



Monitoring of Sediment Volume in Bedrock Stream Pools (tinajas) in Saguaro National Park, 2005-2010

Repeat photo of a tinaja (bedrock pool) in Loma Verde Canyon, Saguaro National Park before (left) and after (right) the 1999 Box Canyon Fire



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Description
Credits

Monitoring of Sediment Volume in Bedrock Stream Pools (tinajas) in Saguaro National Park, 2005-2010

Natural Resource Report NPS/SODN/NRR-2011/___

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Report to Saguaro National Park, May 2011
U.S. Department of the Interior
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Fort Collins, Colorado

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Abstract

Bedrock stream pools (also called tinajas) in Saguaro National Park's Rincon Mountain District are critical habitat for wildlife and an important indicator of ecosystem health. Wildfires, floods, and the sedimentation of pools and stream channels are part of the natural hydrologic process of this region. However, years of fire suppression appear to have increased fire intensity and post-fire flooding, which have in turn greatly increased the amount of sediment in tinajas. In 2005, Saguaro National Park initiated a monitoring program to track the long-term dynamics of sediment in tinajas and better understand the connection between fire events and stream dynamics. Results of surveys of 24 tinajas conducted during 2005-2006, 2007, and 2010 confirm that large sediment loads following fires move through streams very slowly, on the order of decades rather than years. The data also suggest that major floods, such as occurred in 2006, are also important drivers of sedimentation patterns on a local scale. These surveys have enhanced our knowledge of stream dynamics throughout the Rincons, and have the potential to help us better understand the time scale of these changes in relation to fire events in the arid Southwest.

Acknowledgements

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Introduction

Second Order Heading

Fire has historically been a natural occurrence in the higher elevations of Saguaro National Park and has played an important role in ecosystem health throughout the area (Baisan and Swetnam, 1990). Severe fires have the capacity to greatly affect soils and sediment transport throughout the watersheds where they occur (Parker, 2006). Fire frequency and intensity appears to have been greatly altered due to suppression and management by humans (Baisan and Swetnam, 1990). Although fire suppression in the Rincon Mountain District of Saguaro National Park has in general been less effective than other “Sky Island” mountain ranges of southern Arizona, recent large fires, such as the 1989 Chiva Fire, 1994 Rincon Fire, 1999 Box Canyon Fire, and 2003 Helen’s II Fire, have been severe in some areas (Saguaro National Park, 2004). A study of sedimentation following these large fires in the park indicate that the combination of fire-exposed soils and the huge flood events that occur when vegetation is removed leads to dramatic increases in sedimentation downstream,

both in stream channels and in rocky pools known locally as tinajas (Parker 2006).

In the northern Sonoran Desert and Saguaro National Park (Figure 1), tinajas represent essential habitat for aquatic amphibians and reptiles such as the lowland leopard frog (*Rana yavapaiensis*), Sonoran mud turtle (*Kinosternon sonoriense*), black-necked garter snake (*Thamnophis cyrtopsis*), canyon treefrog (*Hyla arenicolor*), and others (Edwards and Swann 2003). Many of these pools are spring fed and therefore offer a guaranteed year-round habitat for these species in an otherwise dry desert landscape. Larger terrestrial mammals, as well as birds and bats, also use these areas as a water source, especially during drier periods of the year. Because extreme sedimentation events can eliminate surface water and dramatically reduce aquatic habitat (Wallace et al. 2006), understanding sediment dynamics in these pools is important for species preservation and habitat restoration programs. More importantly, monitoring sediment in relation to fire on a park-wide scale can help the park

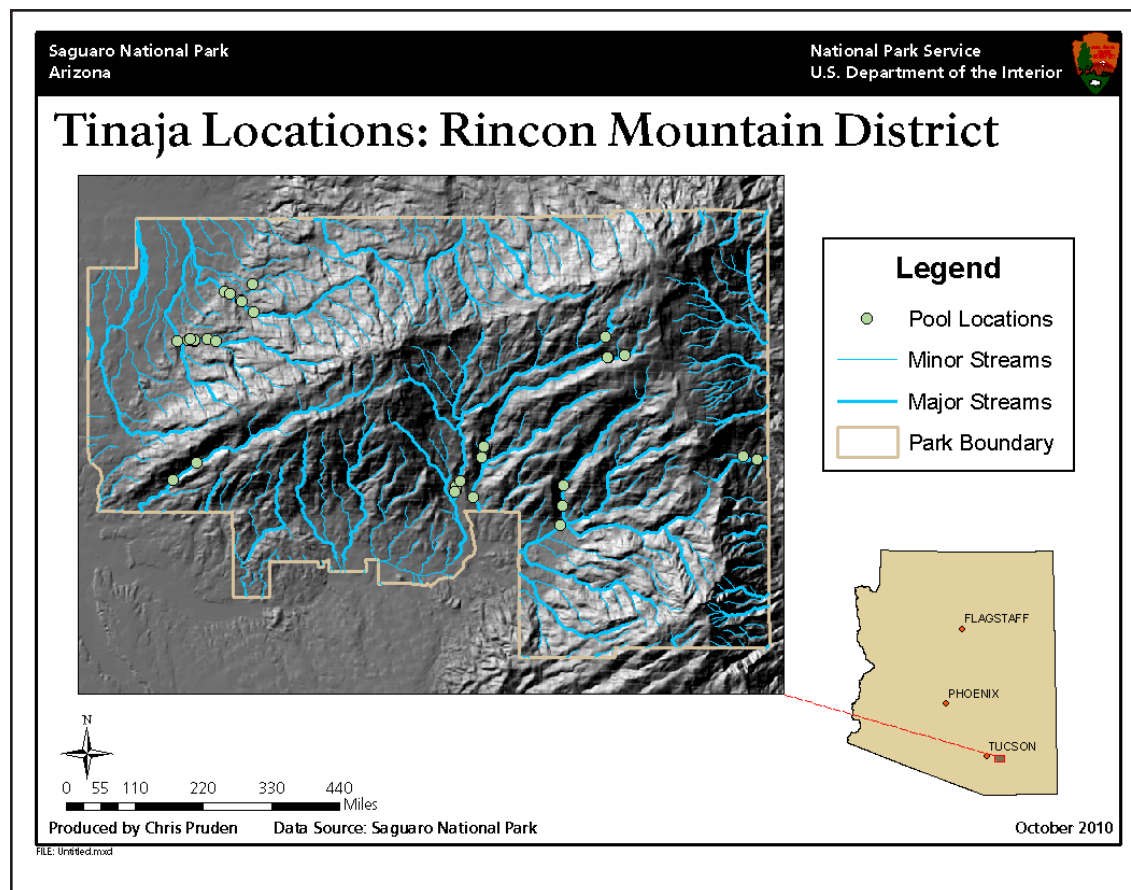


Figure 1. Map of the Rincon Mountain District of Saguaro National Park, showing locations of tinajas surveyed during this study.

anticipate the effects that future fires may have on aquatic habitat and water availability, better understand the broad implications of fire suppression and its effect on flood dynamics, and provide valuable information for fire management. The ultimate goal of this study is to use repeated measurements of sediment volume in tinajas throughout the Rincon Mountain District of Saguaro National Park to understand their dynamics on a decadal and multi-decadal scale.

Methods

Second Order Heading

All pools surveyed during this study are in the Rincon Mountain District of Saguaro National Park, east of Tucson, Arizona (Figure 1). This district of the park encompasses approximately 272 km² (105 square miles), ranging in elevation from 762 m (2500 ft) to over 2591 m (8500 ft). The Rincon Mountains dominate the landscape and are characterized by rugged terrain and severe topography. All but one of the streams surveyed originate at or above 1829 m (6000 ft) and all continue down into the valley below. At upper elevations, their channels tend to be dictated by bedrock while in lower areas the streams become alluvial washes with less distinct bounding.

We focused on tinajas in the upper portion of these channels where bedrock still plays a large role in the course and structure of the stream. These pools can be formed by water erosion in several ways, including sediment scouring and larger rock movements. Under natural hydrologic conditions, some pools appear to have no sediment or a low volume of sediment, while others have larger sediment volumes and development of patches of emergent vegetation, shrubs or trees. These differences are certainly dictated by the flow rate of water, bedrock topography, and other hydrological and geological features. Pools in our study ranged from 2 to 10 meters (6 to 30 ft) in length with depths of 0.3 to 3 meters (1 to 9 ft) deep.

Pool sediment survey methods were developed in 2005 and are described in detail in Perger (2005). We surveyed 25 pools in 2005-2006, 32 pools in 2007 (the original pools plus 7 others) and all 32 pools in 2010 plus one new pool. We did not randomly select streams but chose them based on Saguaro National Park's

monitoring program for lowland leopard frogs (Swann and Wallace 2008), which encompasses all major mapped streams in the park. Within streams, we did not randomly select pools, but selected them based primarily on leopard frog occupancy history and secondarily on geographic representativeness. We surveyed pools using survey equipment (transit level and stadia rod) with a 1 or 2-ft square grid system (Figure 2). Following U.S. Geological Service standards, we collected data in metric English feet. At each pool we established, mapped, and photographed the four datums based on readily identifiable features in the bedrock. Datum 1 is the location of the transit level used to take pool measurements and is located on a stable location where the entire pool can be viewed without obstruction. Datum 2 is located at the inflow point of the pool and the (0,0) point for the survey grid. Datum 3 is the stream outflow point and represents the "end" of the pool. Datum 4 is located at a



Figure 2. Transit level and a measuring tape forming the baseline (x axis) of a pool being surveyed.

fixed point above the high water mark of the pool that can be relocated easily for future surveys. The function of datum 4 is to normalize the height of the transit level between different surveys.

After establishing the datums we set a baseline down the center of the pool that was used for all subsequent measurements. This baseline, actually a tape measure, in intervals of metric feet, stretched between datums 2 and 3 and represents the x axis of the pool. At regular intervals (usually 1-2 feet) along the baseline we laid a second tape perpendicular to the baseline, and took measurements at regular intervals (usually 1-2 feet) along a y axis that continued out to the edges of the pool. In the original survey the elevation of the high water mark was recorded to help calculate pool sediment change. To map the rock contours of the pool on the original survey we inserted a steel probe 2 m in length through the sediment to bedrock, and measured the depth using a stadia rod.

In 2010, as in 2007, we used a team of 3- 4 people to systematically re-map each pool. We located all 4 datums and placed the transit level as close to datum 1 as possible. Using the stadia rod and the survey transit we re-measured all of the datums for data normalization purposes. We then placed the stadia rod on the sediment surface at each coordinate on the original x-y grid (Figure 2) and read the elevation using the transit level. We recorded the distance between the sediment and the transit elevation for each location on paper data sheets in the field, then entered the data into a Microsoft Excel spreadsheet and independently checked each data point. Because the transit elevation was expected to vary among surveys, we normalized the data based on the original and re-survey measurements of the vertical datum 4, then entered the x-y coordinate and sediment elevation data into the topographic mapping software program Surfer® (<http://www.goldensoftware.com/index.htm>) to create a topographical surface image and sediment volume estimate for each pool (Figure 3).

To determine the relationship between wildland fire, stream sedimentation, and time, we examined five major fires in the Rincon Mountains: the 1989 Chiva Fire,

1994 Rincon Fire, 1994 Mothers Day Fire, 1999 Box Canyon Fire, and the 2003 Helen's II Fire (Figure 4). These fires are known to have had a large affect on the sedimentation processes in the watershed areas of nearly all the streams we sampled (Parker 2006). We focused on three factors to assess the effect that these major fires have had on sedimentation processes in the Rincon Mountain range: date of fire, area of watershed burned, and elevation of the fire event. These data were readily available in digital format from Saguaro National Park. We examined burn areas on a watershed scale by using geospatial analysis applications in the ESRI ArcMap®. These techniques allowed us to extract, visualize, and measure the area of burned landscape within affected watersheds. We also used ArcMap® to visualize the topographic elevation lines, enabling us to determine the elevation profile of each fire.

We also analyzed the large flood that occurred in July of 2006 in relation to our sedimentation data. We did this to determine how large hydrologic events factor into sedimentation processes.

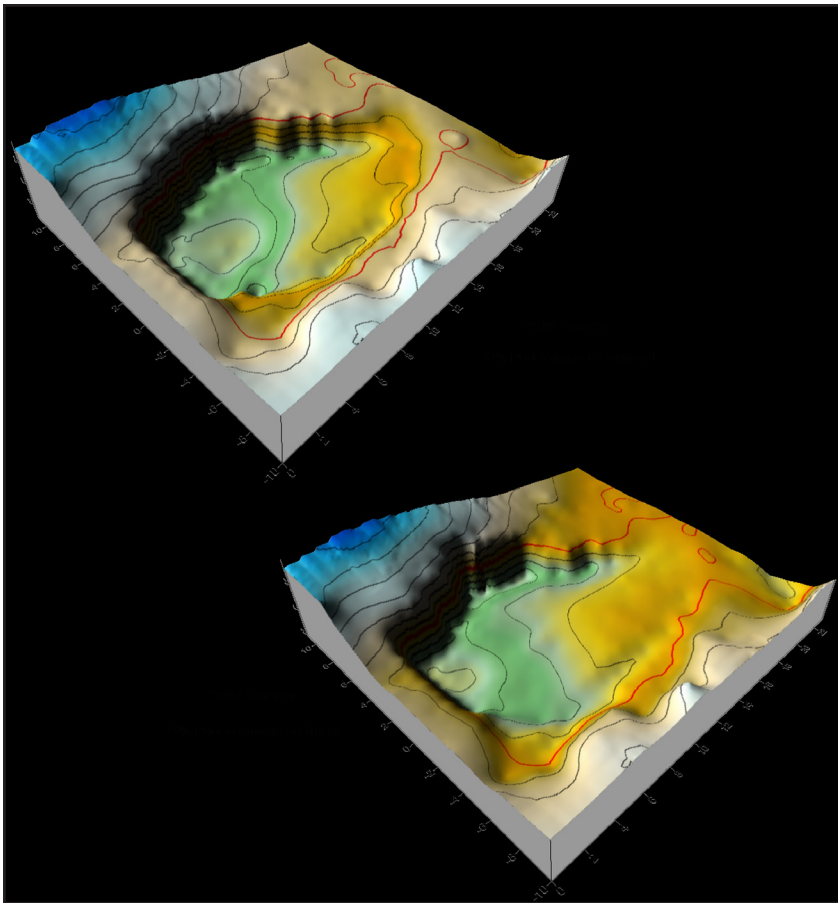


Figure 3. Visual output from the topographic mapping software Surfer, showing bedrock pool contours (above) and pool sediment contours in 2007 and 2010. Surfer output for all pools is in Appendix A.

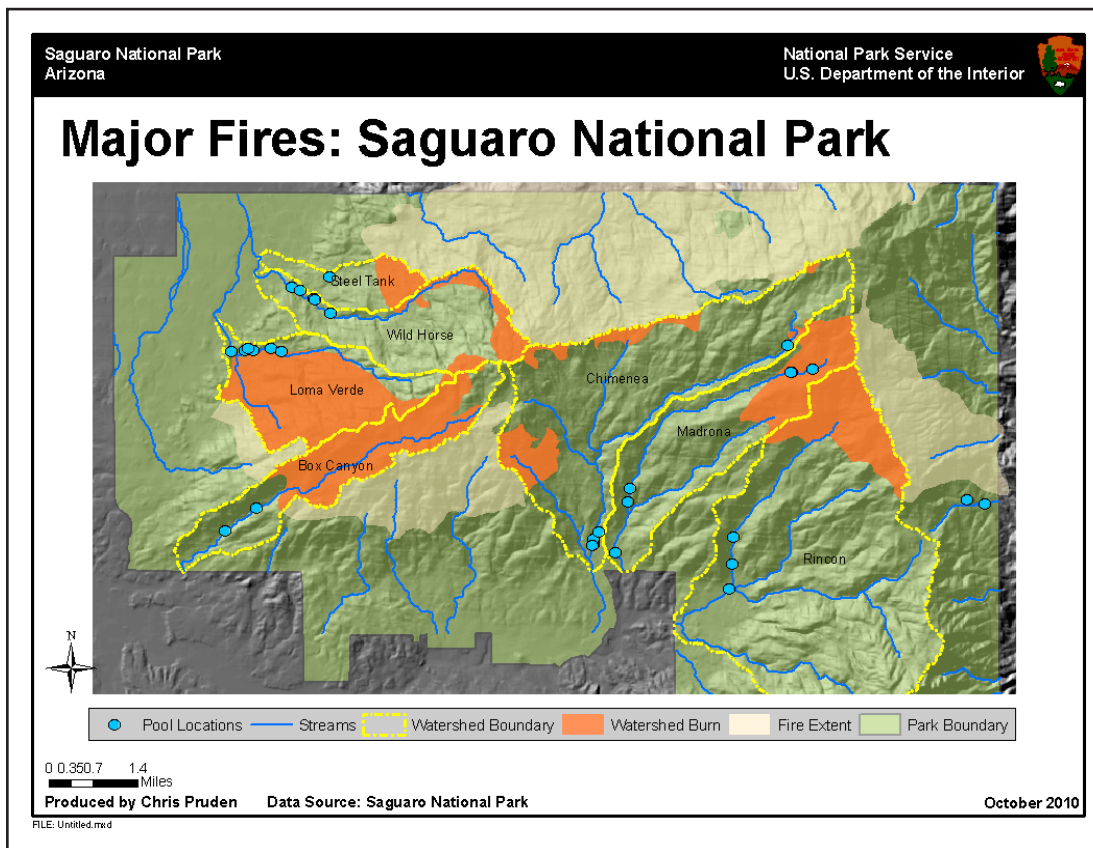


Figure 4. Rincon Mountain District of Saguaro National Park, showing recent (since 1989) wildland fire perimeters within major watersheds of streams surveyed during this study.

Results

Second Order Heading

Patterns over time. The percentage of pool volume that was sediment (hereafter, “percent sediment volume”) changed in all pools sampled during the three surveys of 2005-2006, 2007, 2010 (Table 1).

Several pools had no recorded sediment in 2005-2006, but all pools had at least some sediment in 2007 and 2010. The largest percent sediment volume in a pool was 123% in Loma Verde 6 in 2010. The largest increase recorded between surveys was 85% from 2005-2006 to 2007 in Rincon 5. The largest decrease was a 74% decrease from 2005-2006 to 2010 in Loma Verde 10. Some pools

only changed slightly between 2005-2006 and 2010; for example, percent sediment volume in Chimenea Pool 1L increased only 7% during the study period.

During the entire study period from 2005-2006 to 2010, percent sediment volume increased in 6 of 7 streams, and in 18 of the 24 pools sampled. During the shorter interval of 2007 to 2010, sediment change was more variable, with 3 of the 7 streams and 14 of the 24 pools increasing in percent sediment volume. Overall sediment volume was 0.36% in 2005-2006, 0.45% in 2007, and 0.42% in 2010 (Figure 5).

Table 1.

Pool Number	2005-2006 Survey	2007 Survey	2010 Survey
Box Canyon 6	0%	13%	12%
Box Canyon 1	27%	44%	35%
Chimenea 2J	20%	36%	24%
Chimenea 1L	0%	1%	7%
Chimenea 1E	18%	27%	28%
Chimenea 1C	14%	9%	10%
Loma Verde 10	153%	82%	79%
Loma Verde 9	36%	38%	13%
Loma Verde 6	110%	46%	123%
Loma Verde 4	101%	63%	13%
Loma Verde 2	95%	77%	66%
Loma Verde 1	44%	46%	83%
Loma Verde AV2	32%	86%	101%
Madrona 13	0%	9%	4%
Madrona 9	31%	42%	56%
Madrona 2	42%	79%	33%
Rincon North 2	23%	47%	52%
Rincon 5	0%	85%	39%
Steel Tank 4	0%	32%	10%
Wild Horse 19	0%	62%	11%
Wild Horse 15	26%	23%	68%
Wild Horse 13	0%	1%	47%
Wild Horse 8	7%	42%	11%
Wild Horse 4	75%	80%	93%

Table 1. Percent sediment volume for each pool surveyed in 2005-2006, 2007, and 2010. Zero percent indicates no sediment lies within the bed-rock contours of the pool; 100% indicates the pool is completely full of sediment to the high water mark; above 100% indicates that sediment is piled above the high water mark. For graphics for all pools, see Appendix A.

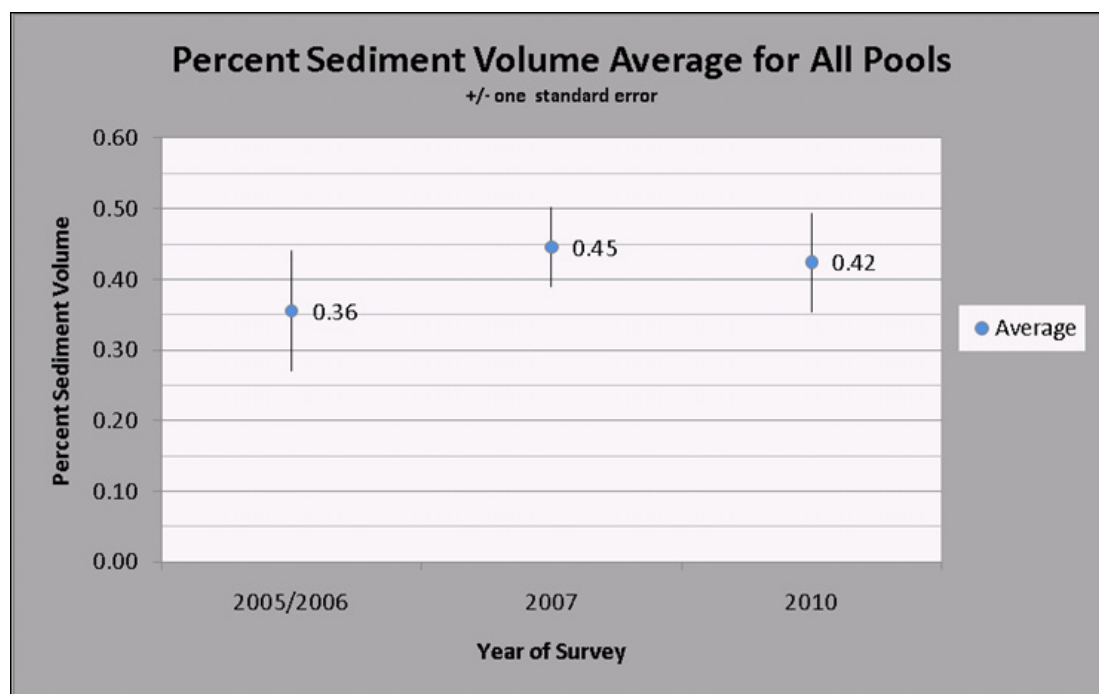


Figure 5. Plot of mean percent sediment volume for all pools surveyed in all three survey years.

Patterns among and within streams.

Overall percent sediment volume varied among streams throughout the study (Table 1 and 2, Figure 5). For example, pools in Chimenea and Box Canyon consistently had very low percent sediment volume (35% or less), whereas Loma Verde pools were generally high and other drainages were intermediate. The two streams where leopard frogs have been regularly monitored since 1996, Loma Verde and Chimenea, were significantly different in terms of percent sediment volume (one-sided t-test: $t(10) = -3.06$, $p < .01$). However, percent sediment volume also varied among pools within streams. For example, even though most pools in Loma Verde had high percent sediment volumes in

all 3 surveys (Table 1), pool 9 never had more than 38% sediment and in 2010 contained only 13% sediment.

New pools

In addition to repeating surveys of the 24 pools established in 2005-2006, we surveyed seven additional pools (Table 3), including six established in 2007 and one established in 2010. Two pools (Miller Lower 3 and Upper Chimenea 8) increased in sediment volume between 2007 and 2010, and 4 pools decreased. These pools will be included in the future surveys.

Effect of fire

Although we did not test for statistical dif-

Table 2.

Drainage	# of Pools	2006/2007 Mean (SE)	2007 Mean (SE)	2010 Mean (SE)
Box Canyon	2	0.135 (.135)	0.288	
Chimenea	4	0.130 (.045)		
Loma Verde	7	0.816 (.172)		
Madrona	3			
Rincon	2			
Steel Tank	1			
Wild Horse	5			

Table 2. Mean and standard error (in parenthesis) of percent sediment volume by stream at Saguaro National Park during 2005-2006, 2007, and 2010.

ferences for pool sediment volumes among watersheds, there appear to be trends in sedimentation based on fire histories. The stream with the highest percent sediment volume, Loma Verde, also had the highest percentage of watershed burned (Table 4); Chimenea had low percentage sediment volume and low percentage of watershed burned, and other drainages were intermediate. Elevations burned in the five major fires

that we examined were highly variable, ranging from 914 meters (3000 ft) for the Mothers Day Fire to 2682 meters (8800 ft) for the Helens II Fire. Chimenea, Loma Verde, and Wild Horse watersheds were affected by multiple fires, while Box Canyon, Rincon, Madrona, and Steel Tank were all only affected by one fire event.

Figure 6. Plot of mean pool sediment volume by stream during 2005-2006, 2007, and 2010 pool surveys. For standard errors, see Table 2.

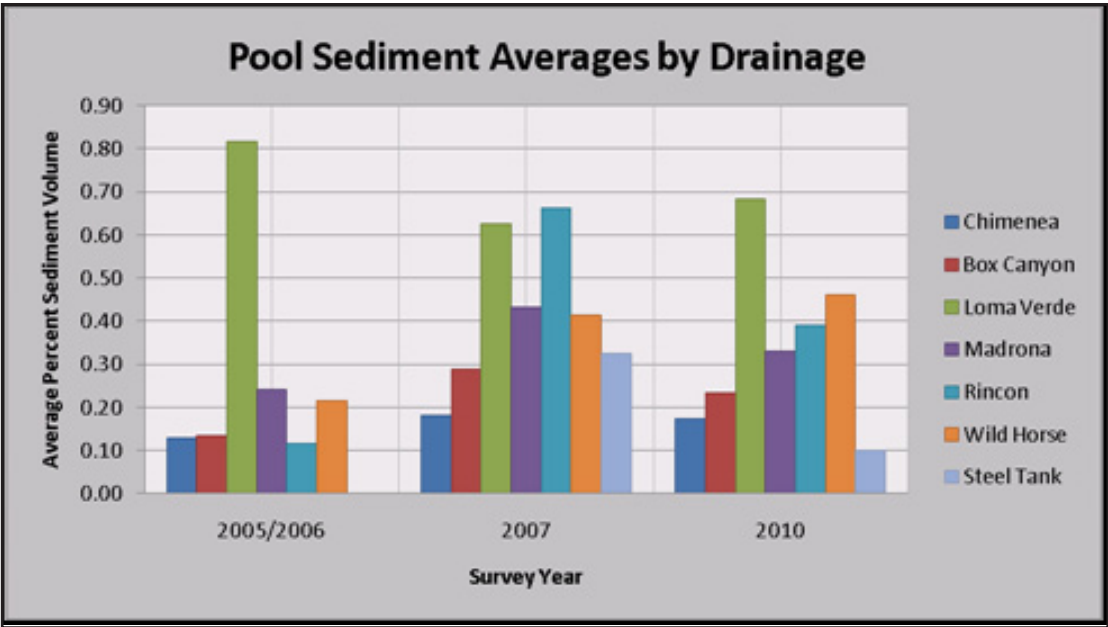


Table 3. Percent sediment volume for each pool surveyed only in 2007 and 2010. See Table 1 for explanation of sediment percentages.

Table 3.		
Pool Number	2007 Survey	2010 Survey
Miller Lower 3	22%	43%
Miller Upper 4	101%	90%
Rincon North 14	31%	17%
Upper Chimenea 8	16%	36%
Upper Madrona 1	12%	14%
Upper Madrona 6	No Data	6%
Upper Madrona 7	14%	10%

Table 4.

Watershed	Fire Name	Date of Fire	Fire Elevations (Feet)	Watershed % Burn	Overall Sedi- ment Avg.
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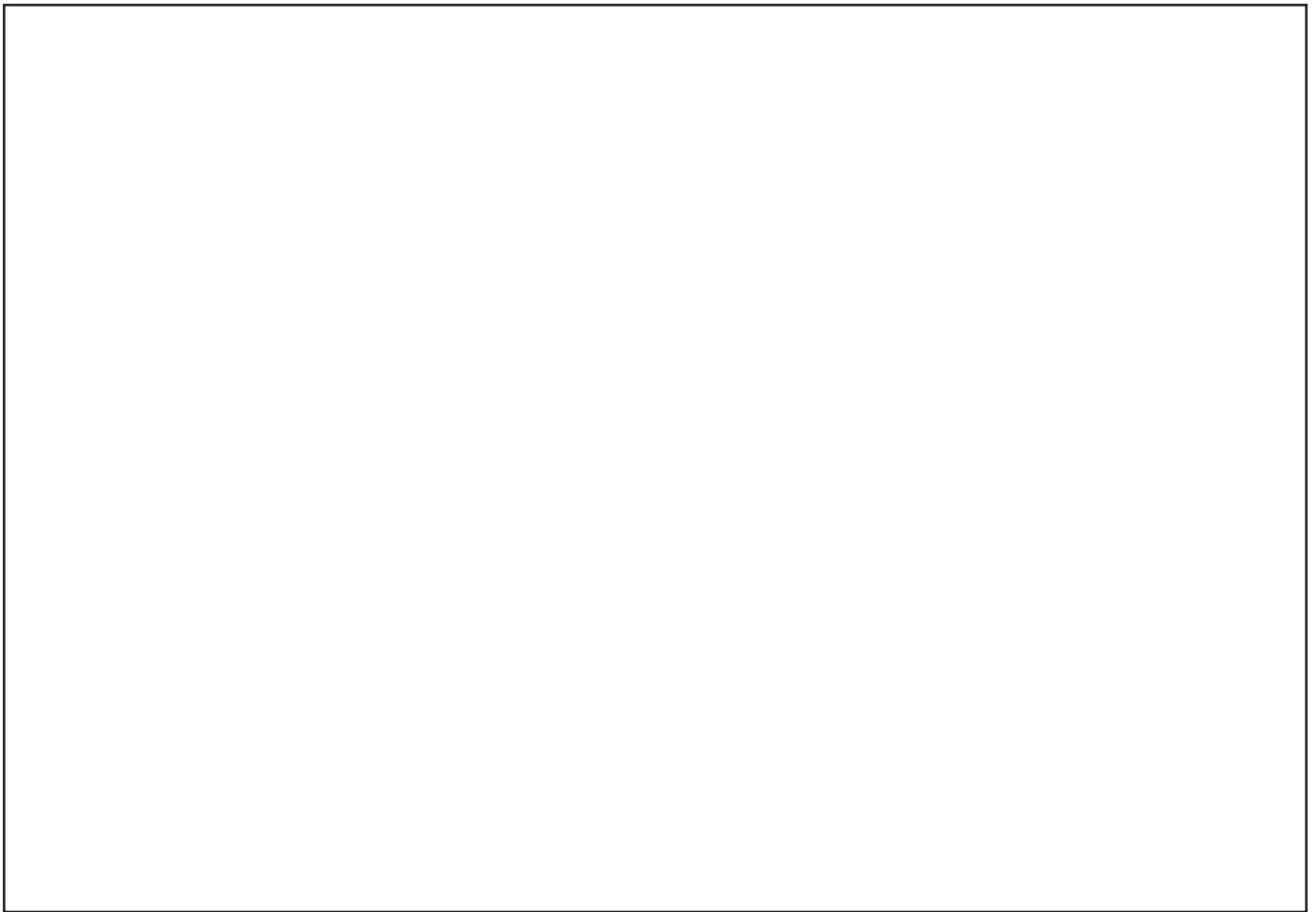


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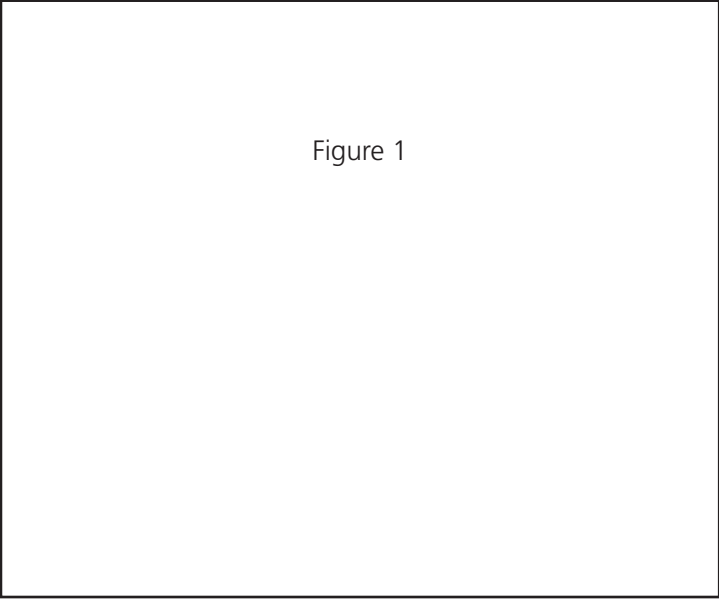


Figure 1

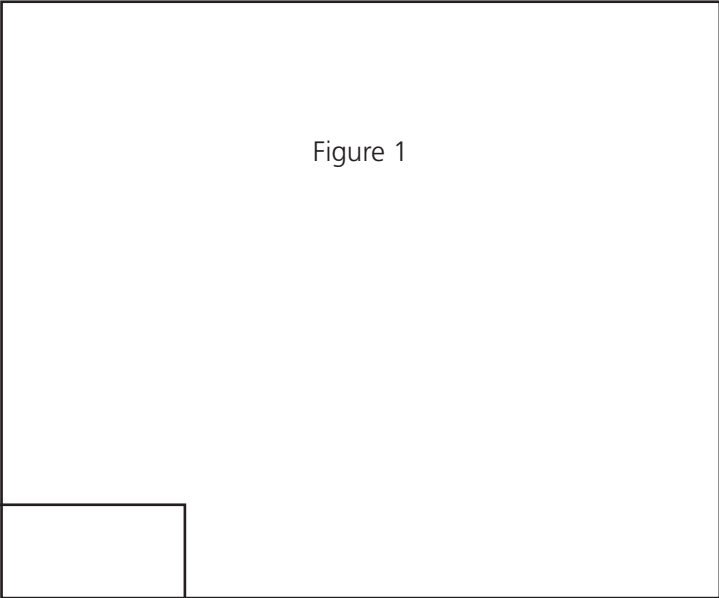


Figure 1

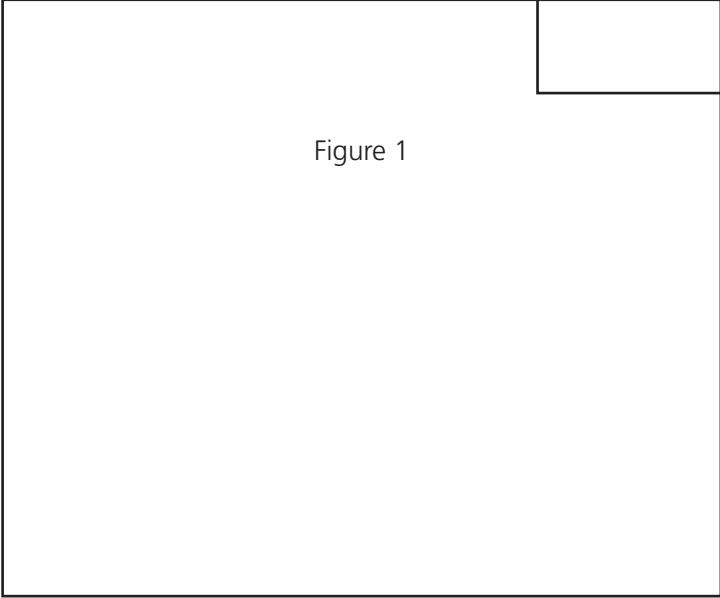


Figure 1

Discussion

Saguaro National Park began formally monitoring sediment in tinajas following several major events, including the Box Canyon Fire of 1999, which led to the filling of nearly all tinajas in Loma Verde Canyon and the extirpation of the lowland leopard frog population there; the Helen's 2 Fire of 2003, which filled pools and greatly impacted leopard frogs in Joaquin Canyon and other tributaries of Tanque Verde Creek; and the studies by Parker (2006) and Wallace et al. (2006) which provided indirect evidence of the links between fire suppression, fire severity, sedimentation, and declines of leopard frogs in areas of the park. Parker's study and repeat photos from streams in the park, particularly from Wildhorse Canyon (burned during the Chiva Fire in 1989) suggested that aquatic habitat in tinajas that were filled with sediment after fires could take decades to recover. However, we were not aware of any studies in the desert Southwest that had looked at these processes in any great detail over the appropriate time frame.

Since initiating monitoring in 2005, we have observed large differences in sediment volume of tinajas both among and within streams in the Rincon Mountains during 2005-2006 and 2010 that illustrate the dynamic nature of sedimentation processes. Sediment volume appears to be influenced by many factors, including stream hydraulics, flood events, and sediment loads upstream.

Stream hydraulics may dictate how flood events affect sedimentation in streams and are probably a major factor influencing the variability of sediment among pools within a stream. For example, pools oriented in high flow rate areas may be more prone to scouring by large floods, leaving them bare of sediment. Conversely, pools that are located in flatter areas with slower flow rates may be more prone to collect sediment during these events. Overall, it seems that sediment moves down the stream in a step-wise pattern. Scouring and sediment movement in a higher pool may result in an accumulation of the same sediment in lower pools, although it is very difficult to track the movement distinct sediments through these pools.

Major flood events may play a large role

in the distribution of sediment within and between streams throughout the surveyed area. The July 31, 2006 flood event, which led to massive debris flows in Sabino Canyon and elsewhere in the Santa Catalina Mountains, also dramatically altered many of the riparian landscapes in the Rincons (although curiously, no debris flows were observed in the Rincons, possibly due to previous fires being less severe than in the Catalinas). Described as a "100 year event" this flood was the largest ever recorded in Saguaro National Park history (Perger 2007). The large influence of flooding on these processes was illustrated by sediment movement in the Rincon watershed after the 2006 flood. Our data (table 2) shows a distinct increase in percent sediment volume within our survey pools in 2007. Our assumption is that sediment that was previously somewhat stable in the upper watershed was dislodged by this flood and moved into the lower portion of streams where most of our surveyed tinajas are located. However, the 2006 flood did not affect all streams in a uniform way. While Rincon Creek saw a distinct increase in percent sediment volume, other streams such as Loma Verde saw a decrease in percent sediment volume of almost 20% throughout the drainage. Our guess is that the flood could only reduce the very high previous volume of sediment in Loma Verde, while increasing the previously low volume of sediment in Rincon Creek. Rain events that cause flooding on this scale may affect some areas of the park more than others. Variability in rain intensity and duration between different drainages may also have a large effect on how sediment loads move and react.

In our analysis we examined five major fires in the Rincon Mountains: the 1989 Chiva Fire, 1994 Rincon Fire, 1994 Mothers Day Fire, 1999 Box Canyon Fire, and the 2003 Helen's II Fire. These major fires seem to play a large role in how sediment is distributed within and between streams.

The area of watershed burned, time elapsed since a fire event, and the elevation profile of the fire were expected to have an influence on sedimentation patterns throughout the park. Loma Verde and Chimenea streams together illustrate the expected relationship

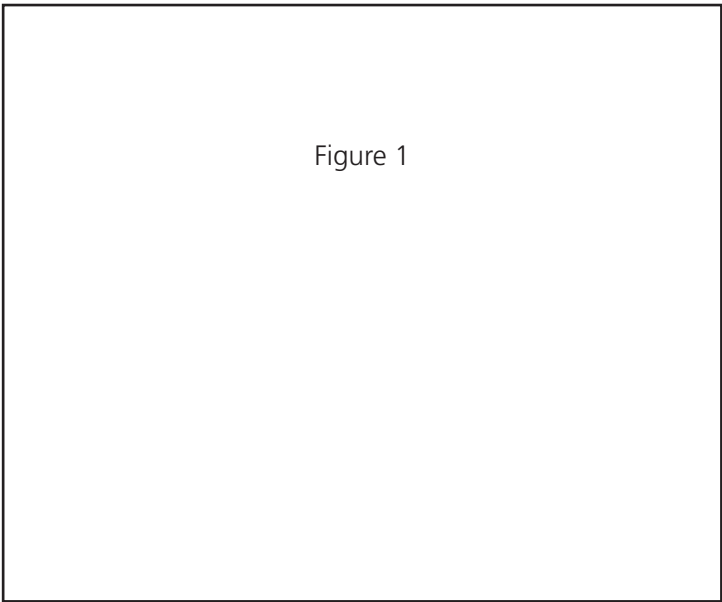
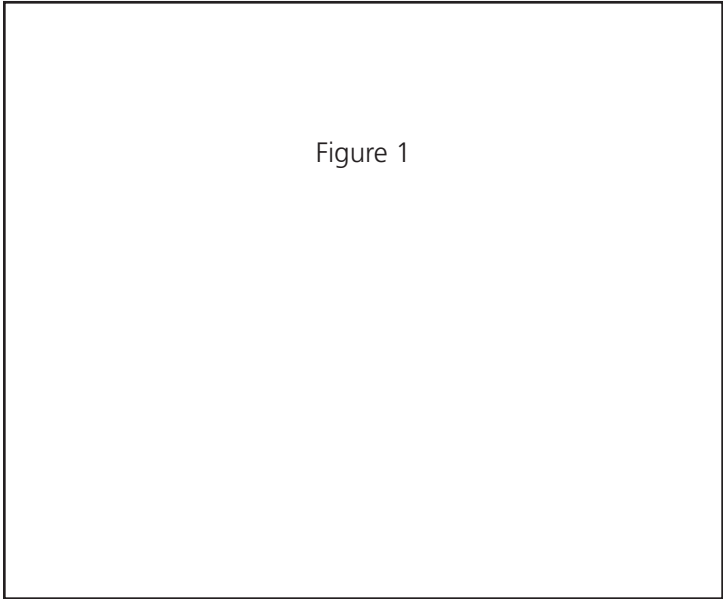
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Appendix A: Pool Survey Graphics

Box Canyon Pool 1

Example of bulleted list



Appendix B: Pool Survey Protocol

POOL SURVEY PROTOCOL

Pools are surveyed using a 1 or 2-ft square grid. A grid base line is established, normally down the center of the pool, from which all other measurements are taken. Several datums are established to ensure repeatability for any future surveys and to fix a point from which water surfaces measurements can be taken during water surveys. Once the grid is placed on the pool and the high water elevation determined, only two measurements are recorded at each grid coordinate: the elevation of the pool bottom and the elevation of any sediment in the pool. A data set of x, y, and z values is created which is used in Surfer to calculate volumes, areas, and topography.

Equipment List

Transit

Transit tripod

Survey staff

Sediment probe

Hammer

Camera

GPS

Permanent marker

50 ft tape

Small tape measure

Carpenter's rule

Clipboard / paper

Pencil / Pen

Phone / radio

Short rebar

Duct tape

Wire

Water gear, as req'd

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NPS XXXXXX, Month 20XX

Discussion

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Major flood events may play a large role in the distribution of sediment within and between streams throughout the surveyed area. The July 31, 2006 flood event, which led to massive debris flows in Sabino Canyon and elsewhere in the Santa Catalina Mountains, also dramatically altered many of the riparian landscapes in the Rincons (although curiously, no debris flows were observed in the Rincons,

Discussion

possibly due to previous fires being less severe than in the Catalinas). Described as a “100 year event” this flood was the largest ever recorded in Saguaro National Park history (Perger 2007). The large influence of flooding on these processes was illustrated by sediment movement in the Rincon watershed after the 2006 flood. Our data (table 2) shows a distinct increase in percent sediment volume within our survey pools in 2007. Our assumption is that sediment that was previously somewhat stable in the upper watershed was dislodged by this flood and moved into the lower portion of streams where most of our surveyed tinajas are located. However, the 2006 flood did not

affect all streams in a uniform way. While Rincon Creek saw a distinct increase in percent sediment volume, other streams such as Loma Verde saw a decrease in percent sediment volume of almost 20% throughout the drainage. Our guess is that the flood could only reduce the very high previous volume of sediment in Loma Verde, while increasing the previously low volume of sediment in Rincon Creek. Rain events that cause flooding on this scale may affect some areas of the park more than others. Variability in rain intensity and duration between different drainages may also have a large effect on how sediment loads move and react.

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In our analysis we examined five major fires in the Rincon Mountains: the 1989 Chiva Fire, 1994 Rincon Fire, 1994 Mothers Day Fire, 1999 Box Canyon Fire, and the 2003 Helen's II Fire. These major fires seem to play a large role in how sediment is distributed within and between streams.

The area of watershed burned, time elapsed since a fire event, and the elevation profile of the fire were expected to have an influence on sedimentation patterns throughout the park. Loma Verde and Chimenea streams together illustrate the expected relationship between area burned and sedimentation. Seventy-seven percent of Loma Verde watershed has been burned since

1990 and 301 hectares (37% of total burn area) has been burned twice, once in 1994 by the Mothers Day fire and once in 1999 by the Box Canyon fire. Loma Verde also has the highest percentage of pool sediment of all surveyed streams with an average of 71% of pool volume being sediment. Although the last fire to affect Loma Verde was over 10 years ago, there are still high percentages of sediment volume in pools in this stream, illustrating how long it can take for sediment to move through these drainages. In contrast, Chimenea Creek has had relatively little fire within the watershed (12% area burned, and most of it through wildland fire use) and also has

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a very low sediment levels (stream average of 16%). Comparison of these two streams suggests that burn area is the largest driver of sedimentation. However, Box Canyon is an exception in that it has a relatively large percent burned area (61%) and relatively small percent sediment volume (stream average of 22%).

Surprisingly there was no clear relationship between the elevation of past fires and sedimentation in the stream pools below. Our expectation was that vegetation would play a larger role in stabilizing the soil at higher elevations, especially since slopes generally are steeper at high elevations. Fire and the resulting loss

of soil stability would be compounded by these higher gradient slopes (Parker 2006). We also found no clear relationship between time since the fire elapsed and sedimentation. The elevation of the fire and the time elapsed since the fires surely play a role in the distribution of sediment in the surveyed streams but our sample size may have been too small to observe these less influential factors. Other factors such as fire burn severity and the role of vegetation may also be influential and their effect could become clearer if the study is expanded. Due to the complex nature of hydrologic processes in the Rincon Mountain range and our large study area it is difficult to fully understand all

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the variables at play in this process.

Starting in 2005 an experimental tinaja excavation program was implemented to remove sediment from four pools in the Loma Verde drainage: Loma Verde pools AV-2, 1, 6, and 10. Although this program has seen short term success in the rainy seasons directly following excavation, the pool survey data shows that these pools have been filling up with sediment in the years since. Although these excavations have probably not been effective over the long-term because the upper reaches of the watershed still had not recovered enough to stabilize the soil, there may be potential for the success of the

program in the future as the sediment flow diminishes. Interestingly, although the excavations do not appear to reduce overall sediment volume, they appear to have benefited frogs in at least a limited way by allowing water to remain in pools between large water flow events. In 2010, tadpoles survived in two pools that had been excavated in late 2009 and metamorphosed into juvenile leopard frogs (Caldwell et al. 2010).

This study thus far has been largely exploratory in nature with the goal of understanding the large trends of sedimentation in streams across the Rincon Mountains. In the future it may be valuable to increase

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the number of streams that we survey in order to get a more complete picture of sedimentation processes and what factors influence this phenomenon.

Based on the data that we have already collected, it may also be useful to compare two streams that highlight a difference in fire history and sedimentation levels. Surveying randomly selected pools within these drainages may help us better understand the relationship between fire and sedimentation. On a smaller scale, channel cross-sections within streams can help us visualize the topographical and geological factors that influence how sediment moves downstream from pool to pool. This can give us a valuable perspec-

tive on how time will influence sedimentation levels in different parts of a given stream. Although the methods of this study have been an overall success, more standardization and training can help reduce errors for future surveys. Better training on how the analysis relies on sound data collection can give field surveyors greater confidence during the survey, reducing errors.

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