The Influence of Timber Harvest on the Structure and Composition of Riparian Vegetation in the Coastal Redwood Region: A Report for Save-the-Redwoods League

William H. Russell

Recommended Citation:
Russell, William H. 2002. The influence of timber harvest on the structure and composition of riparian vegetation in the coastal redwood region: A report to Save-the-Redwoods League. University of California, Berkeley.

This report was produced with funding from Save-the-Redwoods League. The views and findings contained within are those of the researchers and not necessarily those of Save-the-Redwoods League.

THE INFLUENCE OF TIMBER HARVEST ON THE STRUCTURE AND COMPOSITION OF RIPARIAN VEGETATION IN THE COASTAL REDWOOD REGION

A Report For the Save-the-Redwoods League

William H. Russell, PhD
USGS/BRD
Western Ecological Research Center
Golden Gate Field Station
Fort Cronkhite, Bldg. 1063
Sausalito, CA 94965
(415) 331-0847, wrussell@usgs.org

ACKNOWLEGEMENTS

This project was made possible by a grant from the Save-the-Redwoods League. Christopher Cisper, Sayaka Eda, and Asha Setty provided invaluable assistance in the field. Rene Pasquanele of the California State Parks and Mia Monroe of the National Park Service provided logistical support. Special thanks goes to Dr. Joe McBride for his help in the initial conceptualization and planning of this project, and to Ruskin Hartley for his comments on this manuscript.

Presented to the Save-the-Redwood League
October 2002

ABSTRACT

The effects of various timber management histories on the dynamics of riparian forests was analyzed to determine if the length of time since timber harvest and the width of the riparian buffer zone had a measurable effect on variables such as canopy cover, solar radiation, the ratio of hardwood to conifer dominance, and the occurrence of individual species.

Ten sites were sampled in the coastal redwood forest type within a range of post-harvest age groups and riparian buffer strip widths. Data was collected using randomly selected sample plots adjacent to perennial coastal steams. Two data analysis methods were used to examine the relationship between the sample variables and the experimental parameters "years since harvest", and "width of harvest". These methods included a correlation Fisher's r to z test, and comparison between sites with an unpaired two-tailed t-test. Comparisons between sites indicate that a variety of stand structural and compositional characteristics are significantly affected both directly and indirectly by timber harvest. Variables found to be associated with these experimental parameters included canopy cover, the ratio of hardwood to conifer dominance, stand density, quantity of large woody debris, and the frequency and dominance of a variety of species.

Canopy cover was negatively correlated to "years since harvest." The highest level of canopy cover was found on the youngest sites and the lowest level on the old-growth sites. The hardwood to conifer dominance ratio and the basal area of *Alnus rubra* (red alder) were correlated negatively to both "years since harvest" and "buffer width" indicating that timber harvesting favors hardwood species. Understory species such as *Oxalis oregana* (redwood sorrel), *Anthyrium filix-femina* (lady fern), *Vaccinium parviflorum* (billberry) were found preferentially in older forests and sites with wider buffer zones, while species such as *Hedera helix* (English ivy), *Pampas cortedaria* (pampas grass), and *Myosotis latifolia* (forget me not) were found preferentially in younger forests and areas with smaller buffer zones.

The results of this study indicate that the edge effects associated with riparian forests are similar to those experienced by their upland counterparts. Community composition and structure are directly and indirectly affected by timber harvest history.

BACKGROUND

In recent years the direct and indirect effects of timber harvesting on riparian systems within coast redwood forests have become increasingly important management issues. A perceived correlation between logging activities and declining fish population has led to a debate on the possibility of increasing the current width of stream side protection zones as described in section 6 of the California Forest Practice Rules (California Department of Forestry and Fire Protection 1999). The indirect impacts of logging on the structure and composition of redwood and similar forest types has been studied in detail (Russell et al. 1999,Chen et al. 1992, Rosenberg and Raphael 1986, DiGiovanni 1971). In addition, extensive research has been conducted on the direct influence of timber harvest on hydrology and sediment yield, particularly in the Caspar Creek watershed (Surfleet and Ziemer 1996, Ziemer et al. 1996). What has been neglected in the literature is the bridge between these two issues. With this study I examined the indirect impacts of timber harvest on the structure and composition of forests within the riparian zone and the resulting effects on the recruitment of organic material into stream channels.

Riparian systems are affected both directly and indirectly by timber harvest activities. Increases in temperature, seasonal streamflow, subsurface flow, erosion, and suspended sediment within streams have been noted following logging on a number of sites (Alley 1999, Keppeler and Brown 1998, Lewis 1998, Lisle and Napolitano 1998, Ziemer 1998). Habitat for aquatic wildlife may also be affected through the simplification of stream channels and changes in large woody debris inputs (Nakamoto 1998, Roelofs 1996, Bisson 1987). In addition, tree fall rates in riparian buffer strips are increased adjacent to the timber harvest edges, which in turn affect the rate of large woody debris input into streams (Reid and Hilton 1998).

Vegetation dynamics associated with timber harvest boundaries have been studied in some detail (Russell and Jones 2002, Harris 1984, Burgess and Sharpe 1981). Edge effects associated with logging in upland coast redwood forests not only alter the rate of tree fall, but also affect a variety of factors related to the composition and structure of forest communities, including the diversity and dominance of species (Russell et al. 1999).

In order to better understand the impacts of timber harvest activities on vegetation and riparian systems the effects of various timber management options on the dynamics of forest composition and structure within riparian zones were analyzed to determine if the length of time since timber harvest and the width of the riparian buffer zone were correlated with canopy cover, solar radiation, the ratio of hardwood to conifer dominance, and the occurrence of individual species.

RESEARCH METHODS

Data was gathered from selected study sites in order to determine the effect of buffer zones width, harvest treatment, and regeneration time on forest structure and composition following timber harvest adjacent to riparian corridors. Sampling was conducted within coast redwood forests along the northern California coast. Ten sites were selected so that the physical and ecological features were as similar as possible (table 1). All sampling was conducted on class-2 perennial streams, with surrounding vegetation dominated by coast redwood forests.

Table 1. Study Site Characteristics

		years	buffer width (meters)
1	North Fork Caspar (1991)	10	60
2	North Fork Caspar (1990)	11	60
3	South Fork Caspar	29	60
4	Brewery Creek	110	30
5	Little River	100	0
6	North Fork Caspar (1900)	100	0
7	Russian Gulch	100	0
8	Redwood Creek	NA	NA
9	Wadell Creek	NA	NA
10	Montgomery Creek	NA	NA

Because of the abundant data available on the history of timber harvest in Jackson State Forest the Caspar Creek drainage in Mendocino County was selected for four of the sites. The Caspar Creek watershed has been employed for a number of years as an experimental treatment area for timber harvest studies conducted by the California Department of Forestry and Fire Protection in cooperation with the USDA Forest Service Redwood Sciences Laboratory. The sample sites were located outside the zone of direct coast influence.

Four of the remaining six sample areas were also located in Mendocino County. Two of these, Little River and Russian Gulch are both managed by the California State Parks and were harvested approximately 100 years ago. All marketable trees were removed on these sites down to the stream bank during harvesting. In contrast the Brewery Creek drainage, which is also administered by the State Parks, was only partially harvested due to the difficulty in removing timber from the site using pre-industrial logging equipment. Montgomery Creek, also managed by the State Parks, was never harvested and represents one of the best examples of old-growth redwood in Mendocino County. On Brewery Creek a strip of old-growth trees 50 to 200 meters wide was left along both sides of the creek. Because the practice of leaving a riparian buffer strip during harvest was not employed at the time Brewery Creek was the only site in the older age class that had a riparian buffer strip. This is an unfortunate artifact of past management regimes, and results in a correlation between years and buffer width on the sites.

The two final sites, Redwood Creek and Wadell Creek, were selected as old-growth reference sites. Redwood Creek is the main drainage in Muir Woods National Monument in Marin County, and Wadell Creek flows through Big Basin State Park in Santa Cruz County. It was necessary to choose sites geographically distinct from the treatment sites due to the lack of any significant coastal old-growth in Mendocino County

Forest Sampling

Data regarding species composition and stand structure was gathered using a system of thirty randomly located 10-meter by 10-meter sample plots on each site. The sample plots were located with the center 5-meters from the stream adjacent to stream channel perpendicular to the direction of stream flow. Data collected within each sample plot included the species and diameter at breast height (dbh) for all trees, and the occurrence of all understory species. At the center of each plot elevation, slope, aspect, canopy cover, percent solar radiation, and the percent cover of herbaceous and shrub species was also recorded.

Analysis of Data

The data gathered using these procedures was used to compare sample variables between sites and between groups of sites based on timber harvest history and width of the riparian buffer. Data were analyzed using the Statview statistics package (published by SAS). A Fisher's r to z test was used for the initial correlation test. Two-tailed t-tests were used to compare variables between the sample sites.

RESULTS

The discussion of results is organized into two sections. The first section of the analysis, "correlations between variables" was conducted with data collected on the first seven sites including all four Casper Creek sites, Brewery Creek, Russian Gulch, and Little River. These sites were selected for initial examination because they had all experienced timber harvest at some point in their history. This allowed for statistical tests that included continuous variables based on years since harvest and the width of the riparian buffer. In addition, these seven sites were in close proximity geographically and were very similar in their natural history. The second section of the analysis, "group comparisons", included three old growth sites Redwood Creek, Wadell Creek, and Montgomery Creek. Though these sites were somewhat distinct geographically they were ecologically similar enough to serve as reference points for apparent trends in relation to harvest history.

Correlations Between Variables

The first section of this analysis was conducted with data collected on seven sites including all four Casper Creek sites, Brewery Creek, Russian Gulch, and Little River. These sites were selected for initial examination because they had all experienced timber harvest at some point in their history allowing for statistical tests that included continuous variables based on years since harvest and the width of the riparian buffer. In addition, these seven sites were in close proximity geographically and were similar ecologically. A Fisher's r to z test was used to analyze correlations between "years since harvest" and "width of buffer" with one hundred fifty-two sample variables (see appendix).

Twenty-six variables were significantly correlated with "years since harvest" (table 2), and twenty-two variables were correlated with "width of buffer" (table 3).

Table 2. Correlations between sample variables and "years since harvest" on seven riparian woodland sites within the coast redwood forest. Positive Z-scores indicate correlations with sites with longer periods since timber harvest. Negative Z-scores indicate correlations with sites with shorter periods since timber harvest. Variables with a P-value of 0.05 or better were included in the table. Tree size classes listed in the table include; mature (dbh > 30 cm), pole (dbh > 10 cm, dbh < 30 cm), sapling (height > 1 m, dbh < 10 cm), and seedling (height < 1 m).

Variable	Z-score	P-value
Solar Radiation	0.239	< 0.001
Canopy Cover	-0.140	0.044
Density of Pole Sized Trees (dbh > 10 cm, dbh < 30 cm)	-0.256	<0.001
Species Richness of Shrubs	0.258	<0.001
Density of Large Woody Debris (LWD) Units	-0.324	<0.001
Basal Area of *Alnus Rubra*	-0.168	0.015
Basal Area of *Tsuga heterophylla*	0.244	<0.001
Density of Pole Sized *Pseudotsuga menziesii*	-0.140	0.044
Frequency of *Adenocaulon bicolor*	-0.180	0.009
Frequency of *Anthyrium filix-femina*	0.258	<0.001
Frequency of *Blechnum spicant*	0.197	0.004
Frequency of *Claytonia perfoliata*	0.212	0.002
Frequency of *Clintonia andrewsia*	0.188	0.007
Frequency of *Corylus cornuta*	0.253	<0.001
Frequency of *Disporum hookerii*	-0.148	0.033
Frequency of *Dryopteris arguta*	0.327	<0.001
Frequency of *Elymus glaucus*	-0.149	0.033
Frequency of *Gaultheria shallon*	0.250	<0.001
Frequency of *Heracleum lanatum*	-0.282	<0.001
Frequency of *Hieracium albiflorum*	-0.194	0.005
Frequency of *Iris douglasiana*	-0.211	0.002
Frequency of *Pteridium aquilinum*	0.163	0.019
Frequency of *Urtica holsericea*	0.169	0.015
Frequency of *Vancouvaria planipetala*	0.212	0.002
Frequency of *Veratrum fimbriatum*	0.211	0.002
Frequency of *Veronica americana*	-0.267	<0.001

Table 3. Correlations between response variables and "width of buffer" on seven riparian woodland sites within the coast redwood forest. Positive Z-scores indicate correlations with sites with longer periods since timber harvest. Negative Z-scores indicate correlations with sites with shorter periods since timber harvest. Variables with a P-value of 0.05 or better were included in the table. Tree size classes listed in the table include; mature (dbh > 30 cm), pole (dbh > 10 cm, dbh < 30 cm), sapling (height > 1 m, dbh < 10 cm), and seedling (height < 1 m).

Variable	Z-score	P-value
Hardwood to Conifer Dominance Ratio	-0.289	<0.001
Density of Mature Sized Trees	-0.237	0.001
Total Basal Area	-0.320	<0.001
Density of Large Woody Debris (LWD) Units	0.220	0.002
Basal Area of *Lithocarpus densiflorus*	-0.262	<0.001
Frequency of *Adiantum pedatum*	0.203	0.005
Frequency of *Anthyrium filix-femina*	0.282	<0.001
Frequency of *Cardimine california*	-0.151	0.039
Frequency of *Corylus cornuta*	-0.199	0.006
Frequency of *Dicentra formosa*	-0.181	0.011
Frequency of *Disporum hookeri*	0.260	<0.001
Frequency of *Dryopteris arguta*	-0.253	<0.001
Frequency of *Hedera helix*	-0.175	0.016
Frequency of *Heracleum lanatum*	0.359	<0.001
Frequency of *Heuchera micrantha*	0.274	<0.001
Frequency of *Myosotis latifolia*	-0.169	0.020
Frequency of *Petasites palmatus*	0.175	0.016
Frequency of *Pteridium aquilinum*	-0.183	0.011
Frequency of *Polystichum munitum*	-0.145	0.046
Frequency of *Rubus spectabilis*	-0.170	0.019
Frequency of *Scoliopus biglovii*	-0.253	<0.001
Frequency of *Woodwardia fimbriata*	-0.183	0.0115

Grouped Comparisons

For this section of this analysis the study sites were grouped into three categories defined by the length of time since the last harvesting event. These categories include previous harvest at 0 to 30 years, previous harvest at greater than 100-years, and no previous harvest. Unpaired two-tailed t-tests were used to compare the means of the sample variables between the groups.

Significant variation was found between groups in relation to canopy cover of hardwoods, the canopy cover of conifers, and total canopy cover (figure 4). A general decrease in canopy cover was found with respect to "years since harvest", which was applied to both conifers and hardwoods. Results of a two-tailed t-test between the three sample groups with respect to total canopy cover indicated significant differences between the 0-30 years and the > 100 year groups (P-value = 0.0396, df = 177), the 0-30 year and the old growth group (P-value < 0.0001, df = 206), and the >100 year groups and the old growth group (P-value < 0.0001, df = 207). An inverse relationship with "years since harvest" and solar radiation was also found between groups with the highest measures within the old growth sites and the lowest in the 0-30 year age class.

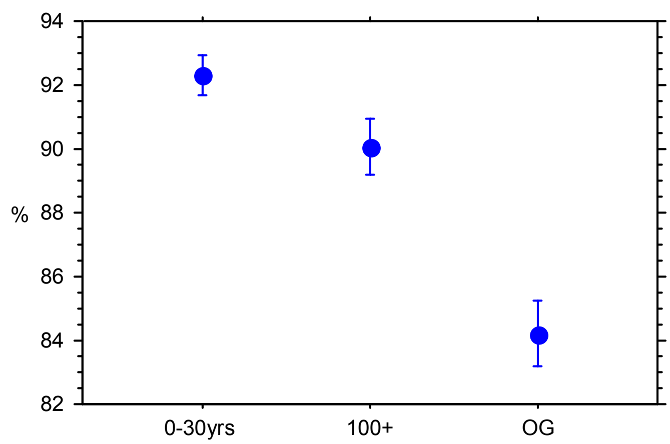

Figure 4. Average percent canopy cover of trees in riparian redwood forests grouped in three post harvest age groups. Error bars indicate one standard error.

A comparison between groups with regard to the ratio between hardwood and conifer canopy "canopy hw/con" yielded mixed results. Highly significant differences were found between both the 0-30 year group and the > 100 year group and the old growth group (P < 0.0001, df = 207, 208) but no significant difference was found between the two harvested groups. Comparison between groups of the average basal area of two common hardwood species better define this relationship. The basal area of *Ltihocarpus densiflorus* (tan oak) was significantly different between the harvested groups and the old growth group with the highest measures in the old growth areas, 0-30 year and > 100 year with the old growth group (P-value < 0.0001, df = 208) for both comparisons. The inverse was found for the average basal area of *Alnus rubra* (figure 5). Both the old growth group and the > 100 year group were significantly lower than the 0-30 year group (P = 0.0021, 0.0001, df = 208, 208) but there was no significant difference between the two groups.

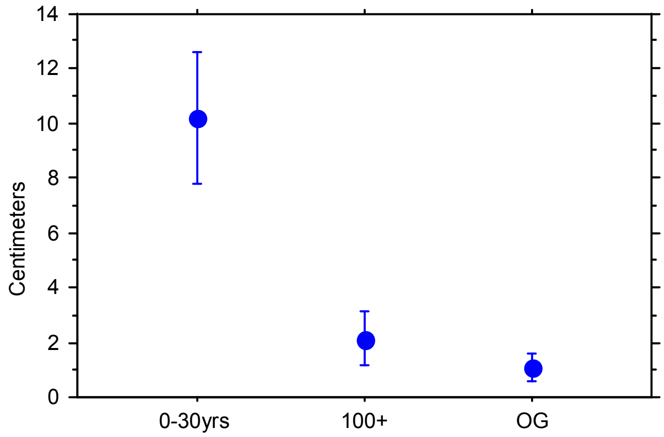

Figure 5. The average basal area, per 1/10th hectare plot, of *Alnus rubra* in riparian redwood forests grouped in three post harvest age groups. Error bars indicate one standard error.

A significant difference was found between all three groups with regard to the density of tree seedlings, 0-30 years and the > 100 year groups (P-value = 0.0407, df = 178), the 0-30 year and the old growth group, (P-value < 0.0001, df = 208), and the >100 year groups and the old growth group (P-value = 0.0003, df = 208), with the highest density in the old growth areas (figure 6). This relationship held true for nearly every species of tree present on the study sites but was most dramatic for *Tsuga heterophylla* (western hemlock) where it ranged from 0.181 to 0.492 individuals per 1/10-hectare plot, and *Alnus rubra* which ranged from 0.056 to 0.442 individuals per 1/10 hectare plot. *Sequioa Sempervirens* (coast redwood) and *Pseudotsuga menziesii* (Douglas fir) seedlings were also significantly higher in the old growth areas, ranging from 0.278 to 0.575 and 0.033 to 0.167 individuals per 1/10-hectare plot respectively. The only species of tree that was common across all groups that did not exhibit the same trend was *Lithocarpus densiflorus*, with no significant variation between groups.

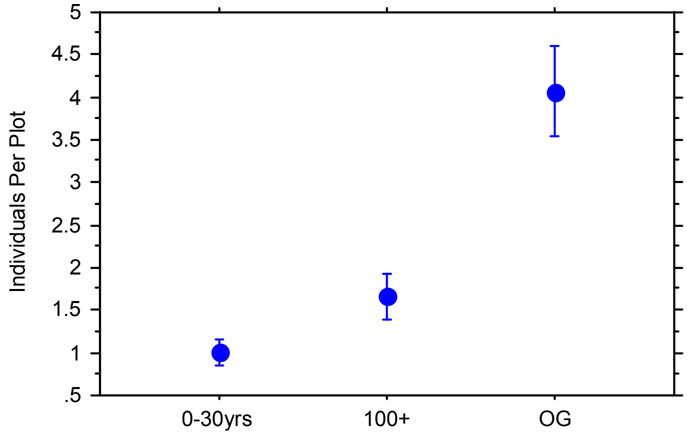

Figure 6. The average density of seedlings per 1/10-hectare plot in riparian redwood forests grouped in three post harvest age groups. Error bars indicate one standard error.

The percent cover of the shrub layer exhibited a relationship with "years since harvest" inverse to that of seedling density. A significantly lower cover of shrubs was found in the old growth than either of the harvested groups, with no significance difference between the harvested groups, 0-30 year and the old growth group, (P-value < 0.0001, df = 204), and the >100 year groups and the old growth group (P-value = 0.0003, df = 203).

Highly significant variation was found between groups in relation to the average number of large woody debris (LWD) units encountered (figure 7). The lowest density of LWD was found on the old growth sites, with progressively higher measures in the other groups, 0-30 years and the > 100 year groups (P-value = 0.0003, df = 177), the 0-30 year and the old growth group (P-value < 0.0001, df = 207), and the >100 year groups and the old growth group (P-value < 0.0001, df = 208). No significant difference was found between groups in the average length or diameter of LWD.

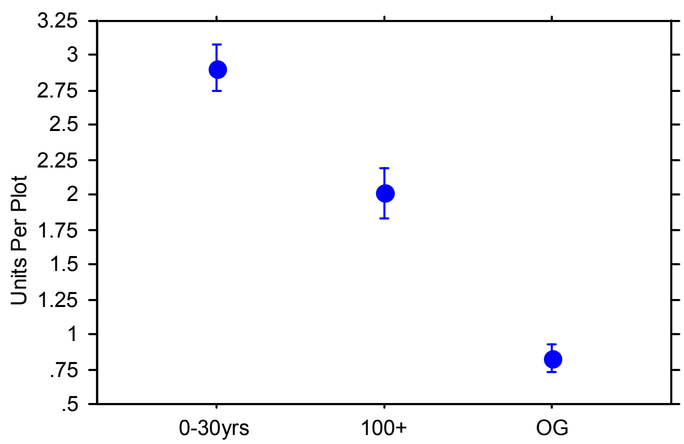

Figure 7. Average number of large woody debris (LWD) units encountered per 1/10-hectare plot. LWD was defined as any woody material greater than 10-centemeters in maximum diameter, and 1-meter in length. Error bars indicate on standard error.

Results of two-tailed t-tests between the three sample groups also indicated significant variation in relation to the abundance of several common understory species. The abundance of these species in relation to group identity fell into three types including young forest associates (figure 8), old forest associates (figure 9), and those species with no apparent association. The third category of species included those with no significant difference between the groups, those with significant differences that were not related to age of groups, and those with sample sizes too small to determine significance.

Species associated with young forest stands included exotic species such as *Pampas cortaderia* (pampas grass) with its lowest density in the old growth sites, and progressively higher measures in the other groups, 0-30 years with > 100 year groups (P-value = 0.0117, df = 178), the 0-30 year and the old growth group (P-value < 0.0001, df = 208), and the >100 year groups and the old growth group (P-value = 0.0088, df = 208). Native species, such as *Rubus parviflorus* (salmonberry) and *Heracleum lanatum* (cow parsnip), which are prone to disturbed areas, exhibited similar relationships. Significant variation was found between the 0-30 years and the > 100 year groups (P-value = 0.0617, df = 178; P-value = 0.0385, df = 178), the 0-30 year and the old growth group (P-value = 0.0002, df = 208; P-value < 0.0001, df = 208), and the >100 year groups and the old growth group (P-value = 0.0013, df = 208; P-value = 0.0007, df = 208).

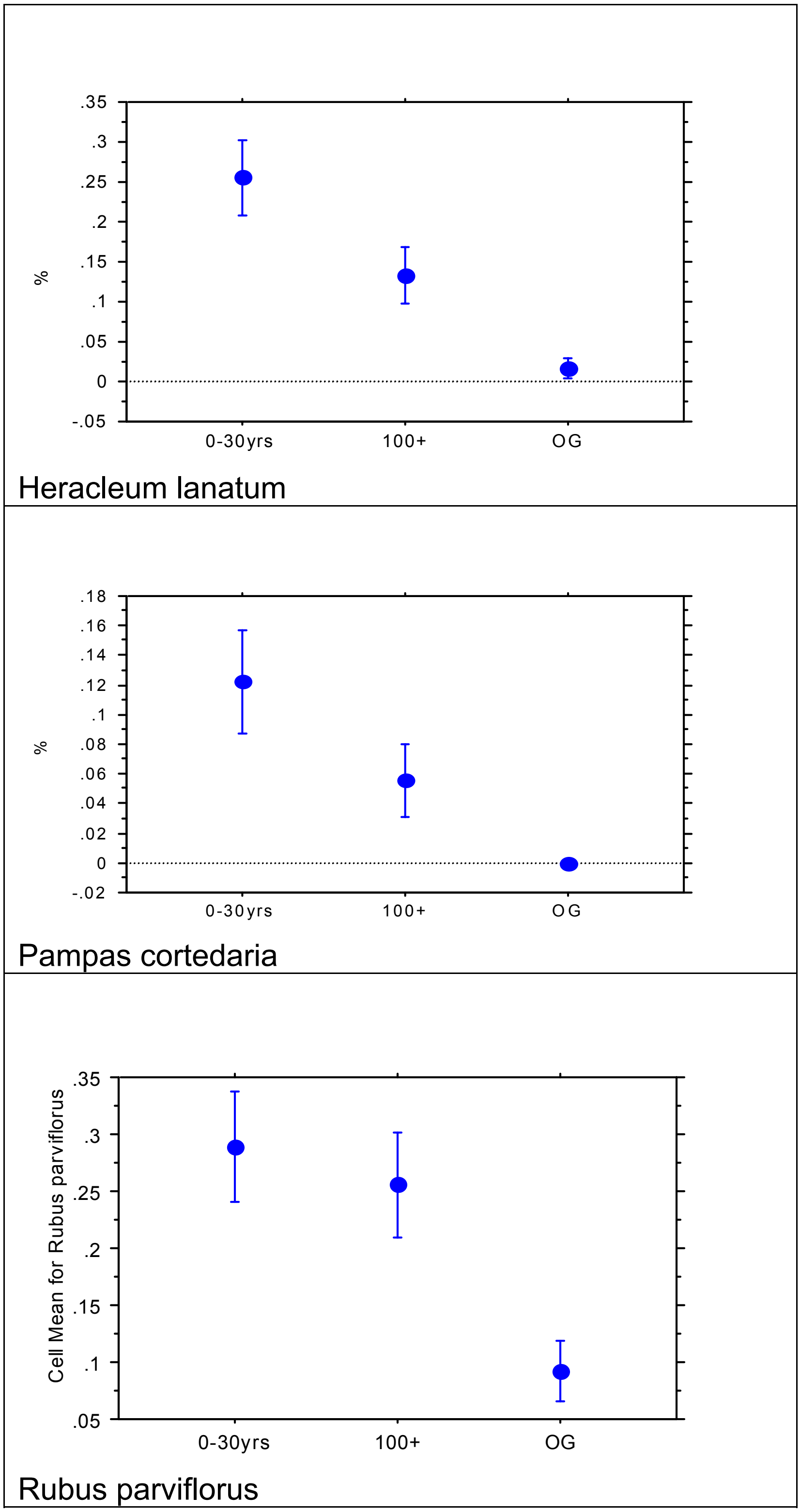

Figure 8. Frequency of common coast redwood riparian understory species associated with young forests grouped in three post harvest age groups. Error bars indicate one standard error.

Common understory plants associated with old forests included shade tolerant species such as *Trientalis latifolia* (starflower), *Viola sempervires* (redwood violet), and *Whipplea modesta* (modesty). These species all exhibited similar relationships between groups with varying significance between the 0-30 years and the > 100 year groups (P-value = 0.0497, df = 178; P-value = 0.0405, df = 178; P-value = 0.0469, df = 208), the 0-30 year and the old growth group (P-value = 0.0458, df = 208; P-value = 0.0003, df = 208; P-value = 0.0127, df = 208), and the >100 year groups and the old growth group P-value < 0.0960, df = 208; P-value = 0.1303, df = 208; P-value = 0.0076, df = 208).

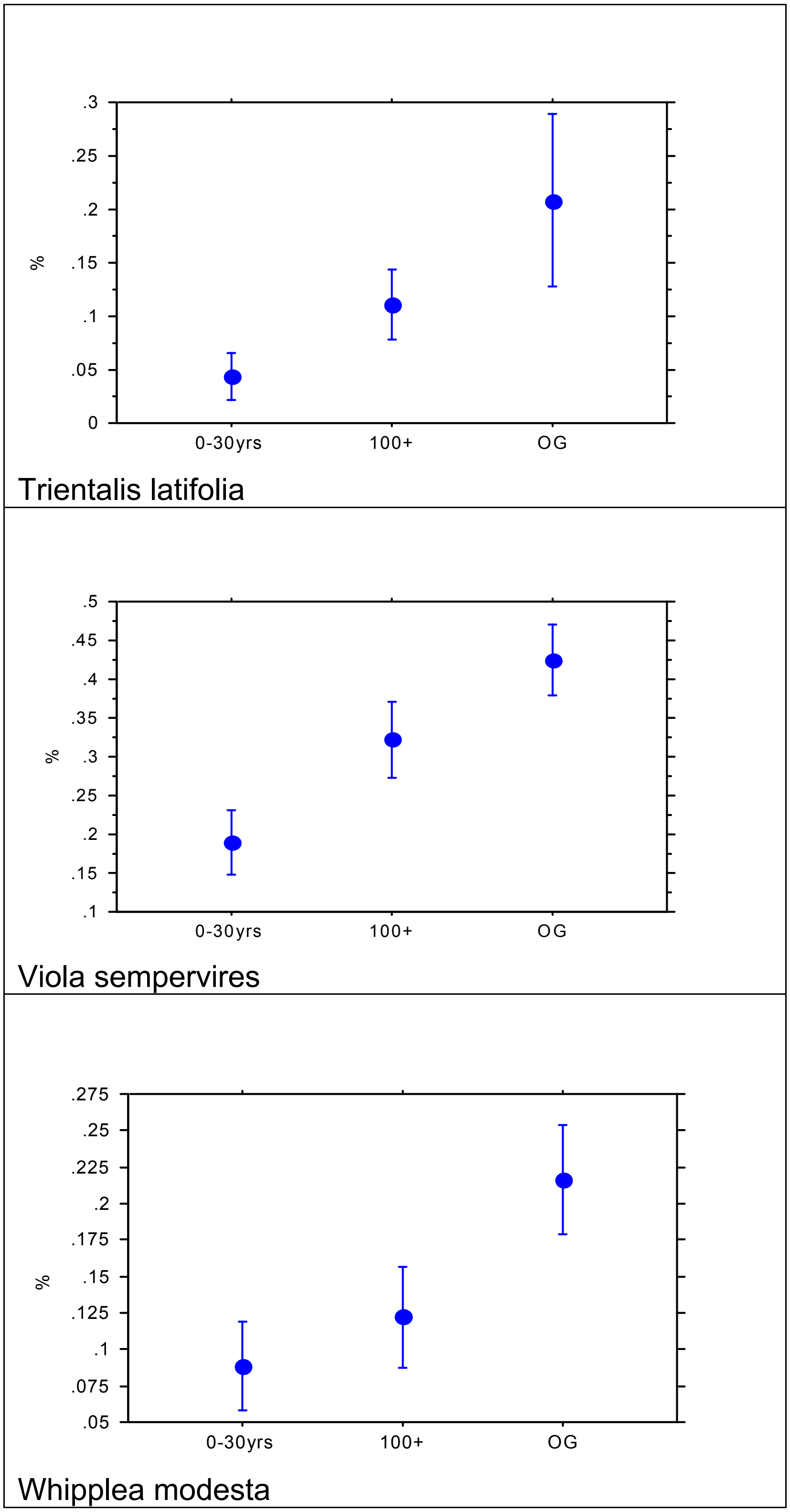

Figure 9. Frequency of common coast redwood riparian understory species associated with old growth forests grouped in three post harvest age groups. Error bars indicate one standard error.

Variations Within Groups

A great deal more variation between sample plots existed within the old growth than the younger age groups (table 6). The statistical variation between sample plots indicates a greater degree of heterogeneity within the older sites.

Table 6. Comparison of the variance between three post harvest age groups for three variables.

	Variance		
	0-30 Years	100+ Years	Old-Growth
Total Canopy Cover	35.04	69.98	134.26
Solar Radiation	10.73	17.15	20.15
Seedling Density	2.10	6.92	33.31

CONCLUSIONS

The Purpose of this study was to determine how the composition and structure of vegetation in riparian communities associated with coast redwood forests responds to timber harvesting. Seven sites were sampled within a range of post-harvest ages from 10 to more than 100 years, and a range of buffer widths from 0 to 70 meters. Three additional sites were sampled with no history of timber harvest as reference sites. The effects of various timber management histories on the dynamics of riparian forests was analyzed to determine if the length of time since timber harvest and the width of the riparian buffer zone had a measurable effect on variables such as canopy cover, solar radiation, the ratio of hardwood to conifer dominance, and the occurrence of individual species. Two data analysis methods were used to analyze the relationship between the sample variables and the experimental parameters “years since harvest” and “width of harvest”. These methods included a correlation Fisher’s r to z test, and comparison between sites using an unpaired two-tailed t-test used to characterize the relationship between variables. Comparisons between sites indicate that a variety of stand structural and compositional characteristics are significantly affected both directly and indirectly by timber harvest. Variables found to be associated with these experimental parameters included canopy cover, the ratio of hardwood to conifer dominance, stand density, quantity of large woody debris, and the frequency and dominance of a variety of species.

Both methods of analysis indicated that canopy cover was negatively correlated to "years since harvest.” The highest level of canopy cover was found on the youngest sites and the lowest level on the old-growth sites. This elevated level of canopy cover results from increased light levels following timber harvest (Russell et al. 1999) allowing for the recruitment of the trees and the expansion of existing the canopy. Expansion of the canopy following timber harvest eventually leads to a reduction of solar radiation on the forest floor. This response was illustrated by the data that were collected in this study. Solar radiation, in contrast to canopy cover, was found to have a positive correlation with “years since harvest." The two variables, canopy cover and solar radiation, are two sides of the same coin. They both illustrate the same ecological response to timber harvest. It is noteworthy that this response occurred in all sites with and without buffer strips. This indicates that canopy responds both directly on sites that have been harvested, and indirectly on sites adjacent to timber harvests.

Further analysis of the changes in canopy cover following timber harvest indicates that the balance between conifers and hardwoods is also affected. Disturbance tends to favor hardwood species (Russell and McBride 2001). This observation was supported by the data that were gathered in this study. The hardwood to conifer dominance ratio was correlated negatively to both "years since harvest" and "buffer width." The basal area of *Alnus rubra*, the dominant riparian hardwood tree species, was also negatively correlated to “years since harvest” and "buffer width" further supporting this observation. Because these trends were found on harvested sites and sites adjacent to harvested areas these results indicate that timber harvest influence stand dynamics both directly and indirectly as was the case with total canopy cover. The fact that hardwood canopy decreased with time indicates that this is a temporary phenomenon. As the forest stand matures the hardwood component decreases in relation to the conifer component.

The remaining sample variables that were significantly correlated to "years since harvest" and "buffer width" were related to the frequency and dominance of individual species. The relationship of *Tsuga heterophylla* to timber harvest is the inverse of the relationship of *Alnus rubra*. Where *Alnus* is a disturbance-associated species *Tsuga* is associated with mature forests. The positive correlation between the dominance of *Tsuga*, therefore, and the two experimental variables is not surprising. It is simply another piece of evidence suggesting that both areas with a timber harvest history and those adjacent to harvest and areas exhibit the characteristics of disturbed system.

The frequency of a number of understory species indicates the same phenomenon. *Oxalis oregana, Anthyrium filix-femina, Vaccinium parviflorum* in addition to variety of other species were found preferentially in older forests and areas with wider buffer zones. In contrast species such as *Hedera helix* (English ivy), *Dicentra Formosa*, and *Myosotis latifolia* (forget-me-not) were found preferentially in younger forests and areas with smaller buffer zones. In general, exotic species were found most commonly in the areas most heavily influenced by timber harvest. Exotic species were much more rare on the old-growth sites and on sites which had been regenerating for a century or longer.

One of the variables most highly correlated with "years since harvest" was the frequency of large woody debris. The youngest, most recently disturbed sites had a significantly higher quantity of large woody debris. This result is counterintuitive, and is indeed an artifact of human management rather than forest dynamics. The youngest sites were all located within Jackson Demonstration State Forest. This area has received an extraordinary amount of stream habitat restoration, including the initial removal of woody debris from streams, and the subsequent reintroduction of woody debris into the same streams. The other streams sampled have had less input in terms of in stream management. Of all the streams sampled only Brewery Creek could be said to have had no alteration to the natural recruitment of woody debris within the last 100 to 150 years.

Beyond the analysis of the basic composition and structure of these communities the variation within each site was also analyzed. Comparing the variation of three critical variables between the age classes of the sites indicated the highest variability on the old-growth sites, intermediate variability on the sites with over 100 years since her harvest, and the lowest variability on youngest sites. These results suggest that disturbance resulting from timber harvesting has caused a homogenization of these stands.

The results of this study indicate that the edge effects associated with riparian forests are similar to those experienced by their upland counterparts. Community composition and structure are directly and indirectly affected by timber harvest history. Altering streamside vegetation may have consequences for aquatic life as well as terrestrial life. Aquatic ecosystems are based on primary production, which occurs both in a stream, and on the stream bank (Mahoney and Erman 1984). In addition, streamside vegetation provides structure through the recruitment of large woody debris. Though it is difficult to discern the impacts of timber harvest history on streams where the input of woody materiel has been managed directly, it is not difficult to imagine the consequences of altering the density and composition of the forest community on the potential inputs that community can provide. The apparent increase in hardwood dominance on disturbed streams will result in a greater input of hardwood material rather than conifer material. The trunks of hardwood trees such as *Alnus rubra* cannot provide the same size and longevity and the trunk of a species such as *Sequoia sempervirens* can provide. In addition, a deciduous nature of *Alnus* results in a high input of organic material seasonally into the stream. The effect of this input is not known. However, the results of this study indicate that these systems are resilient. With time if the community is allowed to develop without further disturbance it will begin to return to a condition similar to its initial state.

REFERENCES CITED

Alley, D. 1999. Making logging more salmon-friendly: The Santa Cruz County attempt to protects riparian corridors. In: Proceedings of the seventeenth annual salmonid restoration federation conference. Brookdale, California.

Bisson, P. A. 1987. Large woody debris in forested streams in the Pacific Northwest: past, present, and future. In: E. O. Salo and T. W. Cundy (eds.), Streamside management: Forestry and fishery interactions. Institute of Forest Resources. University of Washington, Seattle.

Burgess, R. L., and J. L. Sharpe (eds.). 1981. Forest island dynamics in man-dominated landscapes. New York: Springer-Verlag.

California Department of Forestry and Fire Protection. 1999. California Forest Practice Rules. Sacramento, California.

Chen, J., J. F. Franklin and T. A. Spies. 1992. Vegetation responses to edge environments in old-growth Douglas-fir forests. *Ecological Applications* 2(4):5167-5177.

DiGiovanni, 1971. The impact of clearcut logging on the reestablishment of the north coastal redwood forest plant community. Thesis, University of California, Davis.

Harris, L. D. 1984. The fragmented forest: Island biogeography theory an the preservation of biotic diversity. University of Chicago Press, Chicago.

Keppeler, E. T., and D. Brown. 1998. Subsurface drainage processes and management impacts. In: Proceedings of the Conference on Coastal Watersheds: The Caspar Creek Story. R. R. Ziemer (ed.). USDA Forest Service Gen. Tech. Rep: PSW-GTR-168.

Lewis, J. 1998. Evaluating the impacts of logging activities on erosion and suspended sediment transport in the Caspar Creek watershed. In: Proceedings of the Conference on Coastal Watersheds: The Caspar Creek Story. R. R. Ziemer (ed.). USDA Forest Service Gen. Tech. Rep: PSW-GTR-168.

Lisle, T. E. and M. B. Napolitano. 1998. Effects of recent logging on the main channel of North Fork Caspar Creek. In: Proceedings of the Conference on Coastal Watersheds: The Caspar Creek Story. R. R. Ziemer (ed.). USDA Forest Service Gen. Tech. Rep: PSW-GTR-168.

Mahoney, D. L. and D. C. Erman. 1984. The role of streamside buffer-strips in the ecology of aquatic biota. In: California Riparian Systems: Ecology, Conservation, and Productive Management, University of California Press, Berkeley, CA, pp. 168-176.

Nakamoto, R. J. 1998. Effects of timber harvest on aquatic vertebrates and habitat in the North Fork Caspar Creek. In: Proceedings of the Conference on Coastal Watersheds: The Caspar Creek Story. R. R. Ziemer (ed.). USDA Forest Service Gen. Tech. Rep: PSW-GTR-168.

Reid, L. M., and S. Hilton. 1998. Buffering the buffer. In: Proceedings of the Conference on Coastal Watersheds: The Caspar Creek Story. R. R. Ziemer (ed.). USDA Forest Service Gen. Tech. Rep: PSW-GTR-168.

Roelofs, T. 1996. The Biology and ecology of anadromous salmonids. In: Proc. conference on Coast Redwood Forest Ecology and Management.

Rosenberg, K. V. and M. G. Raphael. 1986. Effects of forest fragmentation on vertebrates in douglas-fir forests. In: Wildlife 200: Modeling habitat relationships of terrestrial vertebrates. Ed: J. Verner et al. University of Wisconsin Press, Madison Wisconsin.

Russell, W. H. and C. Jones. 2002. The effects of timber harvesting on the structure and composition of adjacent old-growth coast redwood forest. *Landscape Ecology* 16:731-741

Russell, W. H., and J. R. McBride. 2001. The relative importance of fire and watercourse proximity in determining stand composition in mixed conifer riparian forests. *Forest Ecology and Management* 150: 259-265.

Russell, W. H., J. R. McBride, and K. Carnell. 1999. Edge Effects and the Effective Size of Old-Growth Coast Redwood Preserves. In: Cole, David N.; McCool, Stephen F. 2000. Proceedings: Wilderness Science in a Time of Change. Proc. RMRS-P-000. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Surfleet, C. G., and R. R. Ziemer. 1996. Effects of forest harvesting on large organic debris in coastal streams. In: Proc. conference on Coast Redwood Forest Ecology and Management.

Ziemer, R. R. 1998. Flooding and stormflows. In: Proceedings of the Conference on Coastal Watersheds: The Caspar Creek Story. R. R. Ziemer (ed.). USDA Forest Service Gen. Tech. Rep: PSW-GTR-168.

Ziemer, R. R., J. Lewis, and E. T. Keppeler 1996. Hydrological consequences of logging second-growth redwood watersheds. In: Proc. conference on Coast Redwood Forest Ecology and Management.

APPENDIX: Variables Used in Statistical Analysis

years since harvest	Baccharis pilularis (cayote brush)	Nemophila parviflora (small flowered nemophila)
buffer width (meters)	Berberis aquifolium	Oenanthe sarmentosa (pacific oenanthe)
(years x width)	Berberis nervosa (oregon grape)	Oxalis oregana (rewood sorrel)
bank full width (meters)	Berberis occidentalis	Pampas Cortederia (pampas grass)
height fm stream	Blechnum spicant (deer fern)	Pentagramma triangularis (goldenback fern)
slope (%)	Bromus californicus (california brome)	Petasites palmatus (coltsfoot)
aspect (degrees)	Cardimine californica (milk maids)	Physocarpus capitatus (ninebark)
Solar radiation	Cardimine oligosperma (bittercress)	Polypodium californicum (California polypody)
canopy (hardwood)	Carex spp. (sedge)	Polypodium glycrrhiza (licorice fern)
canopy (conifer)	Circium vulgare (thistle)	Polypodium scouleri (leather fern)
canopy (total)	Claytonia lanceolata (spring beauty)	Polystichum munitum (sword fern)
shrub cover	Claytonia perfoliata	Pteridium aquilinum (bracken fern)
richness of shrubs	Clintonia Andewsiana	Ranunculus californicus (buttercup)
herb cover	Conium maculatum (poison hemlock)	Rhamnus purshiana (buckthorn)
richness of herbs	Corylus cornuta (califronia hazelnut)	Rhododendron macrophyllum (California rose bay)
Denity of Trees (in four size classes)	Delphimium nudicaule (larkspur)	Rosa Gymnocarpa (wood rose)
Abies grandis	Dicentra formosa (bleeding heart)	Rubus parviflorus (Thimbleberry)
Alnus rubra	Disporum hookeri (fairybells)	Rubus spectabilis (salmonberry)
Pseudotsuga menziesii	Dryopteris arguta (wood fern)	Rubus ursinus (califronia blackberry)
Lithocarpus densiflorus	Elymus glaucus (blue wildrye)	Sambucus racemosa (red elderberry)
Tsuga heterophylla	Equistum spp. (horsetail)	Sanicula crassicaulis (gamble weed)
Sequoia sempervirens	Euonymus occidentalis (burning bush)	Scoliopus bigelovii (fetid adders tongue)
Umbellularia californica	Fragaria chiloensis (wild strawberry)	Smilacina racemosa (fat solomo's seal)
Acer macrocarpa	Gallium spp. (bedstraw)	Smilacina stellata (slim solomon seal)
Total Diameter of Trees (centemeters)	Gaultheria shallon (bracken fern)	Stachys bullata (hedge nettle)
Abies grandis	Gautheria shallon (salal)	Stachys chamissonis (coast hedge nettle)
Alnus rubra	Goodyera oblongifolia (rattlesnake plantain)	Stellaria calycantha (northern starwort)
Pseudotsuga menziesii	Hedera helix (english Ivy)	Taraxacum officinale (dandelion)
Lithocarpus densiflorus	Heracleum lanatum (cow parsnip)	Tellima grandiflora (alaskan fringe cup)
Tsuga heterophylla	Heuchera micrantha (alumroot)	Toxicodendron diversiloba (poison oak)
Sequoia sempervirens	Hieracium albiflorum (hawksweed)	Trientalis latifolia (starflower)
Umbellularia californica	Hierochloe occidentalis (vanilla grass)	Trillium ovatum (wake robin)
Acer macrocarpa	Iris douglasiana (douglas-iris)	Urtica holsericea (stinging nettle)
Frequency of the Following Species	Lathyrus vestitus	Vaccinium ovatum (huckleberry)
Achlys californica (vanilla leaf)	Lonicera hispidula (honeysuckle)	Vaccinium parviflorus (bilberry)
Actaea rubra (baneberry)	Lonicera involucrata (twinberry)	Vancouvaria planipetala (inside out flower)
Adenocaulon bicolor (trail plant)	Lysichiton americanum (skunk cabbage)	Veratrum fimbriatum (corn lily)
Adiantum aleuticum (five figer fern)	Marah fabaceous (wild cucumber)	Veronica americana (american speedwell)
Adiantum pedatum (maiden hair fern)	Marah oreganus	Viola glabella (stream violet)
Anemone deltoidea (windflower)	Monitia perfoliata (miner's lettuce)	Viola sempervirens (redwood violet)
Aquilegia formosa (columbine)	Montia sibirica	Whipplea modesta (modesty)
Asarum caudatum (wild ginger)	Myosotis latifolia (forget-me-not)	Woodwardia fimbriata (giant chain fern)
Athyrium filix-femina (lady fern)	Myrica californica (wax myrtle)	Xerophyllum tenax (bear-grass)
years since harvest	Baccharis pilularis (cayote brush)	Nemophila parviflora (small flowered nemophila)
buffer width (meters)	Berberis aquifolium	Oenanthe sarmentosa (pacific oenanthe)
(years x width)	Berberis nervosa (oregon grape)	Oxalis oregana (rewood sorrel)
bank full width (meters)	Berberis occidentalis	Pampas Cortederia (pampas grass)
height fm stream	Blechnum spicant (deer fern)	Pentagramma triangularis (goldenback fern)
slope (%)	Bromus californicus (california brome)	Petasites palmatus (coltsfoot)
aspect (degrees)	Cardimine californica (milk maids)	Physocarpus capitatus (ninebark)
Solar radiation	Cardimine oligosperma (bittercress)	Polypodium californicum (California polypody)
canopy (hardwood)	Carex spp. (sedge)	Polypodium glycrrhiza (licorice fern)