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Summary of Research in the Redwood Creek Basin, 1973–83

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GEOMORPHIC PROCESSES AND AQUATIC HABITAT IN THE REDWOOD CREEK BASIN, NORTHWESTERN CALIFORNIA

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ABSTRACT

Concern for the effects of timber harvest activities on resources of Redwood National Park stimulated extensive study of geomorphic processes and aquatic habitat in the Redwood Creek basin. This article summarizes work of 32 investigators working in the Redwood Creek basin between 1973 and 1983. The work of these investigators is reported in the 22 articles that follow. This volume describes a rapidly eroding landscape that is sensitive to effects of both land use and major storms.

INTRODUCTION

In 1968, the U.S. Congress passed legislation establishing Redwood National Park in northwestern California. This 235-km^2 park was designed to preserve significant examples of virgin coastal redwood (*Sequoia sempervirens*) forests. Most of the parkland was located in the downstream one-third of the Redwood Creek drainage basin. The boundaries of the park included a narrow 12.9-km-long, 244-m-wide corridor designed to protect the spectacular redwood groves found on alluvial flats along the lower Redwood Creek channel. The grove of most interest, the Tall Trees Grove, contained the first, third, and sixth tallest known trees.

Soon after Redwood National Park was established, conservation groups and government agencies became concerned that timber harvesting on private lands upstream and upslope was threatening resources of the newly created park. These agencies believed that timber harvesting activities had the potential to increase runoff and sediment production in this rapidly eroding drainage basin and that the increases would lead to degradation of parkland resources. Because of this growing concern, studies of erosion, sediment transport, and aquatic habitat were initiated throughout the basin in 1973.

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The studies were designed both to understand natural processes within the basin and to assess how timber harvesting within the basin had affected these processes. Results from much of this research indicated that timber harvesting was capable of increasing the naturally high rates of erosion in Redwood Creek. As a consequence, Congress authorized expansion of Redwood National Park in 1978 to 534 km^2. In addition to the area added, 100 km^2 directly upstream of the park were designated a park protection zone in which timber harvest operations were to be reviewed by the National Park Service.

The papers in this volume are a compilation of work by 32 investigators who studied diverse aspects of geomorphic processes and aquatic habitats in the 725-km^2 drainage basin of Redwood Creek between 1973 and 1983. During this time, land management in the vicinity of Redwood National Park was the subject of three lawsuits and multiple congressional hearings. Consequently, results of much of the initial research conducted in the Redwood Creek basin appeared only in reports prepared for a specific trial or hearing. This volume has been assembled to update these initial findings and to compile results of virtually all research accomplished in the basin.

Most of the Redwood Creek research represents a cooperative effort between the U.S. Geological Survey and the National Park Service. This cooperative effort provided the opportunity to develop an understanding of the physical and biological processes throughout the Redwood Creek basin. Study of erosional processes in this basin has proved rewarding because of the intensity of the study effort and because of the rapid rate at which processes operate. Because processes operate so rapidly, researchers have been able to make frequent observations of geomorphic change and have therefore assembled relatively large data bases upon which to base their conclusions. It is important to note that present regulations for forest practices in California are more rigorous than those regulations that were in effect when much of the research was conducted in the basin. For this reason, results contained in some articles may not be completely applicable to present-day practices.

This article summarizes the large amount of information contained in the overall volume. It capsulizes major findings of each article and briefly describes how articles relate both to one another and to the broader basinwide framework of geomorphic processes or aquatic habitat. Because the papers have not resulted from a single coordinated study, this volume is not intended to present a totally integrated description of processes or habitats throughout the basin.

GEOLOGY, CLIMATE, AND LAND USE

The Redwood Creek basin is within a geologic province characterized by some of the highest rates of erosion in the United States (Brown and Ritter, 1971; Milliman and Meade, 1983). The naturally high rates of erosion in this area result from inherently weak rock units situated in a tectonically active area with a Mediterranean climate. These naturally high rates have been accelerated by extensive timber harvesting throughout the basin.

The dominant rocks in the basin are metamorphic and sedimentary rocks of the Franciscan assemblage, with lesser amounts of Plio-Pleistocene shallow-marine and alluvial sedimentary deposits at the north end (chap. B, this volume). Rocks of the Franciscan assemblage are severely fractured and deformed and highly susceptible to landslides. The basin has recently experienced high uplift rates associated with the Mendocino triple junction (chap. B., this volume). Geologic evidence presented by Cashman and others (chap. B, this volume) indicates that the Redwood Creek basin probably did not develop into its general present-day form until the early Pleistocene.

Eighty-one percent of the virgin coniferous forest in the Redwood Creek basin has been logged. Best (chap. C, this volume) discusses the history of this timber harvesting. Although timber harvesting started in the 19th century, it was most intensive in the 15 years prior to a large storm in December 1964. The earliest timber harvest was concentrated in the upper and middle parts of the basin, but starting in the late 1960's, timber harvest was most active in the lower two-thirds of the basin. With expansion of Redwood National Park in 1978, all timber harvesting ceased in the lower one-third of the basin.

Major storms have received a great deal of attention in the Redwood Creek basin because erosion and sediment delivery associated with those storms produced many of the channel changes that threatened parkland resources. Harden's analysis (chap. D, this volume) of major storms for which historical information is available reveals that storms in 1860 and 1890 produced major floods comparable in magnitude to the storm and flood of December 1964. The latter storm, however, caused much more widespread landsliding and channel aggradation in Redwood Creek and other northern California basins than the major storms of the 19th century. Likely causes for the disproportionate impacts of the 1964 storm include small-scale destabilization of hillslopes by storms in 1953 and 1955, concentration of rainfall in the upper basin where streamside slopes are less densely vegetated and unprotected by flood plains, and intensive road construction associated with logging in the upper basin between 1955 and 1964.

EROSION AND SEDIMENT TRANSPORT

Investigations of erosion and sediment transport make up most of the geologic and hydrologic research conducted in the Redwood Creek basin. The papers presented in this volume are divided into hillslope processes, hillslope and channel processes, and channel processes. Papers in the first group describe erosional processes that remove material from slopes; papers in the second group describe interactions between streamside hillslopes and stream channels; and papers in the third group discuss stream processes.

HILLSLOPE PROCESSES

Papers on hillslope processes describe major landslide types, creep, sheetwash and rilling, and gullying. The relative importance of these different processes differs in different parts of the basin. Some of the papers discuss the effects of land use on particular erosional processes.

Swanston and others (chap. E, this volume) discuss creep and earthflow rates in the basin. Inclinometer measurements indicate that creep is particularly active on schist slopes within the basin, with rates ranging from 1.0 to 2.5 mm/a. Complex earthflows occur primarily on slopes underlain by sandstone and mudstone. Inclinometers installed on earthflows indicate that movement rates can be as much as two orders of magnitude faster than creep rates. In both types of mass movement, the timing and magnitude of displacement respond primarily to within-year variations in precipitation.

Nolan and Janda (chap. F, this volume) describe results of 9 years of study of two earthflows within the basin. Annual moisture conditions appear to control the timing of movement in these two earthflows in a fashion similar to that described by Swanston and others. However, variation in mass distribution within the earthflow body, over time, appears to be a major control of temporal and spatial variations in movement rates. Surficial movement rates of these features ranged from 0.01 to 15.3 m/a. Sediment yield from the two earthflows ranged from 730 to 25,100 (Mg/km^2)/a. Earthflow movement rates reported by Nolan and Janda are an order of magnitude faster than those reported by Swanston and others because Swanston and others used inclinometer data to study less active features or portions of features than did Nolan and Janda, who used resurveys of surficial stakelines to monitor movement. Swanston and others purposely avoided extremely active areas to prevent rapid shearing of the inclinometer tubes.

The history of all mass movement processes in the Redwood Creek basin is discussed by Harden and others (chap. G, this volume). Processes discussed include debris slides, debris avalanches, and earthflows. Harden and others' study was based on interpretation of aerial photographs and indicated a dramatic increase in streamside landslides between 1947 and 1976. Debris slides showed the greatest increase, whereas earthflow activity did not increase significantly. Most of the increase occurred in the interval from 1962 to 1966, reflecting both the impact of the December 1964 storm and intensive timber harvest and road construction in the late 1950's and early 1960's. The impact of storms in 1972 and 1975 on streamside landslides was less dramatic than that of the 1964 storm. Harden and others suggest that this may represent the fact that most unstable slopes had failed during the 1964 storm.

Erosion by overland flow and gullying in the Redwood Creek basin has been studied by Marron and others and by Weaver and others (chap. H and chap. I, respectively, this volume). Both chapters emphasize the impact of logging on these processes. Marron and others investigated the effect of logging on rates of rilling and erosion by overland flow on forested slopes underlain by schist and sandstone. There was no discernible difference between rates of these processes on logged and unlogged slopes underlain by sandstone. However, where timber was harvested by tractor- or cable-yarding on slopes underlain by schist, rates were 4 and 15 times greater, respectively, than rates recorded on unharvested schist slopes.

Weaver and others discuss the causes of gully erosion on logged sandstone slopes in the lower one-third of the Redwood Creek basin. They show that extensive disruption of surface drainage by tractor logging and construction of logging roads can lead to major gully erosion. Large storms in 1972 and 1975, which occurred within 1 to 5 years of logging, triggered much of the gully erosion.

HILLSLOPE AND CHANNEL PROCESSES

Essential to the study of geomorphic process in the Redwood Creek basin is the investigation of the interaction between hillslopes and stream channels. Colluvium delivered to channels by streamside landslides is an important sediment source that appears capable of overwhelming the transport capacities of high-order channels. Four papers in this volume explore the linkage between hillslopes and stream channel processes.

Kelsey and others (chap. J, this volume) present a geomorphic analysis of streamside landslides along Redwood Creek and major tributaries. Along the 100 km length of the main channel, landslides are concentrated in two reaches, both of which have a well-defined inner gorge that is the product of streamside landslides coalescing over thousands of years. Even though landslides are the single most significant source of coarse sediment to the main channel, reaches of high landslide input are characterized by high stream gradients and are therefore reaches of low sediment storage in the main channel. In contrast, low gradient reaches with minimal streamside landsliding are reaches of greatest sediment storage.

The relationship of landslides to sediment storage in 16 tributaries of Redwood Creek was studied by Pitlick (chap. K, this volume). Sediment production by landslides in tributaries is comparable in magnitude to the volume of sediment delivered by landslides along the main channel. In the majority of tributaries, the amount of sediment stored in the channel is small compared to the annual supply of coarse sediment from the hillslopes. Most sediment is rapidly flushed out of tributaries into the main channel during moderate to large storm events. The subsequent transport of coarse sediment down the main channel of Redwood Creek is a much slower process (chaps. N, O, this volume).

In another study of tributary streams, Nolan and Janda (chap. L, this volume) used water and suspended sediment discharge data from eight streams to assess the impacts of tractor-yarded clearcut timber harvesting on sediment discharge to Redwood Creek. The results represent the cumulative effects of hillslope and channel processes in these tributaries. Synoptic sampling during nine storms indicated that water discharge per unit area from streams draining harvested terrain was roughly twice that from unharvested terrain. Suspended sediment discharge was as much as 10 times greater from harvested terrain as from unharvested terrain. Sediment transport relationships examined by Nolan and Janda (chap. L, this volume) agree with the findings of Pitlick (chap. K, this volume), which indicate that tributaries are major contributors of sediment to the main channel during periods of high flow. These high-flow periods are exceptionally effective in removing sediment from tributaries, and sediment is delivered to the main channel faster than it can be removed at these times.

A sediment budget describing all major geomorphic processes in the Garrett Creek basin, a 10.8-km^2 tributary draining sandstone and mudstone slopes on the east side of Redwood Creek, is presented by Best and others (chap. M, this volume). The study period, 1956 to 1980, represents a period of accelerated erosion within the basin because it includes a period of widespread timber harvest and a sequence of major storms. During the study period, fluvial erosion contributed 62 percent of the sediment to the main channel of Garrett Creek, and streamside landslides contributed the remainder. Almost all significant sources of fluvial erosion involved gully erosion caused by road construction and logging. The sediment found in storage along the lower main channel of Garrett Creek represented only 6 percent of the total sediment input for the 25-year study period. Most erosion and sediment transport in the Garrett Creek basin occurred during short-duration, large-magnitude events.

CHANNEL PROCESSES

Four papers in this volume deal strictly with channel processes. The report by Nolan and Marron (chap. N) describes changes in the geometry of Redwood Creek that were instrumental in arousing concerns for parkland resources. The main channel widened by as much as 100 percent and aggraded by as much as 4.5 m as a result of the 1964 storm. Land managers were concerned that, if such channel changes continued, the aquatic habitat would be damaged and many of the riparian redwood trees would be destroyed. Observations of effects from the 1964 storm, coupled with poststorm monitoring of changes in channel geometry and grain size distribution of channel bed material, suggest that events such as the 1964 storm impose a strong and long-lasting impact on channel geometry. Data presented by Nolan and Marron indicate that some basinwide recovery has occurred since the period of major channel changes initiated by the 1964 storm.

The article by Madej (chap. O) relates the channel changes noted by Nolan and Marron to changes in sediment stored along the main channel of Redwood Creek. By use of data from the field and from aerial photographs, Madej quantified the role of various alluvial features (flood bars, point bars, channel aggradation, debris jams, and so on) in the storage of sediment in the main channel. Wide channel reaches are particularly important storage sites. Madej also computed residence times for sediment stored in four reservoirs with decreasing probability of transport: active, semiactive, inactive, and stable sites. The 1964 storm increased sediment stored along the channel by 1.5 times. Both Madej's report and that of Nolan and Marron indicate that channel recovery from the 1964 storm has been slow and that storm effects will probably persist for decades longer. Both indicate that there has been a downstream migration of the locus of channel aggradation with time. Long periods of moderated flow will be needed to flush 1964 sediment from the channel. Future high-magnitude flows would probably slow recovery because these events flush sediment from tributaries and trigger landslides (chap. L and chap. K, this volume), and they deposit sediment in storage sites along the main channel (chap. L, this volume).

Channel morphology and sediment storage in small, steep, forested tributaries are strongly influenced by accumulation of large organic debris. Keller and others (chap. P, this volume) describe effects of organic debris accumulations in several tributaries. Data presented in their article indicate that large organic debris is associated with 30 to 60 percent of the total channel elevation drop along studied streams and with the storage of sediment equal to 100 to 150 years of average bedload transport. They find that redwood-dominated organic debris commonly remains in place longer than 100 years and is therefore considered an integral part of the channel system. The article also indicates that large organic debris sustains a healthy population of anadromous fish because it provides both habitat diversity and sites for organic nutrient processing and it buffers the release of stored sediment.

The last of the erosion and sediment transport papers (chap. Q, this volume) describes sediment transport in the estuary and along the beach at the mouth of Redwood Creek. The distribution and transport of sediment in the Redwood Creek estuary were greatly altered by construction of a flood control levee along lower Redwood Creek in 1968. As a consequence, the sloughs and a portion of the estuary have become filled with sediment since 1968, effectively eliminating 50 percent of the lower estuary. Sediment accumulation has altered the seasonal closure of the outflow channel to the ocean and has adversely affected habitat for both upmigrating and downmigrating anadromous fish.

AQUATIC HABITAT

Five additional reports discuss various aspects of the aquatic habitat of Redwood Creek. The articles by Averett and Iwatsubo (chap. R), Bradford (chap. S), and Triska and others (chap. V) consider aspects of timber harvest impacts on the aquatic habitat.

The general aquatic biota of Redwood Creek and selected tributaries are described by Averett and Iwatsubo. Their analysis is based upon diversity in community structure and indicates that the general habitat was of a high quality. They add, however, that, in areas of exceptionally high sediment transport and bed mobility, aquatic productivity was low. They emphasize that most of their data were collected during the period of maximum land disturbance (1973–75). Nolan and Janda (chap. L, this volume) linked timber harvesting to increased sediment yield, and Janda (1978) has linked it to increased frequency of bedload transport. These two reports coupled with the work of Averett and Iwatsubo suggest that timber harvesting was probably responsible for at least some reduction in aquatic productivity.

The effects of timber harvesting on the chemical quality of water in the main channel and selected tributaries was investigated by Bradford (chap. S). He found water quality throughout the basin at the time of his study to be excellent. However, his work did indicate some logging impacts. Bradford found an increase in calcium and bicarbonate in watersheds subjected to logging. He attributed this to accelerated weathering caused by increased exposure of surface soil in these watersheds. This work also has some implication for hillslope processes. Measurements of specific conductance and alkalinity done by Bradford indicate that overland flow is a larger component of peak flow in logged watersheds than in unlogged watersheds.

The effects of recent sediment deposition on the survival of anadromous fish in Redwood Creek has been a major concern of land managers. Increased streambed deposition has the potential to reduce intragravel circulation of oxygen-rich waters, which are needed for the survival of salmonid eggs. Woods (chap. T, this volume) found that intragravel water at the downstreammost of his three sampling sites had a significantly lower dissolved-oxygen concentration than did the upstream sites. He attributed this to reduced mixing with surface waters due to the smooth streambed surface and dense cover of periphytic algae at this site.

A little recognized factor that may affect the survival of anadromous fish are "cold pools" found by Keller and others (chap. U) along the main channel of Redwood Creek. These pools form high-quality summer habitat because water temperatures are commonly several degrees Celsius cooler than in surrounding areas. Keller and others suggest that "cold pools" are formed by cool effluent ground water from point sources such as dry tributary channels.

The final article in the volume, chapter V by Triska and others, discusses the role of the biotic community in nitrate uptake along Little Lost Man Creek, a 9.4-km^2 tributary basin near the mouth of Redwood Creek. This work indicates that, following clearcutting along one bank of a study reach, maximum uptake of dissolved inorganic nitrogen occurred during daylight hours in the years before development of a closed alder canopy. They expect biotic production to remain low until the canopy is reopened by natural mortality of the riparian alders. This reduced production may have impacts further up the food chain, perhaps even to carnivores such as fish. Triska and others point out that few long-term chemical data are available from clearcut reaches such as their Little Lost Man site, and they do not extrapolate their results to others areas or make basinwide predictions about timber harvest impacts. They do indicate that establishment of dense riparian alder growth following timber harvesting is common.

SUMMARY

Few conflicts exist between major findings of studies presented within this volume. There appears to be some uncertainty about the exact role of fluvial erosion in the basinwide sediment budget. Most articles emphasize mass movement processes because of their direct impact on high-order channels. The articles by Weaver and others (chap. I) and Best and others (chap. M) both indicate that fluvial erosion contributed more than one-half the sediment input in the basins they studied. These two studies were concentrated in areas highly disturbed by clearcut timber harvesting, and the degree to which these results can be applied throughout the basin is uncertain. The dispersed nature of fluvial erosion has made basinwide quantification of this process difficult.

In general, papers presented in this volume describe a delicate landscape that is sensitive to effects of both land use and major storms. Significant increases in sediment yield and runoff caused by the ground disruption and road construction associated with timber harvesting have been documented by Marron and others (chap. H), Weaver and others (chap. I), Nolan and Janda (chap. L), and Best and others (chap. M). The greatest impacts have been found in areas harvested by large-scale tractor-yarded clearcutting.

The landscape within the Redwood Creek basin is particularly delicate not only because ground disruption can easily increase erosion at a specific location but also because such increases can affect areas downstream or downslope. Nolan and Marron (chap. N), for example, suggested that one reason effects related to the 1964 storm were so widespread was that channel and hillslope processes are connected by a positive feedback loop. Such a loop was proposed by Colman (1973) and suggests that colluvium introduced by a single landslide is capable of initiating additional streamside landslides downstream. Such a loop can cause hillslope destabilization throughout long reaches of a channel as a result of a minimum number of failures in upstream locations.

Studies completed to date in the Redwood Creek basin have characterized the types and rates of major geomorphic processes operating within this rapidly eroding basin. This work also has described the general aquatic habitat and has focused on a few specific aspects of that habitat. In a basin where erosional processes are operating so rapidly and where these processes are so complexly interrelated, the potential for additional meaningful studies is great. For that reason it is hoped that the information presented in this volume will prove useful not only to studies directed at understanding geomorphic processes and aquatic habitats elsewhere but also to future studies within the Redwood Creek basin.

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