North Fork, upstream of the first major tributary. Reach slopes range from one to three percent, and mean bed widths vary from 6 m near the weir ponds to 2 m at the upstream ends of the study reaches. Characteristics of the two watersheds include:

Characteristics	North Fork	South Fork
Study reach length (m)	1822	1945
Watershed area, downstream end (ha)	391	393
Watershed area, upstream end (ha)	163	190

Field crews tagged and measured existing and new wood pieces in the study reaches starting in 1998. For each piece, median (or, for oddly-shaped pieces, average) diameter, length within a zone extending 1 m horizontal distance outside of the edge of the active channel, species, position, decay class, and distance from a benchmark were recorded. Any available evidence of input date, source distance from the bank, whether the source tree was a snag, and input mechanism was noted. Length in the active channel was estimated in the South Fork. Down live trees (leaning more than 45 degrees from vertical) and standing trees or stumps that interacted with the stream bed were included.

The original objective of the study was to monitor survival of pieces contributed by a series of windstorms in 1995 (Reid and Hilton 1998), so the 1998 tagging included all pieces $> 0.1 \text{ m}^3$ from trees that entered the channel from 1995 to 1998 and pre-existing pieces $>0.3 \text{ m}$ diameter and $>2.5 \text{ m}$ long or $>0.15 \text{ m}$ diameter and $>0.5 \text{ m}^3$. It quickly became obvious, however, that in order to identify new inputs (particularly from snags) all pieces larger than some minimum size needed to be tagged, so in 1999 all pieces $>0.15 \text{ m}$ diameter and $>2.5 \text{ m}$ long in the North Fork, and in 2000 in the South Fork all pieces $>0.2 \text{ m}$ diameter and $>1.5 \text{ m}$ long were tagged. In the North Fork, tagged pieces were mapped on existing channel maps that show all pieces $>0.15 \text{ m}$ diameter and $>1 \text{ m}$ long. The South Fork channel was surveyed in 2001 and wood pieces were mapped beginning in 2004; before that, pieces were located by distance upstream from the downstream end of the reach. In 2002, 2004, 2006, and 2008, existing pieces were checked and new, moved, broken, or changed pieces $>0.2 \text{ m}$ diameter and $>2 \text{ m}$ long in both channels were tagged and

measured. In 2010, new hillslope inputs were tagged and the current status of 1995 inputs in the North Fork and 1995 to 2000 inputs in the South Fork was checked. The study is continuing; this paper presents preliminary results as of 2010.

I calculated channel input rates from standing hillslope trees from 1995 to 2010. For inputs from 1998 to 2010, I used new tree data from each year's survey. For 1995 inputs I used 1998 survey data and source information. In the North Fork, most trees from 1995 were flagged shortly after they fell, and most of those were checked in the 1998 survey, but because some pieces would have broken up or moved out of the channel by 1998 some volume is missing. In the South Fork, 1995 inputs are based on trees found in 1998 that appeared (from the condition of the bark, branches and twigs, and surrounding vegetation) to have been down for about 3 years. Pieces from snags were difficult to identify and age, so snag inputs are likely to be underestimated in both forks through 1998.

Wood volume budgets (inputs, changes, and net gain or loss) were calculated for pieces >0.2 m diameter and >2 m long for each survey interval. Because field crews did not tag all pieces larger than that size in 1998, I estimated volumes that were present in the channel in 1998 but not tagged. Many pieces were later tagged, and I used notes from the field crews, existing pool maps, and, in the North Fork, existing channel maps, to determine which pieces had been present since 1998. However, there were presumably some pieces >0.2 m diameter and >2 m long that were not tagged in 1998 and left the channel between 1998 and 2002 (or, in the South Fork, 2000), when tagging began on all pieces of that size or larger.

In the North Fork, the channel maps provided information needed for an estimate of this missing volume. For all pieces marked as "gone" in 1999 or 2002, I measured the mapped length within a zone defined by lines drawn 1 m outside of the mapped edge of the bank and summed those lengths by mapped diameter class. I calculated the diameter distribution within each class for pieces tagged in 1999 that had been previously mapped (these pieces were smaller than all pieces tagged in 1999, because the larger pieces had been tagged in 1998), and used the percent by diameter within each class to calculate a total volume gone for each period. In the South Fork, I estimated volumes of untagged pieces that had disappeared by 2000 but were shown in pool sketches from a 480 m subreach drawn in 1998 and 1999. That loss estimate was adjusted for logs not in pools (92 percent of logs tagged in 1998 in the pool subreach were in pools), and scaled back up to the full length of the study reach. Both estimates are approximate, and are likely to be accurate to ± 50 percent.

Results and discussion

Hillslope input rates

Input rates from standing trees from 1995 to 2010 (*table 1*) show the combined effects of episodic events and stand history. High input rates in the North Fork in 1995 and 1996 show the effects of the 1995 windstorms, particularly in buffer strips adjacent to clearcuts, while those same storms had much less effect in the smaller, younger stands in the South Fork. Rates in the North Fork decreased rapidly though the late 1990s, then increased as new fir snags began contributing wood. Snag inputs also increased in the South Fork, both from fir snags and from riparian alders. By 2010, input rates were less erratic, and South Fork rates were approaching North Fork

rates. However, inputs to both channels are dominated by short-lived species (grand fir in the North Fork and grand fir and alder in the South Fork) and may diminish over time as those species disappear from the stands.

Table 1—Volume of large wood contributed to stream channels from standing trees by year, species, and snag status. 1996 inputs entered between January and December 1995; later inputs entered between the previous survey and the listed year. Units are m³/km/yr of pieces >2m long and >0.2 m diameter.

North Fork	1996	1998	1999	2002	2004	2006	2008	2010
Redwood live	2.36	0.38	0.0	0.27	0.49	0.31	0.51	0.19
Redwood snag	0.0 ^a	0.0 ^a	0.0	0.0	0.0	0.0	0.0	0.03
Douglas-fir live	18.96	8.06	2.06	1.30	2.56	0.63	0.0	0.85
Douglas-fir snag	2.48 ^a	3.56 ^a	2.70	2.11	5.93	5.17	4.33	1.96
Grand Fir & other ^b live	3.81	0.97	0.0	0.02	0.06	0.03	0.53	0.0
Grand Fir & other ^b snag	0.56 ^a	0.61 ^a	0.0	0.45	1.18	1.11	0.62	4.17
South Fork	1996	1998	2000	2002	2004	2006	2008	2010
Redwood live	0.30	1.64	0.0	0.02	0.53	0.90	0.29	0.24
Redwood snag	0.0 ^a	0.0 ^a	0.0	0.0	0.0	0.0	0.0	0.0
Douglas-fir live	0.72	0.47	0.0	0.0	0.22	0.38	0.0	0.04
Douglas-fir snag	0.0 ¹	0.0 ^a	0.12	0.0	0.53	1.63	0.94	1.92
Grand fir & other ^b live	0.08	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Grand fir & other ^b snag	0.0 ^a	0.0 ^a	0.10	0.05	0.15	0.25	0.0	0.93
Alder live	1.98	0.36	0.55	0.0	0.19	1.14	0.64	1.56
Alder ^c snag	0.0 ^a	0.0 ^a	0.0	0.06	0.30	0.45	0.14	1.30

^a Snag inputs are underestimated in 1996 and 1998, particularly in the South Fork.

^b Includes western hemlock and “fir”—pieces that might be either grand fir or Douglas-fir.

^c Includes a small amount of tanoak.

Piece survival

Almost all of the volume of large wood input to the North Fork channel during the 1995 windstorms that was present in 1998 was still in the channel in 2010. *Table 2* shows the percent of the 1998 volume that was still in the channel at the time of each survey, with survival noted first by species and next by whether it came from a standing snag or from a live or recently-live tree. Pieces from snags are slightly less stable than those from live trees, but still quite persistent. In the South Fork, most alder volume was gone by 2010, but some pieces were still there. Conifer pieces were generally stable in that channel also, but the small number of trees makes it difficult to determine if they were more or less stable than those in the North Fork.

Table 2—Persistence of 1995 large wood inputs over time. Values are percent of the 1998 volume of pieces input in 1995 remaining at the listed time. Numbers in parentheses are the number of source trees in each category. Very small categories have been omitted. North Fork inputs are grouped by species and by whether the tree was a snag; all 1995 trees in the South Fork were identified as “live” or “probably live.” Volume increases are caused by pieces moving further into the defined measurement area.

North Fork		Percent of 1998 volume remaining				
Species	1999	2002	2004	2006	2008	2010
Redwood (15)	95	96	96	108	105	103
Douglas-fir (74)	100	100	97	94	94	92
Grand fir (17)	98	96	96	96	96	97
Status of source tree						
Live/probably live (76)	99	98	96	96	96	96
Snag /unknown (33)	100	103	96	90	91	80

South Fork		2000	2002	2004	2006	2008	2010
Species							
Redwood (3)		100	100	100	69	79	86
Douglas-fir (2)		100	100	100	100	95	95
Alder (4)		100	100	63	59	47	33

Part of the reason pieces are so persistent in these reaches is the length of the reaches—very few pieces move entirely out of the reach. I evaluated mobility within the reaches by comparing pieces that moved more than 5 m downstream between 2004 and 2006 in the two reaches. The winter of 2005 and 2006 included the highest flow during the study. Just under 10 percent of the pieces moved in each channel (16 of 205 pieces in the South Fork, 73 of 759 in the North Fork), but moved pieces were larger in the South Fork, with a mean moved piece volume of 0.53 m³, compared to 0.32 m³ in the North Fork. South Fork pieces also moved, on the average, about 20 m further. The percent of total volume moved was also slightly higher, 4.2 percent versus 3.8 percent in the North Fork. South Fork pieces appear to be more mobile in a given flow year, but it would be useful to compare movement in other high-flow years.

Wood budgets

Wood budgets for all intervals between surveys are summarized in *table 3a* for the North Fork and *table 3b* for the South Fork. A significant amount of wood entering the active channel in some years was previously-down pieces or standing stumps that had been outside of the active channel and entered the measurement area due to channel migration, or that had been buried in the bed or banks and became unburied, or that entered from adjacent hillsides or terraces by being knocked in by other trees, by sliding downslope, or by landslides (standing trees that entered from landslides are listed as “trees” in the budgets). These pieces are listed as inputs from “Off-channel.” Pieces that left the channel in equivalent ways (by burial, changes in channel location, or transport onto inactive floodplains) are listed as “Off-channel” losses. Budgets start with the tagged volume present at the beginning of the period. Volume losses, in addition to “Off-channel,” include pieces that were never found (Gone), or broke and became too small (Too small), or were transported downstream

beyond the end of the reach, usually into the weir ponds (Downstream). Volumes added include new logs from standing trees, additions from “Off-channel,” unidentified transported pieces, and pieces that moved in from upstream.

Volumes of moved and broken pieces are subtracted from volumes after remeasurement to calculate a net change, which can be positive if pieces moved closer to the channel and thus had more volume within the measurement area. Trail work can also have a positive or negative net effect. Total changes are added to the original volume to calculate the volume at the start of the next interval. Budgets for 1998 to 1999 (or 2000 in the South Fork) and 1999 to 2002 have an additional category for untagged pieces >0.2 m diameter and >2 m long that broke or disappeared during those periods. These estimated volumes are, as described earlier, not very accurate. Since these numbers make up most of the calculated total losses in the years to which they apply, losses in those years could range from half to twice the listed value.

Table 3—Wood budgets for the North and South Forks of Caspar Creek, 1998-2008. See text for explanation of budget categories. Units are m^3/km over the period listed. Estimated numbers are categorized as “untagged.”

3a. North Fork

	1998 to 1999	1999 to 2002	2002 to 2004	2004 to 2006	2006 to 2008
Tagged volume	311.99	314.53	332.98	349.00	357.26
(untagged)	10.4	3.8			
Start volume	322.4	318.4	333.0	349.0	357.3
Losses:					
Gone	-0.42	-1.15	-2.70	-15.64	-5.08
Too small	-0.00	-0.00	-1.36	-1.41	-0.47
Off-channel	-0.70	-0.33	-1.44	-4.72	-1.74
Downstream	-1.68	0.00	0.00	-0.06	-0.12
(untagged)	-6.59	-3.84	0.00	0.00	0.00
Total losses	-9.4	-5.3	-5.5	-21.8	-7.4
Moved/broken	-19.54	-17.72	-24.77	-57.51	-50.52
Inputs from:					
Trees	4.76	12.45	20.45	14.48	11.97
Off-channel	1.40	3.58	5.01	18.13	1.81
Unknown	2.11	2.37	1.82	6.96	0.80
Upstream	0.00	0.11	0.39	0.17	0.00
Total input	8.3	18.5	27.7	39.7	14.6
Moved pieces	16.89	21.16	18.63	47.80	46.73
Net moved	-2.6	3.4	-6.1	-9.7	-3.8
Net trail work	-0.3	-2.0	0.0	0.1	-1.5
Unchanged	289.37	291.55	301.70	267.31	296.70

3b. South Fork

	1998 to 2000	2000 to 2002	2002 to 2004	2004 to 2006	2006 to 2008
Tagged volume	104.62	106.31	105.52	104.16	112.07
(untagged)	3.9				
Start volume	108.5	106.3	105.5	104.2	112.1
Losses:					
Gone	-0.29	-0.97	-3.96	-4.41	-1.70
Too small	-0.00	-0.00	-1.00	-0.00	-0.92
Off-channel	-0.09	-0.00	-1.44	-0.00	-0.00
Transport out (untagged)	-0.00	-0.00	-0.67	-1.86	-0.00
Total losses	-4.3	-1.0	-7.1	-6.3	-2.6
Moved/broken	-3.49	-5.60	-7.48	-13.63	-16.98
Inputs from:					
Trees	1.54	0.25	3.84	9.51	4.02
Off-channel	0.00	0.06	2.38	3.60	0.75
Unknown	0.67	0.27	0.65	1.88	0.87
Upstream	0.00	0.00	0.00	0.07	0.00
Total input	2.2	0.6	6.9	15.1	5.6
Moved pieces	3.35	5.21	6.40	12.74	14.10
Net moved	-0.1	-0.4	-1.1	-0.9	-2.9
Unchanged	100.75	99.73	90.88	84.27	92.47

Most wood in both channels was unchanged in any period, and the largest amount of change was accounted for by pieces that moved within the reaches, which generally did not result in much net volume change. Both reaches showed a net accumulation over the period, but net accumulation in the South Fork was much lower than in the North Fork and almost entirely a result of high inputs in 2006; it may not represent a long-term pattern. The North Fork accumulated volume in every interval, with a net accumulation rate over the budget period of 3.3 m³/km/yr. South Fork inputs, outputs, and changes are consistently lower than those in the North Fork. Surfleet and Ziemer (1996) noted a strong contrast in volumes between the North and South Forks in 1994 (before the 1995 windthrow). They attributed this difference to stream clearing in the South Fork between 1967 and 1973. Data from this study indicates that the contrast has continued and increased, mainly due to differences in input rates to the two channels, exacerbated by differences in piece persistence (mainly due to species composition) and possibly by higher relative mobility in the South Fork.

Inputs from “off-channel” were highest in both forks in 2006, following the highest peakflow during the study. In the North Fork, these inputs were higher in 2006 than inputs from standing trees, and much of that volume was large pieces of old-growth redwood. Many pieces moving back and forth from “off-channel” are old redwood chunks, which persist in the channel for many years.

Conclusions

Wood inputs, outputs, moved volumes and total volumes are consistently lower on the South Fork than the North Fork, in some cases much lower. There are many factors that contribute to this difference, including differences in stand age and species composition, post-logging channel clearing in the South Fork, and post-

logging blowdown in the North Fork. Current input rates in the South Fork are approaching those in the North Fork, but much of that input (26 to 48 percent since 2004) is alder, which does not tend to persist in the channel. Wood is continuing to accumulate in the North Fork, partly because more than 90 percent of the volume from the 1995 blowdown events is still in the channel.

Acknowledgments

Jen Feola, Dustin Idler, Elias Stienbuck, Gina Spratt, Sven Rosengreen, Dina Ederer, Alejandro Ramirez, Shauna Little, Megan Arnold, Forrest Phifer, Basilia Lopez, Ziza Bibic, and Alana Bartoli tagged and searched for and measured logs through the years, and many other people in Ft. Bragg and Arcata entered data, answered questions, and helped in many ways. Liz Keppeler provided her usual good advice and support, and Leslie Reid and Tom Lisle provided inspiration and insight. The study was partially funded by the California Department of Forestry and Fire protection.

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