GARCIA RIVER LARGE WOODY DEBRIS INSTREAM MONITORING

Prepared for
Mendocino County Resource Conservation District

by

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Introduction

This investigation of large woody debris (LWD) in selected reaches of the Garcia River watershed, located in Mendocino County, California, is an element of a larger monitoring program being implemented by the Mendocino County Resource Conservation District (MCRCD). The monitoring program is being conducted in conjunction with implementation of Total Maximum Daily Load (TMDL) standards of the Clean Water Act, Section 303(d), as developed for the Garcia River. The standards and attainment strategy are described in Resolution No. 98-66 (Revised Dec. 10, 1998), California Regional Water Quality Control Board, North Coast Region (NCRWQCB), Santa Rosa.

The monitoring program is guided by a plan developed for the MCRCD and the California Department of Forestry and Fire Protection (CDF) in conjunction with watershed assessment conducted in cooperation with the NCRWQCB staff (FSW Inc., 1998). The LWD investigation has two major objectives. First, the data will serve as a baseline for evaluating status and trends of LWD conditions in the Garcia River over the next several decades. Second, current LWD conditions in the Garcia River will be evaluated through comparisons with existing data for LWD load in streams draining old growth and second growth coast redwood forests in northern California.

This brief report presents the following:

?? the LWD survey protocol
?? comprehensive (but not exhaustive) summaries of data collected at each cluster of 4 sample plots distributed in 12 tributary streams of the Garcia River
?? discussion of selected elements of the data set, focused on comparisons of LWD loads, LWD recruitment rates and processes, and the role of LWD in formation of pools
?? recommendations regarding the use of baseline data for future monitoring.

Methods

The sample reaches in which LWD data collection occurred were selected and laid out by MCRCD and its consultants. The twelve reaches are identified by number only; geographic references have been omitted to allay concerns of land owners. The LWD survey protocol was developed cooperatively by the MCRCD, CDF, representatives of industrial forest owners in Mendocino County, and O'Connor Environmental, Inc. Prior LWD protocols were reviewed in development of the protocol used for the Garcia River, including those utilized by O'Connor and Ziemer (1989), and those proposed by Taylor (1998) for the Forest Farm Fish Cooperative Field Protocols Handbook.

The LWD protocol used for the Garcia instream monitoring program is found in Appendix 1, along with a copy of the field form, including a sample of a form completed in the field. The intent and background for each of the items in the protocol is discussed below.

Minimum Size for LWD

Inventories of LWD generally select a minimum length and diameter for LWD. In this survey we used a minimum diameter of 10 cm (about 4 inches) and a minimum length of 2 m (about 6 feet). These sizes are commonly used in LWD studies, but there are various standards that may be applied for various purposes. We selected a more inclusive standard to provide a greater range of options for future monitoring work, and to facilitate comparison with other existing data sets on LWD load in streams.

Plot Data

The section of the protocol called "Sheet Headers" addresses data that apply to a sample plot as a whole. These data include the name of the monitoring site (locations are mapped and catalogued in another element of the monitoring program), the names of the surveyors, and the date of the survey. In addition, a description of flow conditions at the time of the survey is provided; if stream flow was high, it was thought that some LWD might be missed owing to reduced visibility. Also, one of the position categories described below ("Zone 1") specifies LWD that is in the water column, so interpretation of data should consider cases where flow stage may have been unusually high. Measurements of bankfull width were taken at 2 to 4 locations in each plot, typically at locations where other members of the monitoring program team placed monuments for surveyed cross-sections. Bankfull depth was also measured to allow future analysis of stability of LWD in relation to channel depth.

A general description of riparian forest stand condition is desired to investigate whether existing stand conditions correlate with existing LWD load in adjacent channels, as well as providing data on baseline riparian conditions. Two sets of observations were collected according to two different established protocols to characterize riparian stand conditions along both stream banks of each survey plot extending 170 horizontal feet from the channel margin. The first is the vegetation classification system developed for purposes of identifying wildlife habitat in California, usually referred to as the wildlife habitat relationships (WHR) system (CDF, 1988). The second is the riparian forest stand classification system developed in Washington for Watershed Analysis (Washington Forest Practices Board, 1997). Both systems classify dominant canopy species or species types, stem size or canopy height class, and canopy density class. Both systems were used in the baseline survey to allow consideration of which classification system may be most useful in future monitoring.

Inventory Data for Individual LWD Pieces

For each piece of LWD surveyed, a row of data was collected and entered into an EXCEL spreadsheet. For each piece surveyed, the plot number was recorded. The survey proceeded upstream from the downstream end of each plot. A hip chain was attached to the plot monument or to a nearby point to establish the "0" position in the plot. As the surveyors proceed upstream and encounter LWD, the location in the plot upstream from 0 was recorded, along with a unique sequential numeric identifier for each surveyed piece. The distance data establish the spatial distribution of LWD in the plot, which can be used to monitor for significant LWD movement during the monitoring period.

The "type" of LWD piece was classified as a log with no rootwad, a rootwad with no log (typically a stump), or a log with a rootwad attached. Each piece was classified according to its spatial relationship with other LWD pieces. Pieces in contact with 9 or fewer other pieces were classified as "accumulations"; pieces in contact with 10 or more pieces were classified as debris jams. Pieces not touching other pieces were classified as "single" pieces. In cases where jams were identified, a jam identification number (sequential in each plot) was added to the row of data.

The species of LWD was classified as either "redwood", "other conifer", "hardwood", or "unknown". The determination of species was based primarily on bark, and observed experience with characteristic appearance of wood grain and color. These determinations proved to be relatively easy to make in the field.

The relative age class of LWD was classified according to three categories, where age class 1 was freshly recruited wood with leaves, twigs and unweathered heartwood and bark. This age class is easily identified, and is important in estimating LWD recruitment rates from this type of survey data. Although the precise age of such wood is not known with certainty, field observations suggest that such LWD was recruited within the past 2 years, but more likely within the past year. Age class 3 is LWD that is significantly decayed. Age class 2 is described as sound wood with varying degrees of weathering, but clearly not in class 1 or 3. These data will allow general interpretation of the recruitment history and projected longevity of the existing LWD load in a given plot. There are more detailed LWD decay classification systems (see Harmon et al. 1986), however, experience with in-stream LWD data suggests that this is an adequate level of detail.

The size of LWD pieces were measured. Mid-point diameter was measured in cm using log calipers. LWD piece length was measured using either hip chain or stadia rod. For pieces that could be seen but not physically measured (e.g. LWD within a jam), diameter and/or length was estimated. In some jams, not all LWD could be observed, in which case it was not inventoried. Consequently, in some plots the amount of LWD may be underestimated. LWD volumes were computed based on length and diameter assuming LWD has the geometry of a rod. In cases where a piece of LWD could be seen, but its full length could not be reasonably estimated due to burial in the channel bed, a terrace or by a jam, a notation was made that the full piece length was not measured.

LWD position in relation to the channel was classified according to three categories (O'Connor and Ziemer 1989, Swanson et al. 1984). The length of a LWD piece was apportioned in each zone; volumes of LWD in each zone were computed accordingly. "Zone 1" was defined as LWD in the water column at the time of survey. "Zone 2" is within the bankfull channel, excluding zone 1. "Zone 3" is the area above the bankfull channel and the area on the streambank within 1 m of the bankfull channel margin. Zone 1 LWD has a potentially direct effect on rearing habitat, providing cover and velocity diversity during periods of relatively low flow. Zone 2 LWD, combined with Zone 1 LWD, affects the water column at bankfull flow when fluvial geomorphic processes are active. This LWD provides velocity shelter for fish, generates flow resistance, and creates high velocity streams of water that may scour pools. Zone 3 LWD is considered available for recruitment to the stream. It represents the stock of LWD that is already downed and is likely to be delivered to the channel in the foreseeable future.

The input mechanism for LWD was classified as "undercutting" (input due to bank erosion), "windthrow" (including fragmentation of snags and toppling of trees not caused by bank erosion or mass wasting), and "mass wasting", where a landslide or debris torrent could be identified as delivering the LWD. LWD in habitat enhancement structures was classified accordingly. No other management-induced recruitment processes were classified, despite the likelihood that much of the LWD in some plots originated from historic logging operations. For most LWD, the input mechanism cannot be determined. Interpretation of the input data must therefore be cautious. Nevertheless, observations of input mechanisms that lead to LWD accumulation in channels over the duration of the monitoring program will reveal the dominant processes.

The stability of LWD pieces was also classified. Criteria proposed for Washington streams were used (TFW 1994). The descriptive classes include "roots" where a remnant root system attaches LWD to the bank or bed, "pinned" where LWD is wedged in place against a stable structure such as a debris jam, a stable ("key") piece of LWD, a boulder, or channel constriction, "buried" where the piece is buried in the channel bed or bank, or no evidence of stability. These qualitative data facilitate assessment of stability of habitat features associated with LWD, the general level of stability of LWD in a sample plot relative to other plots, and potential future analyses of factors related to LWD stability. Stable LWD is typically presumed to be of greater habitat value than unstable LWD. On the other hand, unstable LWD can potentially be routed downstream to a stable location with some beneficial habitat values (e.g., mainstem channel debris jams).

The relationship between LWD and pools was observed in the field for each LWD piece. Pools were identified as deeper water features, typically with slower low flow velocity, that had a length or width greater than or equal to one-half the bankfull width. Residual pool depth was determined based on the difference between the maximum pool depth and the maximum depth in the downstream rifflecrest. Pools were classified according to two depth classes: greater or less than 3 ft (0.9 m). Where LWD was in, above, or adjacent to a pool, a determination was made as to whether the LWD played a role in formation of the pool, or whether the LWD was merely in proximity to a pool. This field determination is somewhat subjective, and in some cases the distinction between LWD that forms pools and LWD that is associated with pools was indeterminate; in such cases, the attribution "pool-associated" was chosen. Pieces that were classified as "pool forming" had relatively unambiguous effects on the channel such as inducing lateral scour or creating a step feature with a scour pool below and/or a dam pool above. LWD association with pools is typically regarded as beneficial in providing cover from terrestrial and aquatic predators and velocity shelter during peak flows. The formation of pools by LWD is considered the primary beneficial effect of LWD in streams with respect to fish habitat.

Results

Field surveys were conducted in the winter and spring months of 1999. The data were entered to EXCEL spreadsheets. The data were then summarized for presentation in this report. All the raw data forms and EXCEL files will be provided to MCRCD. The following is a summary of the findings.

A great deal of additional analysis could be conducted, depending upon future monitoring objectives. Sufficient analysis has been conducted to compare LWD loads to other sites in northern California, and to estimate recruitment rates. The data are generally reported as raw values and means for quantitative data, and as percentages of total piece counts for the subjective attributes.

More formal statistical analyses using ratio estimator techniques have not been conducted (see O'Connor and Ziemer 1989 and Surfleet and Ziemer 1996 for description of the techniques and references). These statistical techniques are necessary because the data may ultimately be analyzed in terms of volume per unit area, and the area of sample plots are unequal, requiring a special statistical approach. The simple approach used in this preliminary analysis is regarded as adequate for general evaluation and comparison to regional data. However, in the context of future monitoring where the trend in LWD load may be tested, it is recommended that appropriate statistical tests be employed.

Quantitative Measures of LWD Abundance

LWD has been quantified by a variety of methods, varying with the purpose of measurement and the desired level of measurement intensity. Several studies of LWD abundance express LWD quantity in terms of volume of LWD per unit area of stream channel. This is typically the form of data reported in studies published in scientific journals. Knopp (1993) reported LWD as volume per km of reach length for northern California streams in second growth redwood forests. However, the minimum LWD diameter varied with bankfull width, and the data reported did not include bankfull width for each site. In Washington Watershed Analysis, LWD quantity is expressed in terms of number of pieces per unit channel length, where the unit of length is the bankfull channel width. This set of units scales LWD counts to channel size. LWD counts are relatively easy to conduct, but they do not always account for LWD size characteristics and therefore may not adequately reflect LWD function.

For the Garcia River LWD monitoring data, we have presented four measures of LWD abundance to illustrate the differences between the data:

1. LWD counts per unit channel length (bankfull width units--#/bankfull width),

2. LWD counts per unit channel area (#/ha)
3. LWD volume per unit bankfull channel area (m^3/ha),
4. LWD volume per km of channel length (m^3/km to facilitate comparison with Knopp's data; provided only as a total for plots in each reach-Table 2).

This range of measures is intended to provide the basis to determine the most appropriate form(s) for LWD monitoring in the Garcia River.

Summary of Data-Plot Averages by Stream

The first set of summary data is presented as the average values for LWD load or abundance at the plot scale, averaged for each stream (Table 1). This set of values is provided primarily to provide perspective on the plot averages as opposed to comparable values calculated as though each cluster of four plots was a single reach. Again, the proper statistical analyses should be performed as appropriate when the parameters and formal hypotheses of interest have been determined in the context of the full monitoring program. The differences between LWD count data and LWD volume data are illustrated in Figures 1 and 2, which draw on the plot average data given in Table 1.

Comparison of Figures 1 and 2 reveals that count data (Fig. 1) and volumetric data (Fig. 2) on LWD abundance yield substantial differences. The rankings of LWD abundance for these sites would differ between these two units of measure (e.g., sites 2, 3, and 11).Additionally, in Figure 1, sites 3 and 4 have very large differences, while in Figure 2 they are nearly identical. This presumably results from size differences in the LWD present in sites 3 and 4; site 3 has abundant small diameter LWD, while site 4 has low numbers of large diameter LWD.

Table 1. Plot-scale average values by stream.

Stream #	1	2	3	4	5	6	7	8	9	10	11	12	Mean
Total # LWD Pieces	15	51	68	12	12	14	17	14	73	37	61	34	34
Mean Bankfull Width (m)	11.4	11.4	29.8	13.1	17.2	7.5	21.3	15.4	10.9	15.2	9.5	17.2	15
Mean Plot Length (m)	70	68	76	92	146	101	43	107	92	102	99	91	90
Mean Plot Area (ha)	0.078	0.076	0.225	0.119	0.251	0.075	0.080	0.166	0.100	0.156	0.094	0.158	0.13
Mean LWD Count (pieces/BW)	2.5	8.4	21.7	1.8	1.4	1.0	5.0	2.0	8.5	5.6	6.2	6.2	5.9
Zone 1 & 2	2.2	8.0	20.8	1.7	1.2	0.8	5.0	1.7	8.1	5.1	5.7	5.8	5.5
Zone 3	0.28	0.38	0.90	0.08	0.16	0.26	0.04	0.33	0.39	0.49	0.43	0.50	0.35
Total LWD (pieces/ha)	186	660	319	91	49	190	178	87	734	235	660	236	302
Zone 1 & 2	168	582	306	87	44	143	176	70	702	214	610	220	277
Zone 3	19	40	14	6	5	47	2	17	33	21	50	17	22
Total LWD (m^3/ha)	69	546	209	55	45	157	77	319	540	235	702	364	277
Zone 1	6	157	68	21	3	22	16	99	150	36	285	55	76
Zone 2	35	325	119	30	32	91	57	154	295	169	322	180	151
Zone 1 + 2	41	482	187	51	35	113	73	253	445	205	607	235	227
Zone 3	29	64	23	4	10	45	4	66	96	31	95	129	50
LWD Diameter Median (m)	0.28	0.31	0.26	0.59	0.32	0.28	0.16	0.46	0.33	0.32	0.30	0.25	0.32
Average (m)	0.30	0.37	0.32	0.60	0.40	0.33	0.22	0.67	0.39	0.41	0.43	0.38	0.40

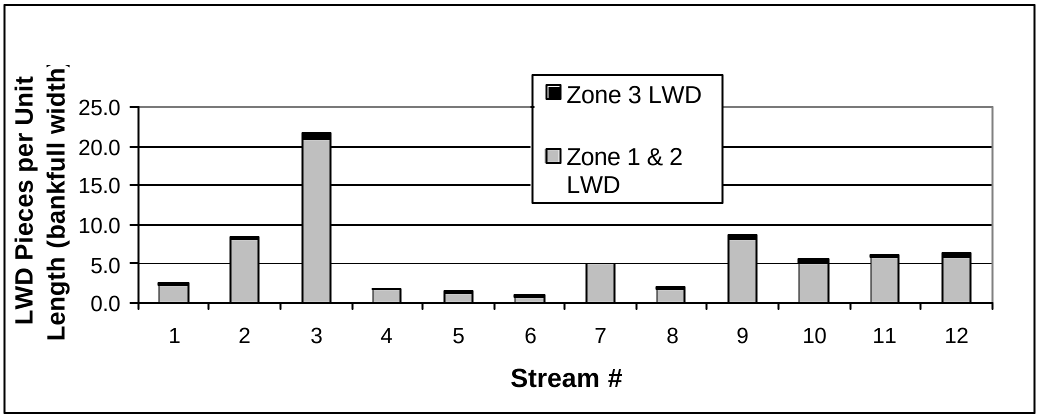


Figure 1. Average LWD abundance in plots for each stream expressed as number of LWD pieces per unit channel length. Channel length is expressed in units of bankfull width, a scaling procedure that makes results from different size streams more comparable.

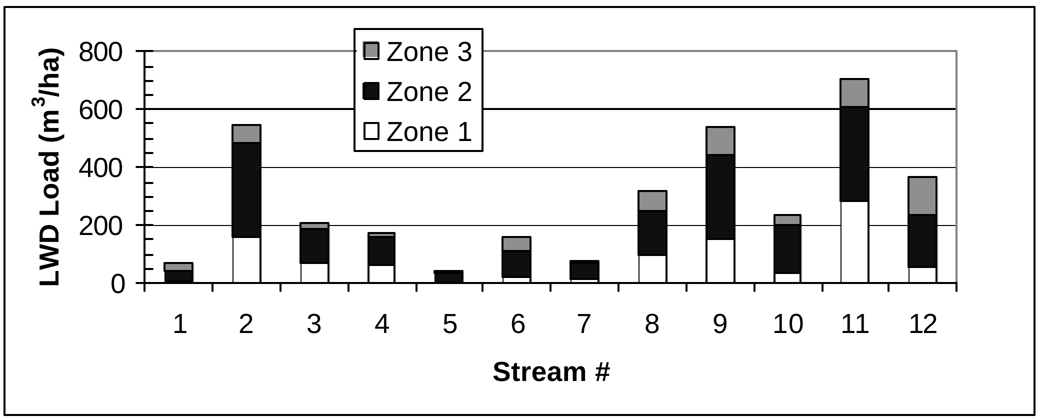


Figure 2. Average LWD abundance in plots for each stream expressed as volume of LWD pieces per unit channel area by position in the channel (zone). This measurement system is favored by scientific researchers.

Summary of Data-Sum of Plot Data by Stream

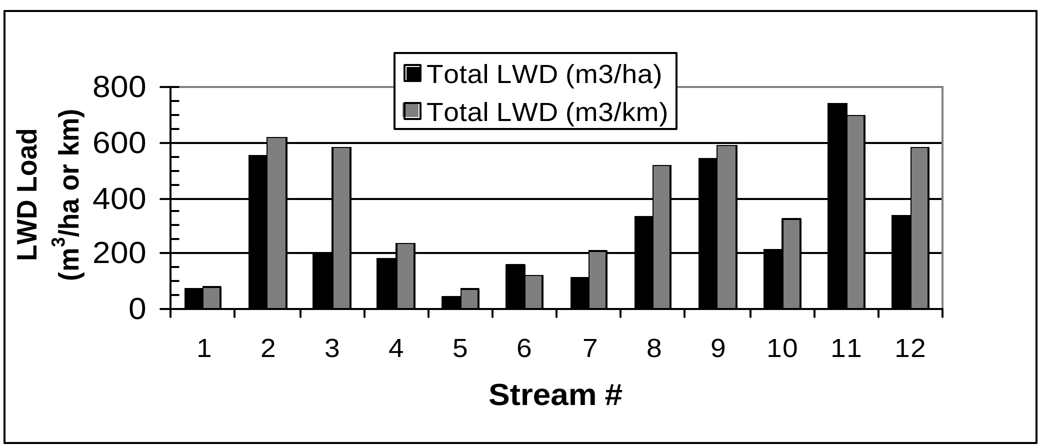
LWD conditions in different streams can also be considered in terms of a reach total, where the data from the four plots are aggregated as a single reach. This is probably preferable in evaluating the overall status of a monitoring site. The data as presented here provide a good basis for comparing the LWD status at the monitoring sites. It is not, however, a statistically proper treatment of the data that yields an expression of variability such as confidence intervals for the estimated total or the variance, which is required for formal hypothesis testing. Nevertheless, these values do not substantially misrepresent average total LWD conditions. The results for reach-total values for each of the 12 streams surveyed are presented in Table 2.

Table 2. LWD abundance expressed as a total of the four plots within each stream.

Stream #	1	2	3	4	5	6	7	8	9	10	11	12	Mean
Total # LWD Pieces	58	204	270	46	47	57	66	55	293	148	245	134	135
Length (m)	278	273	304	366	583	402	173	426	368	408	396	365	362
Length (bankfull width units)	24	24	10	28	34	54	8	28	34	27	42	21	28
Area (ha)	0.31	0.31	0.90	0.48	1.00	0.30	0.32	0.66	0.40	0.62	0.37	0.63	0.53
Total LWD (pieces/BW)	2.4	8.5	26.5	1.6	1.4	1.1	8.1	2.0	8.7	5.5	5.9	6.3	6.5
Total LWD (pieces/ha)	185	668	301	96	47	191	206	83	735	237	655	212	301
Total LWD Load (m^3/ha)	69	553	197	179	43	159	112	333	543	213	741	335	279
Total LWD (m^3/km)	78	618	581	233	74	118	208	517	588	325	699	581	385
Median LWD Diameter (m)	0.27	0.30	0.25	0.31	0.32	0.24	0.22	0.39	0.34	0.31	0.31	0.22	0.29
Mean LWD Diameter (m)	0.30	0.37	0.39	0.44	0.40	0.33	0.32	0.73	0.39	0.40	0.44	0.38	0.41

The metrics of LWD abundance with the most comparative value in northern California coastal redwood forests are volume per unit area of stream and volume per unit length of stream. The former metric has been used to quantify LWD volumes in old growth redwood forest. The latter has been used by Knopp (1993) to quantify LWD volumes in streams in second growth redwood forest. Figure 3 graphically compares these two metrics for the reach total data (Table 2) for the Garcia River sites. With notable exceptions (sites 3 and 12), these two metrics yield similar rankings of the sites. This is in part a consequence of the relatively small variation in stream width among Garcia River sites.

Figure 3. LWD abundance as volume per units area and per unit length.



Summary of Data-LWD Attributes

A wide range of LWD "attributes" were observed for each piece of surveyed LWD as described in the Methods Section. These data are summarized as a proportion of the total number of pieces counted in each monitoring reach comprised of four plots (Table 3).

Table 3. Summary of LWD attributes expressed as a proportion of the total number of LWD pieces surveyed in all four plots comprising each survey reach.

Stream #	1	2	3	4	5	6	7	8	9	10	11	12	Mean
LWD Type													
Log (no rootwad)	0.71	0.90	0.83	0.74	0.89	0.68	0.71	0.51	0.87	0.68	0.83	0.59	0.75
Rootwad (no log)	0.02	0.02	0.01	0.20	0.04	0.00	0.02	0.33	0.02	0.04	0.04	0.00	0.06
Log with rootwad	0.28	0.08	0.16	0.07	0.06	0.32	0.27	0.16	0.11	0.28	0.13	0.41	0.19
Enhancement	0.00	0.00	0.00	0.02	0.02	0.00	0.00	0.22	0.00	0.00	0.00	0.00	0.02
Jam Status													
Single Piece	0.57	0.85	0.10	0.57	0.60	0.51	0.48	0.62	0.36	0.22	0.24	0.37	0.46
Accumulation	0.43	0.06	0.33	0.13	0.40	0.49	0.52	0.38	0.37	0.45	0.47	0.39	0.37
Jam (> 10 pieces)	0.00	0.09	0.57	0.30	0.00	0.00	0.00	0.00	0.27	0.33	0.29	0.25	0.18
Species Class													
Redwood	0.24	0.93	0.71	0.63	0.38	0.18	0.53	0.89	0.69	0.82	0.74	0.56	0.61
Other conifer	0.22	0.01	0.04	0.35	0.36	0.46	0.05	0.04	0.13	0.09	0.09	0.01	0.15
Hardwood	0.48	0.05	0.24	0.02	0.23	0.37	0.42	0.07	0.17	0.09	0.13	0.43	0.23
Unknown	0.05	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.01	0.00	0.04	0.00	0.01
Relative Age Class													
Fresh	0.07	0.01	0.03	0.39	0.00	0.12	0.08	0.07	0.04	0.01	0.04	0.01	0.07
Sound, weathered	0.69	0.63	0.89	0.54	0.64	0.46	0.44	0.87	0.75	0.90	0.68	0.84	0.69
Significant decay	0.24	0.36	0.07	0.09	0.36	0.42	0.48	0.05	0.21	0.09	0.29	0.15	0.23
Input Mechanism													
Undercutting	0.26	0.02	0.04	0.17	0.00	0.00	0.08	0.16	0.03	0.05	0.03	0.23	0.09
Windthrow	0.00	0.01	0.00	0.35	0.04	0.02	0.00	0.00	0.01	0.00	0.00	0.00	0.04
Mass Wasting	0.00	0.00	0.00	0.00	0.11	0.18	0.00	0.05	0.00	0.15	0.00	0.01	0.04
Management	0.00	0.00	0.02	0.02	0.02	0.00	0.00	0.22	0.05	0.01	0.09	0.00	0.04
Unknown	0.74	0.97	0.94	0.46	0.83	0.81	0.92	0.56	0.90	0.80	0.87	0.75	0.80
Stability													
Root system in bank	0.21	0.04	0.06	0.07	0.04	0.23	0.17	0.29	0.05	0.06	0.03	0.14	0.12
Pinned by other LWD/boulders	0.36	0.31	0.80	0.30	0.38	0.37	0.27	0.35	0.56	0.54	0.24	0.54	0.42
Buried in channel or terrace	0.33	0.55	0.08	0.46	0.43	0.25	0.39	0.29	0.29	0.30	0.21	0.26	0.32
No evidence of stability	0.10	0.09	0.06	0.17	0.15	0.16	0.17	0.07	0.10	0.09	0.07	0.03	0.11
Legacy LWD													
Diameter >= 0.5 m	0.10	0.19	0.11	0.30	0.30	0.19	0.15	0.36	0.22	0.25	0.29	0.22	0.22
Diameter >= 1.0 m	0.02	0.05	0.03	0.15	0.04	0.02	0.03	0.25	0.02	0.06	0.08	0.05	0.07
Pool Association													
Assoc. with Pool < 3 ft deep	0.05	0.00	0.41	0.17	0.04	0.04	0.11	0.00	0.11	0.15	0.19	0.01	0.11
Assoc. with Pool > 3 ft deep	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.15	0.01	0.02	0.04	0.00	0.02
Forming Pool < 3 ft deep	0.03	0.04	0.06	0.11	0.02	0.09	0.18	0.00	0.26	0.14	0.21	0.00	0.09
Forming Pool > 3 ft deep	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.24	0.04	0.01	0.07	0.00	0.03
No Pool Association	0.91	0.96	0.52	0.63	0.94	0.88	0.71	0.62	0.58	0.46	0.48	0.99	0.72

A few general statements regarding LWD attributes in the Garcia River Watershed can be made based on Table 3. About three-fourths of LWD pieces were logs with no attached rootwads. Almost half of the LWD pieces were solitary pieces. Over half were located in LWD accumulations or jams, the latter accounting for nearly one-fifth of pieces. LWD was about 60% redwood and about 25% hardwood. Seven percent of pieces were classified as "fresh" recruits to the channel, while about one-fourth were significantly decayed. Nearly 70% were weathered but sound LWD pieces. As in most surveys of this type, the input mechanism for LWD could not be determined for the vast majority of pieces, in this case 80%. However, 9% of pieces were recruited by undercutting (bank erosion), and 4% were input by windthrow, mass wasting (landslides), and management (habitat enhancement), respectively. Regarding LWD stability, only one-tenth of LWD pieces appeared to be easily mobilized by stream flow. Nearly one-third of the pieces were partially buried in the channel or in terraces, and over 40% were pinned in place by other LWD or boulders. Another tenth of the pieces were stabilized by remnant root systems attached to bed or banks. The prominence of "legacy" LWD—sizes found in the previously-existing old growth stands—was modest. Although 22% of the pieces had diameters greater than 0.5 m, only 7% had diameters greater than 1 m. About one-fourth of LWD pieces were associated with pools, and about half of these appeared to be the primary cause of pool formation. About three-fourths of LWD was not associated with pools. Conditions in any given stream regarding the attributes discussed above are best ascertained by comparing the value for a given stream of interest against the average value for the 12 sites.

LWD Diameter in Relation to Pools

LWD is thought to be important to fish habitat largely because of its role in creating pools and by providing cover in pools. One of the goals of the LWD survey was to investigate the association between LWD size and pools, particularly formation of pools. Table 5 shows the mean diameter of LWD in each monitoring reach associated with pools or forming pools; pools were classified as greater than or less than 3 ft (0.9 m) residual depth.

Table 5. Mean diameter (m)of LWD associated with or forming pools.

Stream#	1	2	3	4	5	6	7	8	9	10	11	12	Mean
Assoc. with Pool < 3 ft deep	0.93	0	0.26	0.63	0.17	0.15	0.31	0	0.38	0.41	0.26	0.21	0.37
Assoc. with Pool > 3 ft deep	0	0	0	0.27	0	0	0	0.3	0.82	0.22	0.27	0	0.38
Forming Pool < 3 ft deep	0.33	0.43	1.11	0.69	0.30	0.61	0.49	0	0.52	0.96	0.51	0	0.60
Forming Pool > 3 ft deep	0	0	0.38	1.03	0	0	0	1.77	0.51	1.3	0.81	0	0.97

The data in Table 5 suggest that LWD associated with pools are of typical diameters (the system-wide average diameter is about 0.4 m). In contrast, LWD that was judged to be causing pool formation had greater diameters by a substantial margin. Further, the data suggest that deeper pools are formed by larger-diameter LWD pieces. Considering the range of data for diameters of LWD forming pools, stream averages were as low as 0.3 to 0.4 m, indicating that these sizes can form pools, but appear less likely to do so.

LWD Recruitment Rates

In general, few data exist that quantify LWD recruitment rates to stream channels. Such data are critical to projecting long-term trends in LWD-related fish habitat in managed forest watersheds. LWD that was observed to have been very recently recruited to survey plots was classified as “fresh”. The volume of LWD in this decay class provides an estimate of LWD recruitment rates. Since the actual timing of delivery of “fresh” LWD to channels could not be determined, we have assumed that recruitment of the observed volume occurred over two years. The criteria used to identify “fresh” LWD probably could include LWD that was recruited as much as three years prior. Observations suggest, however, that the majority of LWD classified as “fresh” was recruited in the preceding winter (one year). Hence the estimated rates are probably underestimates.

Table 6 shows the average diameter and total volume of “fresh” LWD observed at the monitoring sites. It also shows the proportions “fresh” LWD by species class and input mechanism of total LWD at each monitoring site. The diameter of “fresh” LWD is substantially lower than the average for all LWD at all sites (about 0.4 m), indicating that smaller diameter LWD is currently being recruited to channels more rapidly than typically occurred in past decades. It should be recognized, however, that much of the LWD in these channels probably entered as logging debris, and the comparison of diameters of in-channel LWD with currently recruited LWD may not indicate much about current recruitment processes compared to “natural” recruitment.

“Fresh” LWD is predominantly non-redwood conifer and hardwood, with some redwood. This is opposite of the existing LWD load, which is predominantly redwood. Most “fresh” LWD was recruited by windthrow, with lesser parts from undercutting and mass wasting. This is in contrast to the system wide trend where undercutting is about twice the total for any other mechanism. Given the relatively small sample size of “fresh” pieces and the inherent high variability of LWD recruitment processes, these data should be interpreted with caution.

Table 6. Size, volume, species class and input mechanism for “fresh” LWD.

Stream#	1	2	3	4	5	6	7	8	9	10	11	12	Mean
Average Diameter (m)	0.13	0.16	0.24	0.16	0	0.28	0.26	0.22	0.41	0.20	0.24	0.26	0.23
Total Volume (m^3)	0.26	0.13	5.55	1.12	0	4.57	2.26	1.44	18.6	0.45	2.04	0.61	3.08
Fresh LWD Species (proportion of total LWD)													
Redwood	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.02	0.01	0.01	0.01	0.01
Other conifer	0.00	0.00	0.01	0.35	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.03
Hardwood	0.07	0.01	0.01	0.02	0.00	0.12	0.08	0.04	0.01	0.01	0.03	0.00	0.03
Unknown	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fresh LWD Input Mechanism (proportion of total LWD)													
Undercutting	0.05	0.01	0.01	0.00	0.00	0.02	0.02	0.04	0.01	0.00	0.02	0.01	0.01
Windthrow	0.00	0.00	0.00	0.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03
Mass Wasting	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.04	0.00	0.01	0.00	0.00	0.01
Management	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00
Unknown	0.02	0.00	0.01	0.02	0.00	0.04	0.06	0.00	0.01	0.01	0.01	0.00	0.01

LWD recruitment rate estimates are presented in Table 7 in relation to the dominant riparian stand class for each of the 12 monitoring sites. The recruitment rate varied over two orders of magnitude between sites (0 to 23 m^3/ha/yr), with an average value of about 3.7 m^3/ha/yr. This rate can be placed in context by computing the ratio of the LWD load to the estimated recruitment rate, which yields a quantity with units of years. This ratio can be interpreted as the replacement rate for in-channel LWD based on the present estimate of recruitment rates. If the average replacement rate for the 12 monitoring sites is calculated, 410 years would be required to deliver the existing LWD load. This estimate is skewed by site 2, which has a low estimate of recruitment and a high existing load. When the mean LWD load of 290 m^3/ha is compared to the mean recruitment rate (about 3.7 m^3/ha/yr), the average replacement rate is about 80 years (excluding site #5). Given the high variability of recruitment processes and LWD loads, the latter figure is probably more representative of the relationship between recruitment rates and existing LWD loads. It is not known how these figures would compare to old growth redwood forest ecosystems.

Table 7. Estimated LWD recruitment rates, riparian stand classes, and replacement rate.

Stream#	1	2	3	4	5	6	7	8	9	10	11	12	
Riparian Stand Class													
WHR	COW 4P	RDW 5D	RDW 4M	RDW 6M	DFR 3D	MHW 3M	MRI4 S	RDW 3S	RDW 4S	MCH 3P	RDW 3P	RDW 4P	
DNR	MLS	CMD	MMD	CVS	MSD	HMD	MSS	MMS	MMS	MMS	MSS	MMS	
LWD Recruitment Rate[1] (m^3/ha/yr)													**Mean**
	0.42	0.21	3.09	1.18	0.00	7.64	3.53	1.09	23.3	0.36	2.73	0.48	3.67
LWD Load (m^3/ha)													
	69	553	197	179	43	159	112	333	543	213	741	335	290
Replacement Rate[2] (yr)													79[3]
	164	2597	64	152	n.a.	21	32	306	23	590	272	694	410[4]

Notes

1. Assumes 2-yr recruitment interval for "fresh" LWD.
2. Replacement rate is the LWD load divided by the recruitment rate.
3. Calculated as the replacement rate for mean LWD and the mean recruitment rate for all sites, excluding site #5 (divisor = 0).
4. The mean replacement rate calculated for each site; this rate is skewed by site #2.

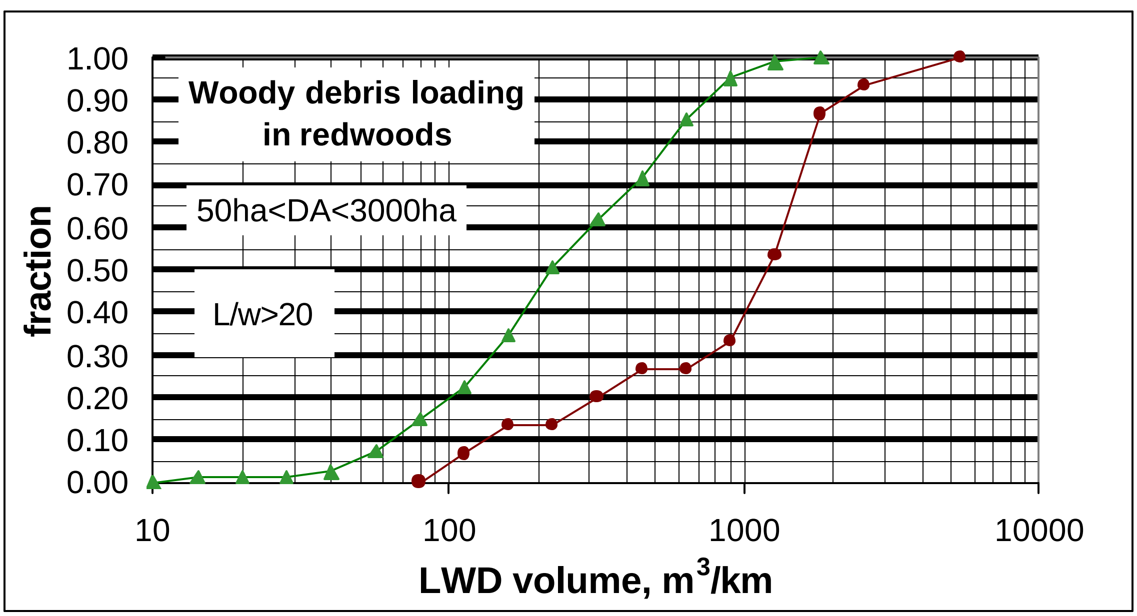
The relationship between riparian stand classes and recruitment rates cannot be definitively characterized because of the qualitative nature of the stand data. However, when riparian stand classes determined according to Washington DNR criteria are considered in terms of stand density, sparse stands (n=8) had an average recruitment rate of about 4.1 m^3/ha/yr, compared to about 2.7 m^3/ha/yr for dense stands (n=4). If diameter classes are considered, the recruitment rates were 2.1, 5.2, 0.4 and 1.2 for stands with average diameters in the small, medium, large and very large classes, respectively. In other words, it appears that less dense stands with smaller diameter trees may generate higher recruitment rates compared to denser stands or stands with larger diameter trees. No statistical tests were used because of the uneven sample sizes and subjective measures of riparian stand characteristics, so this result should not be over-generalized. However, the data do not suggest that dense stands or stands with larger trees are delivering more LWD to streams in the short-term. Moreover, the two streams with riparian stands characterized as large or very large diameter (sites #1 and #4) had below average LWD loads. Again, this may reflect the historical impacts of timber harvest, where logging practices directly or indirectly delivered significant volumes of LWD to streams.

Discussion

LWD Abundance

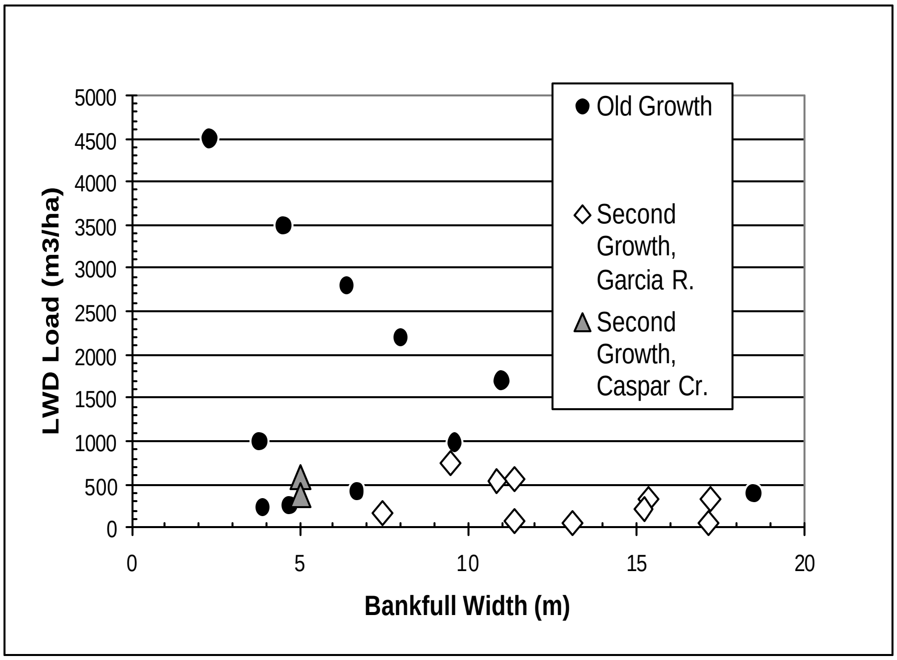
LWD abundance in the Garcia River can be put in perspective through comparison to comparable regional LWD loads in streams adjacent second-growth redwood stands, as well as in streams adjacent to old growth stands. Figure 4 shows the cumulative frequency distribution of LWD load per km of stream based on data available for northern California streams, primarily in redwood forest stands. The data plot shows that the median for second growth is about 220 m^3/km, compared to about 1200 m^3/km for old growth. For the Garcia River sites, the mean was 385 m^3/km, with values ranging from 74 to 699 m^3/km. The data for the Garcia sites (Table 2) can be compared to Figure 4 to rank individual sites with respect to LWD abundance. One interpretation of these data is that the Garcia sites have relatively abundant LWD for second-growth systems, but the load falls well below that found in existing old growth systems.

Figure 4. Cumulative frequency distributions for old growth (circles) and second growth redwood forests (triangles) in northern California. The data for old growth include sites in Redwood National Park (Harmon et al. 1986, n=11), and sites identified in Pacific Lumber Company's SYP-HCP documents (n=4). The data for second growth are from Knopp (1993), Caspar Creek, the Garcia River, and the PALCO SYP-HCP, (a total of 80 sites). The Knopp data, Caspar Creek data, and the data from Harmon et al. was provided by Dr. Tom Lisle, US Forest Service Redwood Sciences Lab, Arcata, California.



Comparison of LWD abundance among streams has in many cases found that stream width (typically bankfull width) has a significant influence (Bilby and Ward, 1989). Wider channels typically have relatively low LWD loads compared to narrower channels. This is in part caused by the lower likelihood of LWD movement in narrow streams, and the higher likelihood of downstream transport in larger streams. The plot in Figure 5 examines LWD abundance as a function of channel width for several northern California sites.

Figure 5. LWD load as a function of bankfull channel width for northern California redwood forests.



The plot of data in Figure 5 suggests that LWD loads tend to be larger in smaller old growth channels. Nevertheless, about half of the old growth sites less than 10 m wide have similar LWD load to second growth streams of similar size. In channels about 10 m wide or greater, the difference between old growth and second growth diminishes. Considering the limited data set, particularly for old growth streams, the influence of channel width in relation to LWD abundance and stand type cannot be unambiguously determined. Channel width should be considered when comparing LWD loads among streams.

LWD Position

The position of LWD in channels of the Garcia River watershed can be compared with Caspar Creek, a system which has riparian forests about 80-100 years old. Garcia LWD found in zone 1 and zone 2 combined is equivalent to the "effective" zone of Caspar Creek and zone 3 LWD is equivalent to "potential" zone LWD ,as reported in Ziemer and O'Connor (1989). In the Garcia, about 80% of LWD volume is in the effective zone, compared with 33% in North Fork Caspar Creek (prior to harvest in the early 1990's). The potential zone in Garcia River streams contains only about 20% of the LWD, while in North Fork Caspar Creek, the potential zone contained 67% of the volume. With respect to volume of LWD associated with and forming pools, 20% of total volume in North Fork Caspar Creek performed this function compared to about 39% of LWD volume in the Garcia. Another perspective is that about 60% of effective zone LWD in Caspar Creek was associated with pools, compared with about 45% in the Garcia.

The data above suggest that a much higher proportion of LWD in Caspar Creek is downed above or adjacent to the channel, but not in the channel. This is in part due to modest channel width at Caspar Creek (about 5 m), which contributed to a high frequency of channel-spanning downed logs. This suggests that Caspar Creek has a relatively abundant future supply of LWD for channel and habitat function. In contrast, Garcia River streams appear to have relatively little LWD prepared for future entry. Most of the LWD near the stream is already functioning in the channel, including a higher proportion functioning in association with pools. These differences are probably largely due to channel width, which is greater in Garcia River monitoring sites than in Caspar Creek (Figure 5).

LWD Recruitment Rates

In second-growth conifer forests in the Pacific Northwest, field studies have shown that about 30 years of growth is required to generate significant recruitment of hardwood LWD to streams, and about 60 years is needed for conifer LWD recruitment (Andrus et al. 1989, Grette 1985). Consequently, where riparian stands have been clearcut, it is likely that local recruitment of LWD will be severely reduced for several decades.

Recruitment rates estimated for Garcia River streams can be compared to rates estimated for North Fork Caspar Creek (O'Connor and Ziemer 1989). At North Fork Caspar Creek, the recruitment rate estimate was based on the assumption that LWD accumulated over 60 to 90 years and started at nearly zero. This yielded a recruitment rate estimate of about 5.3 m^3/ha/yr. For the Garcia River sites, the estimated recruitment rate based on observations of recently recruited LWD was about 3.7 m^3/ha/yr assuming a two-year recruitment period. The latter rate could be as high as 7.3 m^3/ha/yr if it were assumed that the fresh LWD accumulated over one year. These short-term estimates bracket the long-term estimate for North Fork Caspar Creek, suggesting that the Garcia River recruitment rate estimate is reasonable, and comparable to that for 60 to 90 year old second growth stands of Douglas fir and redwood. The simple interpretation of these data is that LWD recruitment rates in the Garcia River are not extraordinarily small or large for second growth redwood forest.

Recommendations

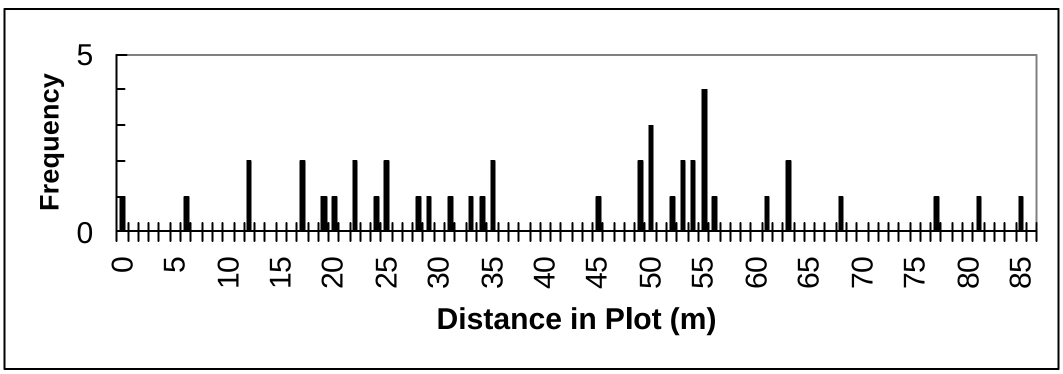
The data on LWD in the Garcia River can serve as a comprehensive baseline condition for long-term monitoring. The brief analysis of the data presented above suggests some key considerations for diagnosis of LWD conditions in the Garcia River watershed. Further analysis of the data may be warranted.

Future monitoring (LWD surveys) should be in part guided by a set of hypotheses that can be statistically tested. For example, since the TMDL goal is an improving trend of LWD load in streams, future survey data should be compared against the data collected in 1999 to test whether LWD has become more abundant over time at the monitoring sites. The monitoring project team should select a metric (e.g. volume per unit area, volume per unit length, number of pieces per unit length, etc.) to test for future increase or decrease of LWD (trend monitoring). To secure the opportunity for long-term monitoring, it is critical that the monitoring plots be securely monumented and otherwise documented.

In addition to monitoring LWD abundance, it is recommended that LWD surveys be conducted periodically to monitor LWD recruitment rates in relation to riparian stand conditions and climatic events such as unusual wind storms or discharge events that may accelerate LWD recruitment. For the Garcia River, LWD should be resurveyed at not less than 5 year intervals to establish recruitment trends and dynamics of in-stream LWD. In order to make better use of these data, however, a more quantitative means of describing riparian stands should be considered. Timber cruise techniques, modified for riparian forest stands, would likely serve this purpose. Additional details regarding "fresh" LWD recruits may be worth observing, particularly the distance from the channel to the stem that delivered LWD and the hillslope angle between the stem and the channel.

One suggestion for using the survey data to monitor for changes in LWD load or distribution is the plot shown in Figure 6. This plot is a histogram of the count of LWD pieces by longitudinal location along the monitoring plot. This type of plot is a graphical display of the spatial distribution of LWD in the plot. These data could be further manipulated to identify pieces of specified size or attributes, such as large diameter pool-forming pieces, or pieces in accumulations or jams, or freshly recruited LWD. A comparison of such a plot would allow the monitoring team to quickly assess the degree of change in LWD in a plot over time.

Figure 6. Example data plot- histogram of LWD spatial distribution at a selected monitoring site (site #12, plot #1)



Acknowledgements

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References Cited

Bilby, R.E., and Ward, J.W. (1989) Changes in characteristics and function of woody debris with increasing size of streams in western Washington. Transactions of the American Fisheries Society, Vol. 118, pp. 368-378.

California Department of Forestry and Fire Protection (1988) A guide to wildlife habitats of California.

Harmon, M.E., Franklin, J.F., Swanson, F.J. et al. (1986) Ecology of coarse woody debris in temperate ecosystems. Advances in Ecological Research, Vol. 15, pp. 133-302.

Lienkaemper, G.W. and Swanson, F.J. (1987). Dynamics of large woody debris in streams in old-growth Douglas-fir forests. Canadian Journal of Forest Resources, Vol. 17, pp. 150-156.

Knopp, C (1993) Testing indices of cold water fish habitat. Final report for North Coast Regional Water Quality Control Board in cooperation with the California Department of Forestry. August 15, 1993. 56 p.

O'Connor, M.D. and Ziemer, R.R. (1989) Coarse woody debris ecology in a second-growth *Sequoia sempervirens* forest stream. Proceedings of the California Riparian Systems Conference, September 22-24, 1988, Davis, CA. USDA Forest Service Gen. Tech. Report, PSW-110, 1989, pp.165-171.

Surfleet, C. and Ziemer, R. (1996) Effects of forest harvesting on large organic debris in coastal streams. Proceedings of the conference on coast redwood forest ecology and management. Humboldt State University, Arcata, CA pp. 134-136.

Swanson, F.J., Bryant, M.D., Lienkaemper, G.W., and Sedell, J.R. (1984) Organic debris in small streams, Prince of Wales Island, southeast Alaska. U.S.D.A. Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon. General Technical Report PNW-166, 12 p.

Taylor, R.N. (1998) A three-tiered large woody debris (LWD) and riparian zone inventory protocol. Draft, Oct. 20, 1998. Prepared for FFFC Field Protocols Handbook. 18 pp.

TFW (1994) Ambient monitoring program manual. Prepared for Timber-Fish-Wildlife by Northwest Indian Fisheries Commission, August 1994.

Washington Forest Practices Board (1997) Standard Methodology for Conducting Watershed Analysis, Version 4.0, November, 1997.

APPENDIX 1. LWD INVENTORY PROTOCOL

Sheet Headers

Stream & Code ID: Stream name; code to be added later
Personnel: Last names of field observers, indicate who measures and who records
Date: Date of survey
Stream flow conditions: Describe flow stage and water clarity

Riparian Stand Condition, 170 ft horizontal distance from each bank for each plot, classified according to Wash. DNR Riparian Condition Module and California WHR criteria

DNR Criteria: Stand Class: Conifer >70%=C; Hardwood >70%=H; otherwise Mixed=M
Diameter Class: <30cm=Small; >30,<50cm=Medium; >50,<100cm=Large; >100cm=Very Large
Stand Density: Canopy Cover > 70%=Dense; <70%=Sparse
Data entry example: Conifer Small Dense = CSD

WHR Criteria: According to WHR guidance

Row & Column Data on Data Sheets (see following for example)

Plot # (1-4 for each site)

Piece # (identifier, sequential for each plot beginning with 1)

Distance (upstream distance of LWD piece from plot end in meters-convert to feet after data entry

LWD Type:
L: log (no rootwad)
R: rootwad (no log)
B: log with rootwad
[Note: the two following modifiers for LWD type were originally intended for inclusion with the "type" class. Subsequent field test indicated that they were more effectively used in conjunction with the "Input Mechanism" Modifiers: E-Enhancement (intentional placement for habitat) M-Management (incidental, unintended management action; e.g. eroded Humboldt crossing)]

Jam Status:
0: Single piece
1: Accumulation (< 10 pieces touching)
2: Jam (10 or more pieces touching)

Jam Identification # (unique sequence number for jams in plot)

Species Class
R: Redwood
C: Other conifer
H: Hardwood
U: Unknown

Relative Age Class
1: "Fresh" wood, recently recruited (within past 2 years); leaves, twigs, fresh breakage
2: Sound wood not clearly in classes 1, 3 or 4
3: Significantly decayed
4: "Legacy" wood; large diameter redwood or conifer from old growth stands not currently present in riparian zone ***[Note: this characteristic was found to be difficult to recognize consistently in the field, and ultimately was not used. The concept of "legacy" wood was evaluated by determining the proportion of sampled pieces with mid-point diameters ? 0.5 m and ? 1.0 m, respectively.]***

Midpoint Diameter
(diameter of piece in cm; convert to tenths of feet later; minimum diameter = 0.3 ft (10 cm))

Length (distributed within various zones describing position in channel)
Zone 1: "Active channel"=wetted channel @ time of survey
Zone 2: Bankfull channel (not including wetted portion)
Zone 3: Potential recruitment zone (spanning above channel, or on terrace within 1 m (3 ft) of channel bank)

Was Full Length of LWD Piece Measured?
Yes or No; accounts for LWD pieces that are partially buried.

Input Mechanism (recorded for pieces ONLY when mechanism can be determined)
U: Undercutting (aka bank erosion)
W: Windthrow (includes fragmentation of snags and whole, uprooted trees)
M: Mass Wasting

Stability (as proposed by TFW Ambient Monitoring)
R: Root system present
P: Pinned (typically a jam or stable accumulation)
B: Buried (in channel or terrace)
0: No evidence of stability

Pool Associated (only classification regarding piece function)
Yes or No, LWD function ("Associated" when LWD piece is in or adjacent to pool, but is not judged to be responsible for pool formation; "Forming" when LWD piece is judged to play a significant role in pool formation/scour), and depth class of associated pool. Data entered as an alpha-numeric code, e.g. A1, A2, F1, F2.
0: Not associated with a pool
A1: Associated with a pool with residual depth < 3 ft
A2: Associated with a pool with residual depth > 3 ft
F1: Forming a pool with residual depth < 3 ft
F2: Forming a pool with residual depth > 3 ft

OTHER CONSIDERATIONS (items not presently included in inventory, but that are relevant to assessing LWD function or potential function, and may be desirable to include for some purposes)

Channel slope
Channel morphology (e.g. Montgomery & Buffington and/or Rosgen)
Dominant channel substrate (d50 of the bed, d84 of the bed; or dominant/subdominant substrate by size classes as done by Fish & Game)
Pool count
Bar types and abundance

APPENDIX 2. SUMMARY DATA FOR SURVEY SITES