Logging Impacts on Jackass Creek: Mendocino, California

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Abstract: The Jackass Creek watershed, located in the Sinkyone Wilderness State Park, Mendocino County, California has experienced channel adjustments due to increased sedimentation from timber harvesting in the twentieth century. Absence of creek data necessitated analysis of air photos taken in 1963, 1975, 1981, and 1994. Linear string analysis of the creek between the mouth of Jackass Creek and the convergence of the North and South Forks has shown an increased sinuosity of .178 between 1963 and 1994. Road density analysis in the watershed shows a decrease of 95,537 ft/mi² to 45,559 ft/mi² over the same period.
Introduction

Timber harvest and road construction practices directly contribute to soil erosion in watersheds by removing stabilizing vegetative cover and by creating pathways through which water and sediment flow unimpeded into riparian zones. This process is particularly degenerative in areas with steep slopes, high annual or frequent precipitation, and loose soils. Areas of this sort that have undergone clear cutting, and necessarily road construction, in Northern California, are typically located in watersheds. The effects of elevated levels of sediment debris delivered to streams and creeks via the aforementioned pathways can lead to changes in fluvial morphology. These changes in previously undisturbed channels can alter traditional pool/riffle patterns, alter the amount of fine grain sediments that run through the system, and widen and reduce the depth of the channel, thereby increasing sinuosity. This affects not only the portion of the channel in immediate contact with the debris flow, but also morphology further upstream and downstream. These changes can be identified with air photo interpretation.

In order to understand and identify human influenced impacts of increased sedimentation on fluvial systems, it is necessary to identify their causes. Areas subjected to logging and road construction are more at risk to increased sedimentation than are undisturbed areas. LaHusen (1984) determined that the greatest potential for slope instabilities occurs where roads and skid trails cross steep slopes and wet soils located in headwater swales or along inner gorge slope positions. The 1984 LaHusen study did not account for clear cuts on slopes. However, he does cite Gresswell et al. (1979), who note that 70 percent of landslides in the northwestern United States are related to roads. We can assume then, that clear cuts (being the most destructive form of logging) associated with roads contribute a fair portion of the remaining 30 percent. Therefore, we can conclude that roads and their associated clear cuts increase the chances for slope failure and consequently to elevated levels of stream sedimentation. Once primary causes of increased sedimentation to streams have been identified, it is important to examine how sedimentation can influence fluvial morphology.
Ryan and Grant (1991) note that downstream effects of forest practices can occur when forestry activities include changes in the ways water, sediment, and woody debris move through the basin and are delivered to higher order channels. Logging and road construction can produce changes in onsite conditions, including altering hillslope cover and contour, compacting soils, and reducing root strength. These changes lead to a reduction in infiltration rates and soil cohesion, and increased sediment and debris input to streams. In their study area, Ryan and Grant (1991) observed that roughly 70 percent of the landslides and all of the surface erosion were associated with clear cuts on roads. The presence of open reaches, debris slides, and morphological changes were identified using historical and current air photos. Air photos taken in 1940, 1956, 1964, 1969, 1979, and 1986 were used to show channel conditions prior to logging and to reconstruct the overall disturbance history of the area. Ryan and Grant (1991) used the change in the number of gravel bars counted in the air photo series to demonstrate the sediment impacts on the Elk River. The change in the number of gravel bars provided a surrogate measure of sediment impact for the area.

Ryan and Grant (1991) also state that channels downstream from the landscape disturbance can experience changes in width, depth, or stability, producing damage to structures and riparian zones and affecting aquatic habitat in areas far removed from the original forestry activity. The primary morphological changes resulting from roads and logging in their study area were channel widening, channel aggregation in the form of gravel bars, and lateral channel migration. These changes occurred in reaches with wide, low gradients. Channel changes did not occur in steep, narrow reaches where channel boundaries abut bedrock.

The study area of this paper--Jackass Creek, California, has undergone severe logging and road construction from the early 20th century to the early 1980s. However, no known data exists as to the effects of logging in this area. Therefore, the purpose of this paper is to assess, with the aid of air photo interpretation, the change in sinuosity at the mouth of
Jackass Creek and the change in road density over a thirty-year period in the hopes that this information can be applied to future remediation projects.

**Site**

Jackass Creek is located in the Coast Range in north-western Mendocino County, California-- it’s headwaters on private lands held by the Intertribal Sinkyone Wilderness Council, running through the Sinkyone Wilderness State Park to its terminus at the Pacific Ocean. Jackass Creek forms its own distinct watershed (Figure 1) that consists of a North Fork, East Branch, and a South Fork with tributaries feeding into them. Jackass Creek is within the sedimentary Franciscan formation-- principally composed of shales, greywacke sandstone, chert, limestone, and conglomerates. Igneous rocks are primarily those of deep-seated origin where the magma is intruded into the deep-lying strata rather than extruded on the surface as lava (Hinds 1952). Physically, the area is dominated by steep-sloped canyons and loose soils. The coastal mountains are lower than those of the interior portion of the range, averaging 2,000 feet above sea level. Jackass Ridge--the headwaters of the creek--is about 1600 feet elevation. The area is subject to inherently wet conditions, particularly during the winter and spring months. The climate is moderate, with no marked variation between the seasonal minima and maxima. The annual precipitation is over 80 inches and fog is common in the dry season (Peak and Associates 1981).
Site History

For most of the late eighteenth and early nineteenth centuries, logging in Northern California was selective and had relatively little negative impact ecological impact. However, after the advent of coastal logging’s industrial revolution, technology became available that permitted increased timber harvests and resulted in greater environmental destruction.

Prior to 1890, logging was accomplished with simple hand tools and therefore was a slow process that resulted in sustainable extraction of timber from a region. Production was generally limited to areas where the local topography allowed transport via waterways and ox teams. Logging operations of this sort were usually small in scale. Most of the logging outfits were operated by local, independent mills logging redwoods in isolated river valleys. However, Jackass Creek is so remote that it is unlikely any logging occurred here in the late nineteenth century--rough seas prevented any ocean transport of timber and the main logging haul road (Usal Road) did not extend to the site. The expense of road construction at the time most likely kept the Jackass Creek watershed insulated from any harvest activity.

In the early twentieth century, lumber companies began to consolidate. By 1915, most of the timber was held by large companies. Changes in technology also occurred and in 1925, the Union Lumber Company first introduced tractors into the forest (Sullenberger 1980) These technologies encouraged increased harvesting and road building in order to access remote areas. Timber harvest history in the Jackass Creek watershed is limited, but it can be assumed that little harvesting occurred until corporate logging companies took ownership of the property in the 1940s. At this time Weyerhauser took control of the lands surrounding Jackass Creek. In 1949, Wolf Creek Timber Company bought the land and built the mill town of Wheeler around 1950 (Figure 2). Wheeler was destroyed in a freak storm in 1960 and was never rebuilt. After a series of ownerships, the land, then called the Upper Usal Tract, was bought by Georgia Pacific (GP) in 1973. Until this time, the method of harvest was tractor yarding, which required roads to be constructed
leading to areas slated to be logged. Tractor yarding is a method whereby trees adjacent to roads are cut and hauled out via tractor. After GP’s acquisition of the land, cable yarding was introduced as a method of extraction (Personal interview with Jere Melo).

This process allowed trees on the steep slopes between roads to be felled and dragged uphill with steel cables. This method not only increased extraction rates, but also created patches where the giant trees had removed vegetation and disturbed soils on their way up-slope.

By the time the Usal Tract was converted into State and private lands between 1983 and 1996, very little old growth forest remained. Today, much of the area has protective second growth and other vegetation. However, it can be assumed that during logging operations, increased erosion led to increased sedimentation into Jackass Creek.

**Variables Affecting Sediment Distribution**

Because no critical erosion or sedimentation analysis has been performed in the Jackass Creek watershed, it must be assumed that increased sedimentation in the creek has occurred as a result of logging. Thus, it is necessary to prove that higher than normal levels of sediments have entered the creek. It is also necessary to examine how an increase in sediment would impact Jackass Creek by examining other watershed and stream studies performed in physically similar areas. Therefore, detailed below are findings from studies conducted in the Pacific Northwest, Alaska, and Northern California that correlate increased sedimentation to logging and changes in fluvial morphology. These studies also attribute slope steepness, precipitation, and bedrock type as primary characteristics of areas prone to mass erosion.
Intuitively, slope steepness is a major factor in slope stability. Studies by Bilby et al. (1989) and Furniss et al. (1991) conclude that steep slopes are high-risk areas for roads and cuts because they are usually the most erosion prone areas in a watershed. A survey of forty management sites by LaHusen (1984) found that the prominent similarity between all study sites where debris flows originated was where local hillslope gradient exceeded 30 degrees. Much of the Jackass Creek watershed (outlined areas in Figs. 3a, 3b, and 3c), with the exception of the creek’s basins has a slope of over 30 percent.

Bilby et al. (1989) concluded that unstable soils also contributed to the delivery of sediment to streams.

Another contributing factor to increased soil erosion is precipitation. Not only is the total annual precipitation for an area important, but also the potential for large seasonal storms that drop large amounts of rainfall in relatively short periods of time. As noted in the site description, the Jackass Creek watershed has an annual precipitation of 80 inches and is shrouded in fog even in the drier summer months. Sudden, intense storms are also characteristic of the area. Ryan and Grant (1991) and Gray (1970) determined that landslides and debris flows in cut areas commonly occurred during large storms. Johnson and Beschta (1980), studying coastal areas with wet, mild winters and dry, warm summers, found that an
annual precipitation average of 48 inches contributed to high incidents of landsliding. Similarly, LaHusen (1984) concluded that mass movements in harvested areas were associated with high annual rains that occurred mostly during a single eight-month period.

The Pacific Northwest watershed studied by Reid & Dunne (1984) has not only steep slopes, but also unstable bedrock. Coupled with the seasonal rains that occur in the area and the intensity with which they fall, we can assume that most of this region is prone to sedimentation that is detrimental to the normal stream process. Bilby et al. (1989) concluded that delivery of sediment to streams as a result of mass movement is directly related to steep slopes and unstable soils. McCashion and Rice (1983) noted that the most erosive of all rock types were the hard sedimentary formations. Dodge et al. (1976) concluded that mass movements can occur in any type of parent material and soil texture when slopes approach or exceed the critical angle of repose. Some shales, and heavy clay soils derived from them may be subject to earth flow on slopes as gentle as ten percent. Fractured and agglomerated rocks—such as Franciscan formation—may slide or flow at low angles. Because the Jackass Creek watershed is characterized by steep slopes, high annual precipitation, and unstable bedrock, it must be concluded that any alteration of the natural environment will increase the potential for increased sedimentation in this already unstable setting. Perhaps the most important hillside stabilizer is the vegetation that is removed during logging.

Vegetation & Hillside Stability

Vegetation on steep, unstable slopes is crucial in limiting slope failure and increased erosion. Once vegetation has been removed, exposed soils are highly susceptible to erosional processes. Not only does timber harvest, particularly clear cutting, remove protective cover, but it compacts soils, reducing infiltration capacity. According to Gray (1970), vegetation acts to preserve hillside integrity through mechanical reinforcement from the root system and modification of soil moisture distribution and pore water pressures.
Mechanical reinforcement of soils from root systems is perhaps the most important effect of trees on slope stability (Gray 1970). In this process, root systems effectively act as anchors, providing support along local zones of weakness within rock and soil mass (Amaranthus et al. 1985). This is particularly important in regions dominated by redwoods. Redwoods, lacking taproots, fan their roots out to cover large areas, often intertwining with the root systems of nearby redwoods. Once a section of land has been cleared, stumps left behind begin to rot, diminishing soil stability until other root systems can establish themselves. However, vegetative reestablishment becomes more difficult once productive topsoils have been washed away.

Modification of soil moisture distribution occurs as trees absorb water from the soil as they transpire. The absorption of water through the roots additionally creates a suction (negative pore water pressure) that increases slope stability. Although this effect is not as crucial as mechanical reinforcement, Hoover et al. (1953) determined that this process is conductive to slope stability. Further, forest canopy and ground litter intercept moisture, which add to a forest’s ability to prevent slope failure. In addition to soil erosion, broad expanses of shallow water moving downslope, or infiltration-excess overland flow (Clark 1990), is dramatically increased by soil compaction. Johnson and Beschta (1980) attribute the majority of this compaction to tractor logging, tractor windrowning of slash, and burning of slash, all common logging practices. Once vegetation is removed from a hillside, mass wasting is much more likely to occur. Mass wasting is spontaneous downward movement of rock and soil (Clark 1990). This can include small movement such as creep, or large movements such as mud/earthflows, slumps, and landslides. These types of movement can deliver large amounts of sediment directly or indirectly into streams and creeks. This sedimentation effectively alters channel morphology once it is introduced to the stream.
Channel Degradation

Changes in terrestrial characteristics due to logging can increase the amounts of sediment, water, and debris delivered to streams. Channel degradation can occur in the form of channel migration, bank erosion, and increased sedimentation, causing channels to become wider and shallower with fewer pools and more riffles (Chamberlain et al. 1991). Typically, vegetation buffers along stream channels prevent large amounts of sediment from entering streams. However, logging creates open reaches, or open canopies, along stream channels. Ryan and Grant’s 1991 study of the Elk River Basin, Oregon found that the number of channels exhibiting open reaches increased concurrently with increased harvesting and road construction. Prior to tractor yarding, logging of Jackass Creek was isolated to level areas. These areas were primarily ridge tops and the flatter creek channels. This activity would account for increased sedimentation in the lower reaches of the creek, although the amounts of sedimentation would probably have been limited, due to shallow slope. However, with the advent of tractor yarding and better road building techniques, the steeper upstream slopes were made accessible and would probably have contributed the bulk of existing sediment to the creek. Therefore, it is safe to assume that major morphological change would have occurred in Jackass Creek after 1940.

Although most streams carry varying amounts of seasonal sediment, roads substantially change the magnitude, timing, and duration of sediment transport. Poorly designed roads and skid trail systems are persistent sources of sediment, as are open slopes whose soils have been exposed by yarding activities, mass movements, scarification, or intense fire (Chamberlin et al. 1991). The use of culverts especially influences degradation because runoff and sediment are concentrated in areas that normally have lower flows. This results in higher overland flows, sedimentation from the road, and increased erosion on slopes and translates into increased sedimentation in watershed areas. Barring historical measurements of in-stream sediment loads, increased load can be indicated by an increase in sinuosity over time. Another indicator, given the impact of roads on
watersheds, is road density. Logical reasoning concludes that an increase in road density in a watershed will lead to an increase in sediments delivered to a stream system. Thus, techniques detailed in the “Methods” section were employed to measure changes in sinuosity and road density.

**Methods**

Although the Jackass Creek watershed has been logged extensively over many decades, no analysis has been conducted on sediment loads in-creek. Therefore, changes in sinuosity and road density over a 30-year period (1963-1994) were measured to give an indication of logging impacts in the watershed. These changes were measured using air photos acquired at the Georgia Pacific headquarters in Fort Bragg, California for the years: 1963, 1975, 1981, and 1994.

Because the air photos were at unknown scales, it was necessary to determine scale using a ground-photo ratio. Scale was determined using the following formula:

\[
RF \text{ (Relative Fraction)} = \frac{1}{GD \text{ (Ground Distance)/PD \text{ (Photo Distance)}}}
\]

GD was measured on the 1969 USGS Bear Harbor topoquad (scale: 1:24000). Distance was measured as the crow flies (ACF) from the mouth of Jackass Creek to the western convergence of the South Fork and converted into feet. This distance was then divided by the corresponding ACF measurement from each air photo. The results showed that the 1963 and 1975 photos were at a scale of 1:15000. The 1981 and 1994 photos were at scales of 1:12000 and 1:16250, respectively. Once scale was determined, sinuosity analysis was conducted.

The area chosen for sinuosity analysis was selected for its gentle topography. This was determined with the 1969 Bear Harbor topoquad and slope analysis (Figs. 3a-3c) conducted by California State Polytechnic University (1995). The study area was also the only area consistently visible in all air photo years. Sinuosity measurements are for
the length of creek between the convergence of the North and South Forks and the mouth of the creek in each photo year. Sinuosity is the measure of stream length in relation to valley length. The formula for this relationship can be represented as:

\[ S (Sinuosity) = \frac{SL (Stream Length)}{VL (Valley Length)}. \]

SL and VL were measured using linear string analysis (LSA), which is a process of using thread to measure PD of VL and SL, measuring the resulting thread length in inches, and converting inches into feet. Measurements for photo years, SL, and VL, respectively, are as follows: 1963: 1.97", 1.44", 1975: 2.25", 1.56", 1981: 3.16", 2.25", 1994: 1.84", 1.19". Once sinuosity was represented mathematically, change in sinuosity was analyzed.

Finally, road density was measured using the formula:

\[ RD (Road Density) = \frac{RL (Total length of roads [ft])}{GA (Ground Area [mi^2])}. \]

The study area for road density analysis was limited to the extent of the 1981 photos. This area was bounded by the Pacific Ocean to the west, and roughly 8000 ft N, 14000 ft E, and 5000 ft S of the mouth of Jackass Creek. Once the study area was defined, a numbered grid overlay consisting of 2000 ft² squares consistent with the corresponding scale was constructed for each photo year. Grid square sizes were: 1963 and 1975 = 1.6 in., 1981 = 2.0 in., 1994 = 1.5 in. Five sample plots for each overlay/photo year were chosen using the random number generation function on a Casio fx-115W S-V.P.A.M. calculator. RL was measured for each plot using LSA. Measurements for sample plots of each photo year were added and converted into feet based on photo scale. The total area of the five sample plots (40,000,000 ft²) was calculated by multiplying the area of one plot by 5. In order to convert the total area into mi², 27,878,400 (ft² area of a mile) was divided into 40,000,000. The resulting figure, .717, was then divided into RL to estimate total road density for each photo year.
Roads are defined as: any man-made route, including haul roads, skid trails, or tractor trails. Roads are generally the lightest terrestrial feature in the photos, but are sometimes obscured by overhanging vegetation. Therefore, any shaded linear feature is counted as road. Any linear feature with discernable second growth vegetation is not counted. Land slides and amorphous bare patches not connected to roads are not counted.

**Results**

Sinuosity and road densities for Jackass Creek are represented in Tables 1 and 2 below:

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<tr>
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</thead>
<tbody>
<tr>
<td>Sinuosity</td>
<td>1.368</td>
<td>1.442</td>
<td>1.404</td>
<td>1.546</td>
</tr>
</tbody>
</table>

Table 1

Sinuosity for the study area increased .178 over the thirty-year period, indicating that increased sediment has reduced the stream power of Jackass Creek.

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Road Density</td>
<td>95,537 ft/mi²</td>
<td>89,785 ft/mi²</td>
<td>48,536 ft/mi²</td>
<td>45,559 ft/mi²</td>
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</tbody>
</table>

Table 2

Road density decreased 49,978 ft/mi² over the thirty-year period. Possible reasons for this inverse relationship between sinuosity and road density are mentioned in the “Discussion” section.

**Discussion**

An increase in sinuosity indicates a reduction in stream velocity. A decrease in velocity is an indicator of elevated levels of in-stream sediment load. The increase in sinuosity at the mouth of Jackass Creek over a thirty-year period, therefore, indicates an increase in sedimentation in the watershed. As noted earlier, Ryan and Grant (1991) concluded that areas with wide, low gradients were more prone to channel migration than were steeper
areas. Thus the impetus for site selection at the mouth of Jackass Creek. Also, the mouth is affected by the total sediment load delivered to the watershed. Unfortunately, the absence of any historical data makes it impossible to link this sedimentation to logging activity in the area. However, given the pre- and post-reactions of similar study areas to logging, it is fairly safe to assume that logging in the watershed was and continues to be a major contributor of sediments to the creek.

Although seemingly counterintuitive, the inverse relationship between sinuosity and road density can be attributed to several factors. First, as timber harvesting techniques changed from tractor yarding (1963 air photo) to clear cutting (1975 air photo), more areas in the watershed were accessible to harvest and more timber was extracted. Because clear cutting employs cable yarding extraction, many preexisting roads may have been used to log the slopes previously inaccessible to tractor yarding. This change in harvest practice resulted in a reduction in the number of new roads needed and an increase in hillside denudation and erosion. Therefore, an increase in sedimentation probably resulted. Also, preexisting roads in clear cut areas may have been obscured once the land had been cleared. Had this study included clear cut and road density, total density would have increased over time.

Secondly, the study area was taken out of timber production around 1983. No new roads were added to the watershed and existing roads were not maintained; allowing secondary growth to obscure smaller roads and skid trails in the air photos. These roads may very well still be contributing sediments to the creek. A more accurate assessment of road location could be made by ground-truthing the area.

Finally, the creek may be demonstrating a lag in reaction time to increased sedimentation. Graf (1977) states that stream systems are usually in a condition that approximates a steady state prior to human interference. He also notes that relaxation (or adjustment) times of fluvial systems do not immediately shift from one state to another. In other words, Jackass Creek may still be adjusting to sediment deposition that occurred a decade or more ago. Additionally, Allan James (1989) found that long-term storage of mining
sediment in the Bear River, California led to elevated levels of sediment discharge more than 80 years after mining activity had stopped in the watershed. One of the signs of sediment storage that he observed was lateral channel migration. Although Jackass Creek was not subjected to sediment levels as high as those on the Bear River, logging in the area did create sediment volumes much greater than pre-logging levels. This lag in response time could account for the inverse relationship between road density and sinuosity.

A critical evaluation regarding this project’s measurement techniques concludes that there is most likely a large margin for error using LSA. More accurate road density and sinuosity analysis can be made using a milometer (a hand-held device that measures feet/meters based on scale). Additionally, the air photo could be scanned into an editing program (e.g. Photoshop) and the study area could be enlarged, aiding in the ease of measurement. Probably the most accurate and less time intensive method of analysis using ERDOS software should be utilized if available. ERDOS is able to select and perform analysis on features based on their spectral wavelengths.

Future study of the Jackass Creek watershed should include road assessment for density and major contributors of sediment to the creek. Because it may be only a few sites responsible for most of the erosion (Peters and Litwin 1983 and Rice and Lewis 1991), it may be more effective to identify these sites and begin remediation rather than trying to estimate erosion volume. Major contributors may include unmaintained culverts and roads on inner slopes of the watershed.

Given the lack of knowledge of the area, this assessment would act as a baseline for future analysis. Methods used in the sinuosity study can be used to determine the change in sinuosity for earlier photo years. If the harvest history (including a chronological record of harvest techniques) can be located and if rates of change in sinuosity can be attributed to different harvest techniques based on earlier air photos, it may be possible to estimate the pre-logging sinuosity of Jackass Creek. This figure could then be used to return the creek to its original form.
Conclusion

Historically, logging in Northern California has gone through a progression of selective cutting to clear cutting. As harvesting practices have changed, so, too have they altered the natural landscape. One effect of intensive cutting practices has been an increase in the levels of sediment delivered to creeks and streams, thereby altering their traditional flow regimes. The removal of trees and other vegetation removes anchoring root systems and reduces soil permeability, resulting in elevated levels of sediment flowing downslope. This leads to physical changes in stream and creek morphology.

One indication of this change is an increase in sinuosity. These changes, in the absence of current and historic on-site measurements, can be measured using air photos. When an accurate method of measurement is employed, reliable figures give an indication of the change of sinuosity over time.

The increased sinuosity at the mouth of Jackass Creek over a thirty-year period indicates that increased sediment load delivery has occurred as a result of timber harvest practices in the watershed. This increased sinuosity is inversely related to the change in road density over the same time period. This can be accounted for by changes in harvest techniques between 1963 and 1975. Also, once the site became a state park in 1986, harvest activity ceased, although it is probable that unmaintained roads/culverts are still delivering sediments to the creek.

For Jackass Creek to begin to return to traditional flow patterns in a timely manner, major sources of sediment must be identified and mitigated. Future research in this area should include an assessment of major sediment contributors to the creek and specific removal/mitigation techniques depending on the type of contributor involved. Attempts should also be made to try to estimate the change in sinuosity since logging began in the watershed.
References


Personal Communications
