

MEASURES OF STREAM RECOVERY AFTER WATERSHED RESTORATION

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ABSTRACT: A watershed rehabilitation program in Redwood National Park in north coastal California has treated over 270 km of abandoned logging roads during the last 15 years. To evaluate the recovery of streams draining the restored lands, several physical parameters were monitored: pool depth and pool frequency, water temperature and canopy closure, channel bed elevation, channel geometry (width, area and wetted perimeter), bed material particle size, large woody debris loading and suspended sediment and bedload. Time trends in these habitat conditions were evaluated. To date, pool depth and frequency, channel bed elevation and channel geometry have been the most useful measures of stream response. Some stream recovery has been documented in several stream reaches. However, it is still unclear how much can be attributed directly to watershed restoration work, and how much recovery would have occurred naturally due to a lack of floods and the cessation of logging within the national park. It will take a 'test' by a large storm, which is capable of generating landslides and gullies on susceptible terrain, to truly evaluate the effectiveness of rehabilitation work.

KEY TERMS: stream recovery, watershed restoration, monitoring, road rehabilitation

INTRODUCTION

Many anadromous fisheries streams in the Pacific Northwest have been damaged by various land uses, including timber harvest, road construction, grazing and mining. Problems facing aquatic and riparian habitats due to forest management activities were addressed by several federal agencies in FEMAT (USDA, 1993). As a result of this assessment, an Aquatic Conservation Strategy was implemented (USDA, 1994), which directs land managers to consider many aspects of ecosystems through watershed analyses. To implement ecosystem-based management, land managers must understand how disturbances affect elements of a watershed across many disciplines, and how efforts to correct problems also affect many watershed elements. In addition, the Aquatic Conservation Strategy directs agencies to evaluate restoration opportunities in the watersheds under study.

The question facing land managers is how to evaluate watershed recovery following both disturbances and subsequent restoration efforts. Disturbances in watersheds are manifested at the landscape scale; however ecological restoration efforts are often practiced on the local, site-specific scale. An evaluation of restoration efforts must extend across several spatial and

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temporal scales and so monitoring techniques must also cover a range of scales. More traditional measurements of success based on point source problems from a single type of disturbance do not apply. Criteria used to measure restoration success must be based on clear objectives of the restoration efforts, but also must be appropriate to the scale of the watershed response.

The focus of this paper is on two specific watersheds, Redwood Creek and its tributary Bridge Creek, in which watershed restoration work has been conducted since 1978. Nevertheless, the approaches used to monitor recovery of streams in this watershed may be applicable to a wide range of streams in the Pacific Northwest.

FIELD AREA

Redwood Creek drains a 720 km² watershed in the Coast Ranges of northwestern California. Redwood National Park is located in the downstream third of the watershed; the upper two-thirds of the basin is privately owned and is primarily used for timber production. The watershed is characterized by high relief, steep unstable slopes and narrow valley bottoms.

The watershed receives 1750-2550 mm of precipitation per year, most of which falls as rain between October and March. Large floods occurred in 1964, 1972, and 1975, which resulted in widespread erosion and sedimentation. It is important to note, however, that no floods of greater than a five-year recurrence interval have occurred since 1975. Basin soils are naturally unstable and highly erodible, and landslides and earthflows are widespread. Even under natural conditions (without timber harvest) streams transport large volumes of sediment. Mean annual sediment yields of over 2800 Mg/km²/yr have been measured (Janda and Nolan, 1979).

THE PROBLEM

The existence of over 1700 km of unpaved haul roads and over 5000 km of skid trails in the Redwood Creek watershed has created severe erosion problems. Road construction on steep slopes has often resulted in massive slope failures, causing large volumes of sediment to be delivered directly into streams. During major storms, culverts and inboard ditches often become blocked, and water is diverted onto road surfaces, forming gullies and saturating road fills, which in turn may lead to slope failures.

Altered drainage patterns, loss of topsoil, soil compaction, destruction of ground cover and subsequent decreased evapotranspiration, increased runoff rates, increased soil temperature, and decreased soil moisture are among the results of logging activities. Downstream from the cutover lands, effects on National Park resources include the aggradation of streambeds, burial of the base of old growth redwoods, loss of anadromous fish spawning and fish rearing habitat, increased streamside slope failures and bank erosion, loss of streamside canopy, lower summer discharge, higher summer water temperatures and increased sediment in the estuary.

The damage to park resources caused by these factors led Congress to expand Redwood National Park in 1978 to include 194 km² of logged lands

immediately upslope and upstream of the original park lands. Congress also authorized the National Park Service to "initiate... a program for the rehabilitation of areas within and upstream from the park contributing significant sedimentation because of past logging disturbances and road conditions, and to the extent feasible, to reduce risk of damage to streamside areas adjacent to Redwood Creek..." (Public Law 95-250). Watershed rehabilitation projects have been implemented in Redwood National Park since 1978.

The scope of Redwood National Park's rehabilitation program is to restore the entire redwood ecosystem within the park, rather than to apply a "quick fix" to a single grove of redwoods. The underlying assumption is that if the structure and physical processes of the ecosystem are restored, so too will be the ecological functions. The primary objective of the watershed restoration program at Redwood National Park has been to reduce erosion and sediment yields generated from disturbed sites. A typical treatment on abandoned logging roads involves removing culverts, excavating unstable road fill, and draining or recontouring road surfaces. Natural drainage patterns are reestablished by outsloping, ditch removal and construction of waterbars. To date 270 km of road have been treated and about 535,000 m³ sediment has been excavated from stream crossings in the lower Redwood Creek basin. In Bridge Creek, 65 km of roads were removed, and 170,000 m³ of sediment excavated from stream channels.

Figure 1-A shows the road network that existed when the park was expanded in 1978. Because of the road obliteration work, present road network density is much less on parklands (1B) than on private lands upstream of park boundaries. Although the main channel of Redwood Creek is still strongly influenced by land use activities upstream from park, some tributary basins are entirely within Redwood National Park boundaries. These tributary basins have a higher potential to be restored than the main channel of Redwood Creek. Also, the effects of watershed restoration may be more easily discerned in tributary basins entirely under federal management, such as Bridge Creek, a 30 km² basin (Figure 1).

PREVIOUS WORK

Several researchers have discussed appropriate measures to use to evaluate the effects of forestry activities on streams. Although these methods were originally designed to detect damage to aquatic and riparian habitats, many of these methods can be used to assess recovery of streams as well. MacDonald and others (1991) evaluated 30 parameters that may be used to monitor stream channel response to forest management activities, such as road building and maintenance. By an extension of their logic, these parameters may not only monitor the effects of road building, but also of road removal. Various organizations, tribal commission and state agencies have set up their own monitoring protocols to assess the impacts of logging and road construction. In addition, Platts and others (1987) developed a standard way of measuring and evaluating riparian conditions, which can also be affected by watershed restoration work. Finally, USDA (1994) lists several factors in aquatic ecosystems by which to monitor the effectiveness of restoration work.

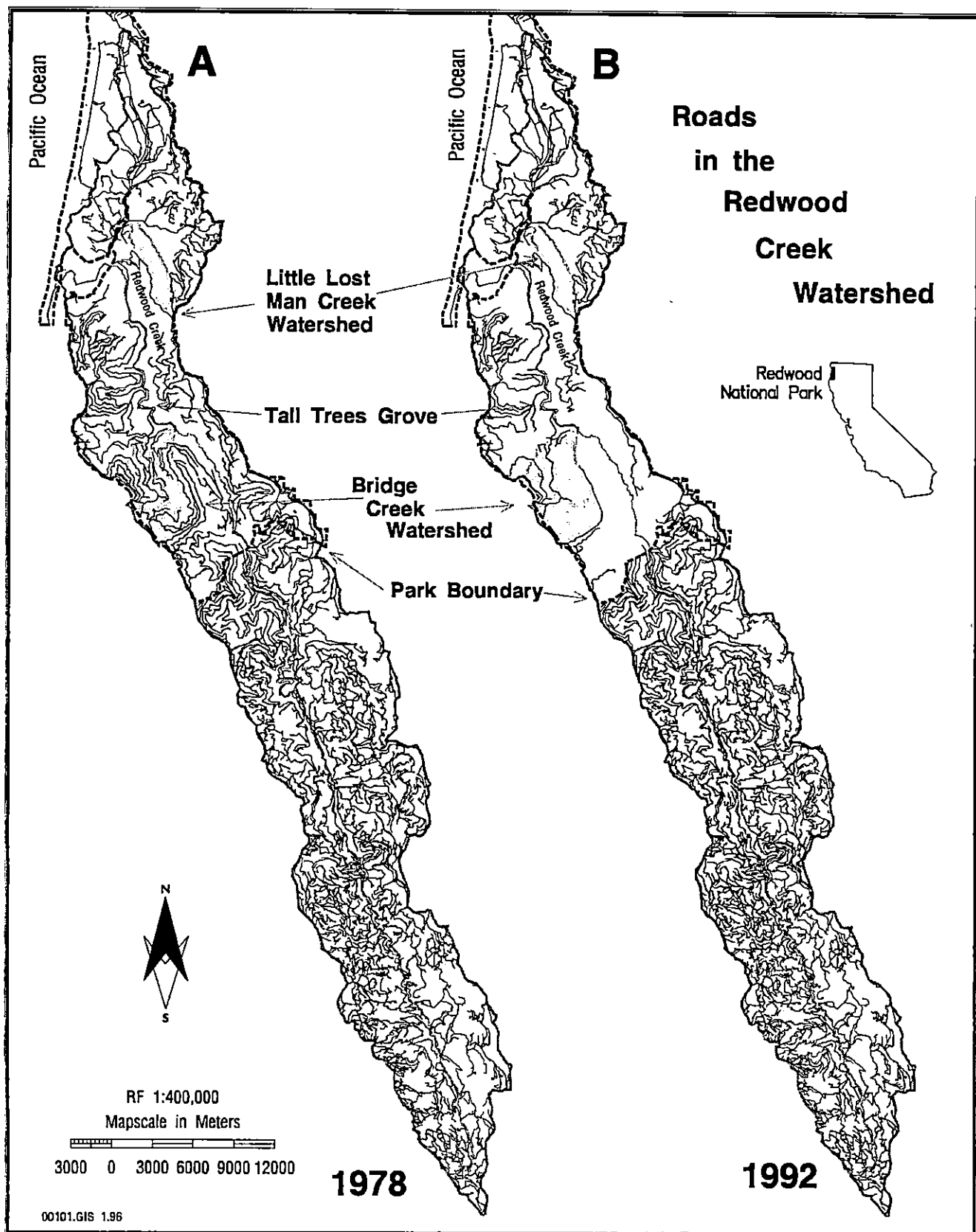


Figure 1: Location map of Redwood Creek showing roads that existed in 1978 and those that remain in 1992. Since 1978 270 km of abandoned logging roads have been obliterated within Redwood National Park boundaries. Of that, 65 km of road were rehabilitated in the Bridge Creek watershed.

APPROACH

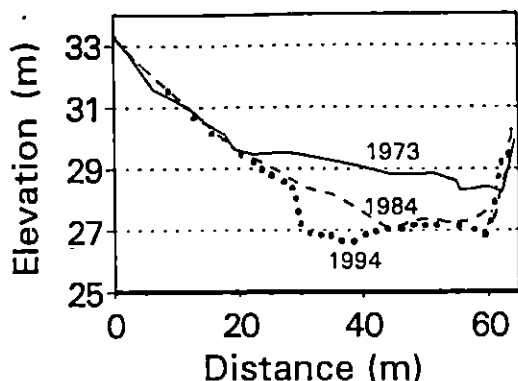
Physical stream recovery in the Redwood Creek watershed was evaluated in several ways--by a return to probable pre-logging conditions of: channel geometry (channel width, area and wetted perimeter); channel bed elevation; former pool depths and pool frequencies; canopy closure and water temperature; bed substrate size; large woody debris loading; and sediment loads. These physical characteristics influence habitat and, consequently, the aquatic and riparian communities associated with these streams. Unfortunately, few pre-disturbance data are available for these factors.

RESULTS

Channel Cross-Sectional Surveys

Since 1973, over 50 channel cross sections have been surveyed throughout the length of Redwood Creek. Redwood Creek aggraded in many reaches during large floods in 1964, 1972 and 1975. Madej and Ozaki (in press) describe the results of 20 years of monitoring stream channel changes. Figure 2 shows examples of changes in cross-sectional form and mean bed elevation at several reaches in Redwood Creek.

Cross Section 25 (Km 26)



Cross Section 6 (Km 10)

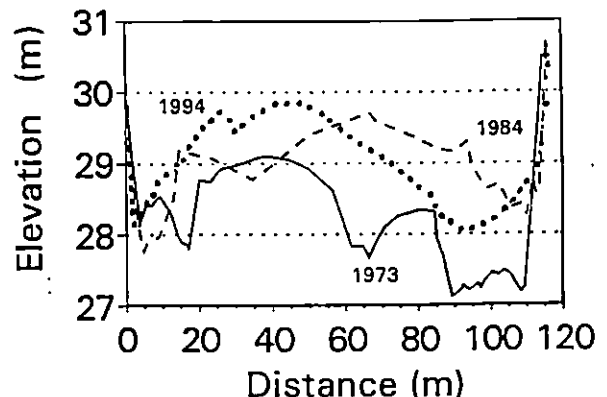


Figure 2: Examples of cross-sectional survey results in Redwood Creek. Cross Section 25 is located upstream of Bridge Creek (26 km upstream from the mouth of Redwood Creek), and is typical of survey results in a recovering reach. The mean streambed elevation has decreased since 1973, and the cross-sectional area, wetted perimeter and asymmetry have increased. In contrast, Cross Section 6 is located farther downstream (10 km upstream from the mouth), where sediment is still accumulating. In this reach, the channel has filled in, streambed elevations are higher than in 1973, and pools are less frequent.

Several channel geometry changes are typical of the survey results in recovering reaches: mean streambed elevation decreases in time, cross-sectional area increases, the asymmetry of the cross section increases, and wetted perimeter increases. Immediately after large floods the channel was smooth and flat. Through time the channel bed has become rougher, and bars became better defined, which may indicate that more diverse microhabitats are now available to aquatic organisms. The time needed for the river to scour down to former stream bed elevations ranged from eight years upstream of Bridge Creek to over 15 years upstream of the Tall Trees Grove. Not until 1995 has any recovery of streambed elevations in the downstream most reach of Redwood Creek been measured, and bed elevations in this reach are still about one meter higher than 1975 elevations. Downcutting in the main channel initiated downcutting in lower reaches of tributaries. For example, in Bridge Creek a comparison of 1990 and 1995 surveys shows that 1200 m³ was scoured out of its lowermost reach as Redwood Creek downcut.

Longitudinal Profiles

The thalweg of Redwood Creek was surveyed in 1977, 1983, 1986 and 1995. Pool spacing decreased and depths increased in Redwood Creek from 1977 to 1986, and again from 1986 to 1995 (Figure 3). Pool depths have not achieved their probable pre-disturbance depths (based on accounts of local residents), but the present pool spacing may be approaching the pre-disturbance spacing. For example, no pools greater than 1.2 m were found in 1977. Based on resurveys of 14 km of channel, the number of pools increased by 25% from 1986 to 1995, and pool spacing decreased from 4.5 channel widths apart in 1986 to 3 channel widths apart in 1995.

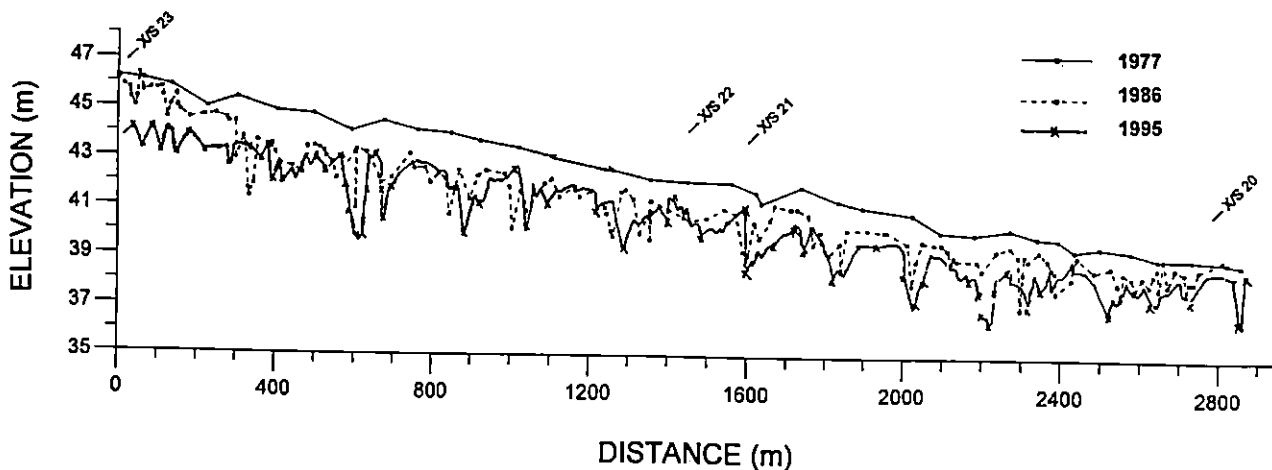


Figure 3: Example of longitudinal profile surveys of the thalweg of Redwood Creek. Bridge Creek enters between Cross Section (XS) 21 and 22. The channel downcutting in Redwood Creek has initiated downcutting in Bridge Creek as well. Surveys from 1977, 1986 and 1995 show a progressive increase in the number and depth of pools in Redwood Creek through time.

In Bridge Creek 2 km of channel were surveyed in 1995, and results were compared to a 1986 survey reported by Klein (Redwood National Park, personal communication). The number of pools increased from 29 in 1986 to 43 in 1995. Mean pool depth was not significantly different ($\alpha = 0.05$), although the range of pool depths was greater in 1995.

Riparian Habitat and Stream Temperature

Riparian zones form a linkage between aquatic and terrestrial environments, and are very productive and diverse. The shade provided by riparian trees is critical in regulating stream temperatures and preventing water from warming too much during summer low flows. Past logging practices frequently removed all large shade trees from the riparian zone, which allowed more solar radiation to reach the stream, and decreased the amount of nutrients the stream received from leaf fall, etc. Harvest of trees in the riparian zone also reduces the potential of woody debris recruitment from treefall into the streams.

To assess disturbance and recovery of the riparian corridor in Redwood Creek, the length of riparian canopy openings (measured from sequential aerial photographs) was compared in the uppermost 11.2 km of Redwood Creek. Here, 67% of the channel length had a closed canopy in 1954, which dropped to 0% in 1966 (after the 1964 flood), was less than 1% in 1978, and had recovered to 40% in 1992. Farther downstream the river channel is wider and did not have a closed canopy even under pristine conditions. The mainstem of Bridge Creek (6.7 km) showed similar trends in riparian coverage. In 1954 canopy closure was 76%, which dropped to 1% in 1966, and increased to 8% in 1966 and 82% in 1992. In both streams, the 1992 riparian canopy consisted of alders, however, which is substantially different from the original conifer canopy of 1954.

Water temperatures can be detrimental to several species in streams, and increased water temperatures have been documented in several areas after logging (USDA, 1993). The dramatic changes in riparian canopy openings in the Redwood Creek basin suggests significant changes in water temperature regimes through time. Stream temperatures would also be expected to rise as a result of the channel widening that was documented by cross-sectional surveys. Unfortunately, monitoring is sparse for this water quality variable in the Redwood Creek basin. Intermittent measurements may not record the maximum temperature reached by a stream. Nevertheless, such measurements suggest a decrease in summer water temperatures in the mainstem of Redwood Creek. For example under similar water flows and air temperature regimes, Redwood Creek water temperature during summer low flows decreased from 33° C in Redwood Creek in 1977 (U.S. Geological Survey) to 24° C in 1995 (Anderson, Redwood National Park, personal communication). Water temperatures may be expected to decrease further as the riparian corridor recovers and provides shade to the stream channel.

Stream Channel Substrate

Size distribution of channel bed particles is important in providing microhabitats for invertebrates, and suitable spawning gravels of salmonids. An increase in the amount of fines is frequently the results of land use

disturbances, and may render the streambed unsuitable for various aquatic organisms. In Redwood Creek, the composition of the channel substrate was most commonly measured by use of pebble counts at all cross section sites. There are many problems with using this method to monitor changes through time because of the high spatial and operator variability (Marcus and others, 1995). The technique does not work well when there is a high sand fraction in the substrate. Nevertheless, gross changes can be documented. In Redwood Creek there is a general coarsening of the substrate through time. For example, in Redwood Creek near Bridge Creek the median particle size D_{50} increased from 15mm in 1979 to 32 mm in 1995. A coarse gravel armor is still not well developed in Redwood Creek in comparison with other streams (Lisle and Madej, 1990).

Large Woody Debris

Coarse woody debris is an important component of forested streams. It influences channel scour, deposition, and sediment transport patterns, provides cover and complexity, and acts as a substrate for biological activity. Historically the harvest of riparian areas and removing wood from the channel itself has reduced woody debris loading in Redwood Creek and its tributaries. Little is known about the pre-disturbance or current debris loading of large wood in Redwood Creek. Debris loading in Bridge Creek (Smith and Barnard, 1990) is less than half of that reported for similar nearby unlogged redwood streams (Keller and Tally, 1979). However, as Bridge Creek scours its bed, it is exhuming several large pieces of woody debris, which may increase the complexity of that stream.

Sediment Yield

Another criterion of recovery is a return to pre-disturbance sediment transport rates. During the last two decades, periodic measurements of bedload and suspended load have been made at three mainstem and four tributary gaging stations. Madej and Ozaki (in press) show that sediment yields have decreased with time. For equivalent water discharges, recent suspended sediment loads in Redwood Creek are substantially less than pre-1978. Few sediment measurements before drainage basin disturbance are available for Redwood Creek, but the present sediment yields (1000 Mg/km²/yr) are still several times higher than the sediment yields measured during the same period in the unlogged tributary basin of Little Lost Man Creek (250 Mg/km²/yr). Sediment yields are not available for Bridge Creek.

DISCUSSION AND CONCLUSIONS

Both Redwood and Bridge Creeks exhibit an increase in pool frequency, a decrease in mean streambed elevation, increased channel cross-sectional area, and an increase in riparian cover after disturbances from large floods and logging activities. Extensive treatment of abandoned roads has decreased the amount of road fill in stream crossings that is susceptible to erosion and sediment transport.

An underlying question is, how much stream recovery would have occurred with the cessation of active timber harvesting and road construction (natural recovery) and how much has recovery been accelerated by the watershed rehabilitation program? This important question cannot be answered for two reasons. First, there is no "control" basin that can be compared to the "treated" watersheds. Secondly, the restored watersheds have not experienced a large storm, which in this region causes the most extensive channel changes. Since the watershed rehabilitation program began in 1978, there has been no flood greater than a 5-year recurrence interval in the Redwood Creek basin. It will take a large storm, which is capable of generating landslides and gullies on susceptible terrain, to test the effectiveness of rehabilitation work.

In addition, the biological responses in streams to changes in physical habitat are not yet well documented. There are other factors influencing the recovery of salmon in Redwood Creek, such as ocean conditions and modification of the Redwood Creek estuary by flood control levees. Both biological and physical responses may be delayed in time as well as occurring off-site from restoration work. Such complexity is not intractable, but it will take a commitment to long-term studies (on the same timescale of the recovery processes) by people working in many disciplines to unravel.

An evaluation of watershed recovery should ultimately include a broader perspective--including terrestrial revegetation, forest ecology, landscape-scale measures, nutrient cycling, and changes in land management activities. To be successful, programs must evaluate effects of a proposed project in the context of an entire drainage basin. In the case of Redwood Creek this will involve assessment and implementation of restoration on private lands as well as those under federal management. The magnitude of damage originating from private lands during the next large flood is unknown. Ziemer (1996) suggests that because many new roads are continuing to be constructed upstream of federal lands (Figure 1), the Redwood Creek watershed will not recover until land use on private lands is also addressed. Indeed, to this end, Redwood National Park is currently embarked on a program to encourage and assist private landowners upstream of parklands in correcting erosional problems on their roads before the next large flood.

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REFERENCES CITED

- Janda, R.J. and K. M. Nolan. 1979. Stream Sediment Discharge in Northwestern California. In: A Guidebook for a Field Trip to Observe Natural and Management-related Erosion in Franciscan Terrain of Northern California.

Cordilleran Section of the Geological Society of America. p. IV-1 to IV-27.

Keller, E.A. and T. Tally, 1979, Effects of Large Organic Debris on Channel Form and Fluvial Processes in the Coastal Redwood Environment. p. 169-197 in: Adjustments of the Fluvial System, D.D. Rhodes and G.P. Williams, Eds. Kendall/Hunt Publishing Co. Dubuque, Iowa.

Lisle, T.E. and M.A. Madej, 1992. Spatial Variation in Armouring in a Channel with High Sediment Supply. In: Dynamics of Gravel-bed Rivers. p. 277-293 in P. Billi, R.D. Hey, C.R. Thorne, and P. Tacconi, eds. John Wiley and Sons Ltd.

MacDonald, L.H., A.W. Smart and R.C. Wissmar, 1991, Monitoring Guidelines to Evaluate Effects of Forestry Activities on Streams in the Pacific Northwest and Alaska (EPA/910/9-91-001) Environmental Protection Agency, Region 10, in cooperation with the Center for Streamside Studies, University of Washington, Seattle, WA. 176 pp.

Madej, M.A. and V.L. Ozaki. 1996 (in press). Channel Response to Sediment Wave Propagation and Movement, Redwood Creek, California, USA. Earth Surface Processes and Landforms.

Marcus, W. A., S.C. Ladd, J. A. Stoughton, and J. W. Stock. 1995. Pebble Counts and The Role of User-dependent Bias in Documenting Sediment Size Distributions. Water Resources Research Vol. 31, No. 10, p. 2625-2631.

Platts, W. S., C.Armour, G.D. Booth, M. Bryant, J.L. Bufford, P.Cuplin, S. Jensen, G.W. Lienkaemper, G.W. Minshall, S.B. Monsen, R.L. Nelson, J.R. Sedell, J.S.Hudy, 1987. Methods for Evaluating Riparian Habitats with Applications to Management. General Technical Report INT-221. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 177 p.

Smith, M. and K. Barnard. 1990. Habitat Inventory and Woody Debris Inventory of Bridge Creek. Unpublished report for Redwood National Park, Arcata, CA. 118 pp..

U.S. Dept. of Agriculture, 1994. Record of Decision for Amendments to the Forest Service and Bureau of Land Management Planning Documents within the Range of the Northern Spotted Owl. 74 pp.

U.S. Dept.of Agriculture, 1993. Forest Ecosystem Management: An Ecological, Economic, and Social Assessment. Report of the Forest Ecosystem Management Assessment Team.

Ziemer, R. R. In press. Concepts of Temporal and Spatial Scales in Restoration Programs. Chapter 6 in Watershed Restoration: Principles and Practices. J.E. Williams, M.P. Dombeck, and C.A. Wood, Eds.. American Fisheries Society.