Persistence of Historical Logging Impacts on Channel Form in Mainstem North Fork Caspar Creek[1]

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***Abstract**: The old-growth redwood forest of North Fork Caspar Creek was clear-cut logged between 1860 and 1904. Transportation of logs involved construction of a splash dam in the headwaters of North Fork Caspar Creek. Water stored behind the dam was released during large storms to enable log drives. Before log drives could be conducted, the stream channel had to be prepared by removing all obstructions, including large woody debris jams, from the channel. Comparison of present-day woody debris loading on North Fork Caspar Creek (24 kg m^{-2}) to physically similar streams in old-growth redwood basins (49 to 268 kg m^{-2}) suggests that wood-loading and stability were greatly diminished by historical logging activities and change to second-growth cover. These changes are important, as woody debris creates large-volume, long-term sediment storage sites and diverse aquatic habitat conditions. Although historical logging appears to have caused lasting channel changes, including channel incision, simplification of form, and reduction in sediment storage capability, the significance of habitat-related changes remains unclear.*

Keller and Tally (1979), in a study of the role of woody debris in steep, headwaters streams draining old-growth redwood forests, found that debris provides: (a) a stepped channel profile where a large proportion of the stream's total energy is dissipated locally at plunge pools below debris dams; (b) stable channel roughness elements that provide large-volume, long-term sediment storage sites (often stable for hundreds of years), effectively buffering the channel from infrequent large sediment inflows; and (c) stable channel structure that creates a diverse assemblage of channel morphologies and flow conditions.

Stable and diverse channel form is often associated with high-quality fish habitat. Physical factors (stream order, discharge, valley width, channel type, channel slope), woody debris input processes, and the size of debris pieces interact to control frequency, distribution, and stability of in-stream woody debris over time (Keller and others 1981). The influence of woody debris on channel form and process is directly related to its amount per unit length (debris loading), distribution, and stability over time.

To evaluate whether historical logging has caused persistent changes in channel form, woody debris loading, and stability, I analyzed: (a) research regarding the effect of woody debris on channel form and function in streams draining second- and old-growth redwood forest; (b) history of 19th- century logging activities at Caspar Creek; and (c) field evidence for historical disturbance or removal of wood from North Fork Caspar Creek. This paper describes analysis of these data and discusses probable channel response to 19th- century logging activities.

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Site Description

The mainstem channel of North Fork Caspar Creek, located in Mendocino County, California, is a steep (slope = 0.02), perennial, gravel-bed stream that is confined within a deeply-incised inner gorge. Position of bank-side trees and occurrence of large woody debris strongly influence channel position, variability in form, and width. Most sediment within the active channel is stored: (a) as localized deposits associated with jams of large woody debris; and (b) along short reaches of channel that are aggrading and widening in response to adjacent recent landslides. Gravel bars in the mainstem channel are unvegetated or covered with short-lived hydrophytes. Valley fill terraces define one or both channel banks along most of the channel length and become increasingly common downstream. Old-growth stumps in growth position on many valley fills confirm that some terraces were deposited at least hundreds of years ago, and that bank erosion and channel migration rates have subsequently been very low.

Comparison of North Fork Caspar Creek to Similar Streams in Old-Growth Coast Redwood Forest

Research by Tally (1980) demonstrates that much of the variability in debris loading along a particular stream draining an old-growth redwood forest is related to frequency of "large diameter redwood trees" (*table 1*) that are located near the channel. When physical input factors are uniform, debris loading is primarily a function of tree frequency, and therefore, physically similar channels should have comparable debris loading given similar forest cover.

Before 19th-century logging, tree frequency on North Fork Caspar Creek is likely to have been within the range for steep mountain streams (e.g., those without extensive floodplains) in old-growth forests that were surveyed by Tally (1980). Tree frequency along these streams varies from 26 to 68 trees per hectare. Keller and others (1981) compared several streams in second- and old-growth redwood basins to assess how the influence of woody debris on channel form and process may be altered in second-growth basins (*table 2*). North Fork Caspar Creek was one of the second-growth basins studied. Keller and others (1981) estimated debris loading of 21 to 24 kg m^{-2} in North Fork Caspar Creek. Of the old-growth streams studied by Keller, upper Little Lost Man Creek is the most similar to North Fork

Table 1*—Large woody debris loading in streams draining old-growth redwood forests. (Source: Tally 1980).*

Stream	Reach	Debris loading (*kg m*$^{-2}$)	Number of large redwoods within 50 m channel	Floodplain
Hayes Creek		170	68	None
Little Lost Man Creek	Upper	141	52	None
	Middle	268	40	None
	Lower	49	26	None
Prairie Creek	Hope Creek	218	80	Minor
	Little Creek	12	25	Yes
	Forked Creek	13	21	Yes
	Zig Zag No. 2	22	25	Yes
	Natural Tunnel	106	41	Minor
	Brown Creek	85	75	None
	Campground	20	32	Yes

r^2 = 0.88 for debris loading vs. large redwood frequency.

Table 2*—Channel attributes for streams in second-and old-growth redwood forests. (Source: Keller and others 1981).*

	Second-growth			Old-growth								
						PRAIRIE CREEK						
	North Fork Caspar Creek upper/lower	Lost Man Creek	Larry Damm Creek	Hayes Creek	Little Lost Man Creek upper/lower	Hope Creek reach	Little Creek reach	Forked Creek reach	Zig Zag No. 2 reach	Natural Tunnel reach	Brown Creek reach	Campground reach
Basin area (km^2)	1.6/3.9	1.1	3.7	1.5	3.5/9.1	0.7	3.5	6.6	8.2	11.2	16.7	27.2
Stream order	2/2	2	3	2	2/2	2	2	2	2	2	3	4
Slope	.016/.013	.048	.014	.120	.033/.048	.020	.014	.012	.009	.010	.010	.005
Debris loading (kg m^{-2})	21/24	105	76	170	142/49	218	12.3	13.1	21.7	106	84.8	19.6
Pool to pool spacing (by channel widths)	3.5/3.8	4.1	2.2	2.4	1.9/1.8	6.2	4.7	2.6	6.6	2.7	6.0	4.0
Area in pools (pct)	24/36	33	27	12	22/18	49	34	46	36	41	26	25
Area in riffles (pct)	30/30	25	14	26	15/21	21	46	49	20	15	18	25
Area in debris-stored sediment (pct)	44/34	43	59	40	39/39	30	18	30	15	21	29	13
Area in undercut banks (pct)	2/1	4	2	4	3/1	1	4	3	4	1	< 1	1
Pool morphology influenced by debris (pct)	82/43	79	59	83	100/90	86	71	87	50	80	67	50
Debris controlled drop in elevation (pct)	57/37	69	17	38	59/30	43	27	34	8	< 1	18	< 1

NOTE: Total percentages in stream environments may be less than or greater than 100 percent owing to overlaps between units (such as pools which contain debris-stored sediment).

Caspar Creek (*table 3*). Both are steep, second-order, gravel-bedded streams with narrow valleys, similar drainage area, channel width, and slope. Therefore, physical factors affecting woody debris input and loading should be similar. There are between 26 and 52 large redwood trees per hectare along Little Lost Man Creek; the creek contains 49 to 268 kilograms of wood per square meter of stream (*table 4*) or two to seven times more than in North Fork Caspar Creek. Therefore, it appears that debris loading, and consequently the influence of woody debris on channel form and process, was much greater in North Fork Caspar Creek before the 19th- century logging, compared to present conditions. Much higher debris loading in Little Lost Man Creek provides significantly greater debris-related sediment storage capacity (*table 4*). For example, log jams in Little Lost Man Creek store about five times as much sediment, and have approximately 20 times as much unfilled storage capacity as in North Fork Caspar Creek.

Woody debris jams in streams that drain old-growth forests are also quite stable. Large trees, found growing on pieces of debris which comprise the jams, are often more than 100 years old (Keller and Tally 1979). Considering the stability of debris jams in old-growth streams, Keller and Tally (1979) concluded that debris-related sediment storage capacity in Little Lost Man Creek (and other old-growth streams) provides an important buffer system for the channel by allowing infrequent large-magnitude sediment inputs to be stored in jams and released slowly over time. In contrast, debris-related storage capacity in North Fork Caspar Creek is less than 50 t km^{-2} (*table 4*), the presence of many collapsed or partially collapsed jams and the lack of mature trees growing through the debris pieces suggest that the debris jams are dynamic, short-lived features (Napolitano 1996; *table 5*). Historical logging activities may be the cause for these differences.

History of 19th-Century Logging at Caspar Creek

Caspar Creek was first logged in 1860, and most of the watershed was clearcut and burned between 1864 and the mid-1890's (Wurm 1986). Caspar Lumber Company records indicate that redwoods logged in the Caspar Creek watershed typically ranged between 0.8 and 2.5 m in diameter. Cut logs were floated downstream to the company mill located on the coast. To make this possible, a logging splash dam was constructed near the headwaters of the North Fork Caspar Creek (Jackson 1987a). The water stored behind the dam was released during large storms to increase streamflow enough to enable log drives. Before log drives could be conducted, a stream channel had to be "improved" by "removal or blasting of boulders, large rocks, leaning trees, sunken logs or obstructions of any kind" (Brown 1936). During each log drive thousands of logs were transported down the creek (Jackson 1987b).

Table 3*—Channel attributes of Upper Little Lost Man Creek*[1] *and North Fork Caspar Creek.*

Stream	Forest cover	Basin area	Slope	Channel sinuosity	Channel width[2]	Channel margins
		km²	*m/m*	*m/m*	*m*	
Upper Little Lost Man	Old-growth	3.5	0.03	1.1	6.4	Hillslopes or narrow valley flat
North Fork Caspar	Second-growth	3.8	0.02	1.1	5.3	Narrow valley flat and/or hillslopes

[1] Data for Little Lost Man Creek from Keller and Tally (1979)
[2] Mean channel width = channel area per centerline channel length

Table 4*—Comparison of characteristics of Upper Little Lost Man Creek and North Fork Caspar Creek*[1].

Stream	Forest cover	Woody debris loading	Sediment storage	Available storage[2]
		kg m^{-2}	*t km^{-2}*	*t km^{-2}*
Upper Little Lost Man	Old-growth	141	1795[3]	1010[3]
North Fork Caspar	Second-growth	24	340[4]	< 50[4]

[1] All Little Lost Man Creek data, and debris loading data for North Fork Caspar Creek are from Keller and others (1981).
[2] Remaining sediment storage capacity in debris jams.
[3] Based on data in Keller and others (1981), and assuming sediment storage per unit drainage area is similar in upper and lower Little Lost Man Creek and bulk density of sediment in storage is approximately 1.8 t m^{-3}.
[4] North Fork Caspar Creek sediment storage based on data collected in summer 1987.

Field Evidence of Channel Improvement and Log Drives

Evidence of channel preparation for log drives along the mainstem North Fork Caspar Creek can be found by examining in-place old-growth stumps on valley fills. The old-growth redwood stumps are commonly obscured by mature stump sprouts or by shrubs growing through the stump. It is likely, therefore, that old-growth stumps are present elsewhere along the creek where they have not been recognized. As the valley width is narrow (3 to 20 m) along most of North Fork Caspar Creek, stumps were cut flush with the ground surface to avoid snagging of floated logs during drives. All other old-growth stumps in the basin (e.g., those farther from the channel and on hillslopes) were cut well above the root swell, several meters above ground surface, because sawyers were paid by the small diameter of each log that they cut (Jackson 1987a).

Direct evidence of removal of woody debris elements from the channel of North Fork Caspar Creek is difficult to find. Characteristics of woody debris within the active channel, however, suggest that logs were removed or blasted. For example, almost without exception, the largest logs in the channel today are 0.5 m in diameter, approximately the same diameter, as the largest second-growth trees within the basin. In one location, an old-growth trunk is protruding from the bank of a valley fill deposit. This trunk had been sawed obliquely, to be flush with the ground surface of the

***Table 5**—Large debris jams in North Fork Caspar Creek having sediment storage volume ≥ 25m³.*

Reach name length (meters)	Geomorphic map I.D	Location	Debris jam formed (water year)	1987 sediment m^3	1985-1987 change in storage[1]	Evidence from maps[1]
A (1120)	O1	80 m upstream of xs 9	1980	53	0-10 m^3 increase	Jam formed in 1980, as noted in 1980 xs survey; bars and some LWD first depicted on 1986 map
	O2	25 m upstream of xs 25	1984 or 1985	34	20-30 m^3 increase	LWD jam but no bars on 1985 map; xs 26 end-pins missing in 1986; step and small bar shown on 1986 map
	O3	15 m downstream of xs 28	Before 1979[2]	71	0-10 m^3 increase	Few LWD pieces and no gravel bars on 1985 map; long bar on 1986 map
	O5	8 m upstream of xs 37	Before 1979[2]	58	0-10 m^3 increase	Most bars and LWD are depicted on 1985 map; no significant changes in 1986-87
	O6	2 m downstream of xs 42	Between 1979 and 1985[3]	73	0-10 m^3 decrease	Stepping noted 1985; step breached 1986, but most stored sediment remained in jam
	O7	15 m upstream of xs 43	Before 1979[2]	47	No change	No changes evident 1985-87
F (695)	O14	16 m upstream of xs 50	Between 1979 and 1985[3]	77	No change	No changes evident 1985-87
	O17	17 m downstream of xs 56	Before 1979[2]	32	0-20 m^3 decrease	Step collapsed in 1986, but most stored sediment remained in jam
	O24	26 m upstream of xs 60	Before 1979[2]	26	No change	No changes evident 1985-87
L (590)	O33	16 m downstream of xs 74	Before 1979[2]	33	0-20 m^3 decrease	No changes evident on maps; 1986-88 scour at xs 74 suggests a decrease in storage
	O35	17 m downstream of xs 76	Between 1979 and 1985[3]	27	No change	No changes evident 1985-87

Total storage as Large Jams (530 m^3)

[1] Based on analysis large woody debris maps (Unpublished USDA Forest Service maps) prepared in 1985 and 1986, and geomorphic maps prepared in 1987 (Napolitano 1996).
[2] Based on review of cross-section field notes prepared in July 1979, which state whether large woody debris was present, and if it created a backwater at a cross-section.
[3] No backwater effect from woody debris noted in cross-section field notes prepared in July 1979; debris jam shown on 1985 large woody debris maps.

valley fill deposit. Before being cut, it probably extended across the valley width and obstructed streamflow, and thus would have hindered efforts to float logs downstream. Other smaller old-growth logs are similarly oriented and partially buried within the same valley fill deposit a few meters upstream, suggesting that there may have originally been a debris jam present at the site.

Channel Response to 19th-Century Logging Activities

Channel erosion and incision would be promoted by increased peak flows associated with splash dam releases and abrasion caused by repeated transport of thousands of logs. A large fraction of the sediment stored in debris-jam backwaters would probably have been liberated because the logs that had stabilized and trapped the sediment were removed during channel preparation. Considering that the diameters of trees logged in Caspar Creek generally ranged between 0.8 and 2.5 m, the streambed may have degraded substantially where jams extended across the channel. Most of the sediment stored in valley fills, however, probably was not eroded because of the resistance to erosion afforded by large and extensive root networks of the old-growth trees growing on the fills.

Before the log drives, the mainstem channel is likely to have more closely resembled the present-day stream reach located upstream of the splash dam backwater. In that reach, the channel is only slightly entrenched (typically channel banks are less than 0.6 m high) and has a much higher width-to-depth ratio than below the-splash dam. Its planform, typically, is anastomosing with a well-defined main channel and auxiliary high-flow channels.

Under present conditions, the largest second-growth trunks in the channel in the reach upstream of the splash dam do not appear to be mobilized by frequently occurring peak flows. Interactions between the forest and the channel in that reach are more likely to resemble those before the initial logging than would the interactions downstream where the logs are more easily mobilized.

Channel morphology in the reach above the splash-dam resembles that of Little Lost Man Creek, the old-growth channel in Redwood National Park which is similar to North Fork Caspar Creek in setting and physical watershed characteristics.

Lack of well-developed soil horizons on the valley fills suggests that the fills were frequently flooded, at least as recently as several hundred years ago (i.e., the time it would take for a A horizon to form). The fact that old-growth trees on the valley fills were cut flush with the ground surface suggests that those preparing the channel for log drives believed this was necessary to avoid snagging cut logs during drives, also suggesting that high flows regularly inundated the terrace surface. Bank tops along North Fork Caspar Creek are typically 1 to 2 m above the channel thalweg, much greater than stages associated with common flows (i.e., a stage of about 0.6 m has a recurrence interval of 6 yr at gaging Station A). This suggests that valley fills have been converted from large-volume, long-term sediment sinks (floodplains) to substantial sediment sources (terraces) as a result of channel incision in response to removal of old-growth debris jams from the channel during 19th-century logging activities. Conversion of the floodplains to terraces signifies a major change of trends in valley sediment storage and a pervasive alteration in the sediment budget for the basin.

The channel has not recovered its previous morphology because jams in the channel are now less stable, stepping is less pronounced with smaller diameter trunks, and the resistance to bank erosion afforded by second-growth trees on the valley fills limits lateral migration. These factors cause the channel to remain entrenched, and to have a narrower width-to-depth ratio than the reach above the splash dam. Comparison of second-growth to old-growth channels also shows that pools are much more frequent and their average depth is greater in the old-growth channels (Keller and others 1981, Montgomery and others 1995). Therefore, it is also likely that pools are less frequent and shallower in North Fork Caspar Creek as a result of historical logging activities. It is unlikely that North Fork Caspar Creek will recover its former morphology, however, until the former relationship between the size of woody debris and flow magnitude is reestablished.

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