Upper Tuolumne River Ecosystem Program

2015–2016 Rim Fire Monitoring in the Hetch Hetchy Reach of the Upper Tuolumne River

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1 INTRODUCTION

On August 17, 2013, a human-caused wildfire began near the confluence of the upper Tuolumne River and Jawbone Creek. Over the next two months, the Rim Fire burned (to varying degrees) over 257,000 acres within the Stanislaus National Forest and Yosemite National Park, becoming the third largest wildfire to date in California. While wildfire is a common and integral component of Sierra Nevada ecology, the Rim Fire stands out as a particularly large, hot, and destructive fire whose effects will be noted for decades to come.

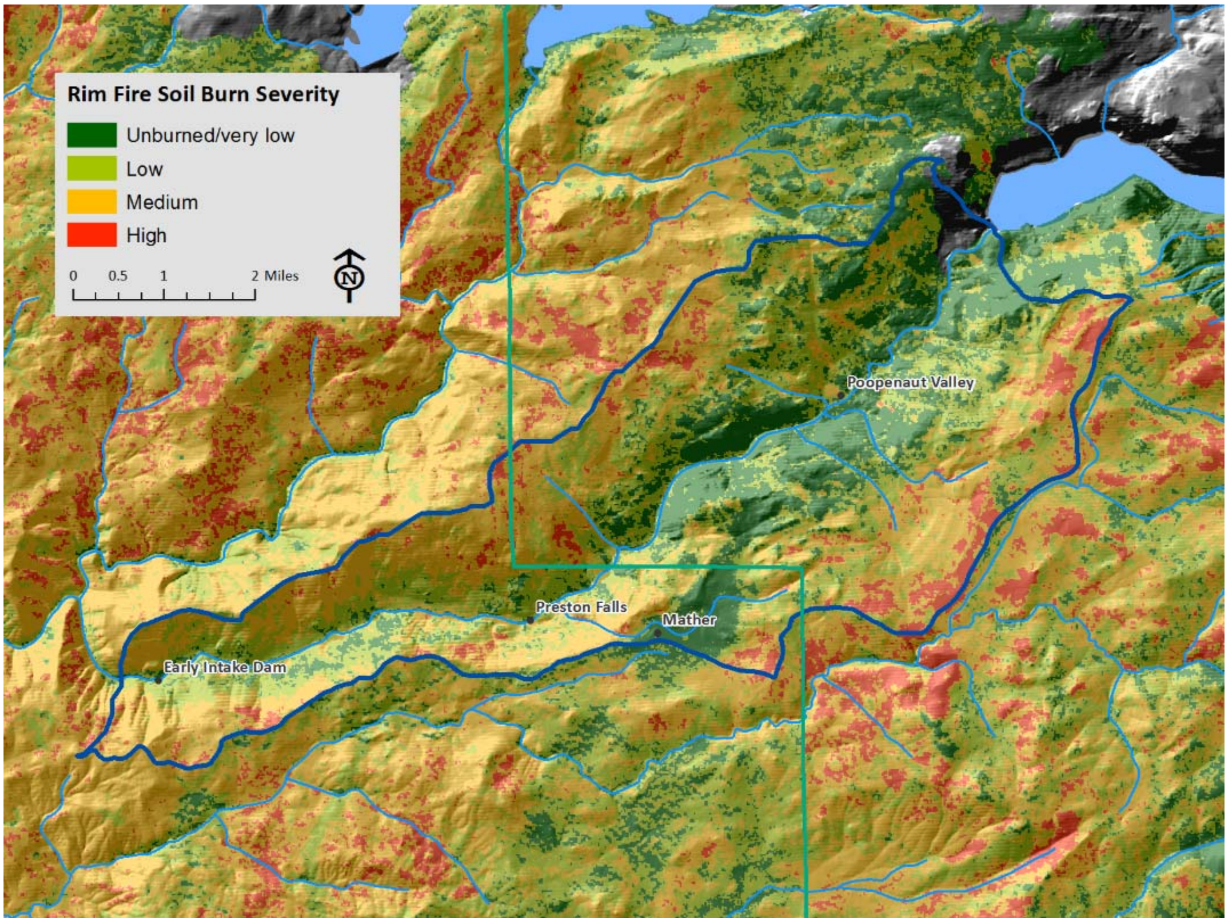

Figure 1. Soil burn severity from Rim Fire within the Upper Tuolumne River Ecosystem Program (UTREP) study area (blue line) adapted from the Burn Area Emergency Response (BAER) Rim Fire Assessment Soils Report (Flores et al. 2013).

The Rim Fire affected the entire Upper Tuolumne River Ecosystem Program (UTREP) study area (Figure 1), and resulted in a range of burn severities within the Hetch Hetchy Reach (O'Shaughnessy Dam to Early Intake, Figure 2). In some areas, the Rim Fire has dramatically affected vegetation characteristics, increased large wood loading, and increased fine sediment loading. Undoubtedly, the short- and long-term effects of the fire will be mixed. It is likely the fire directly impacted wildlife populations, potentially including the small population of foothill yellow-legged frogs (FYLF) near Early Intake. Concurrent drought may delay some effects of the fire, but eventually rain and snowmelt will deliver fine sediment into and through the Hetch Hetchy Reach and upper Tuolumne River.

Since November 2013, annual field work has focused on monitoring the evolution of study sites where fine sediment deposition (sand) has occurred (Figure 2). Specific 2015–2016 geomorphic and riparian tasks that were conducted included (Figure 2):

1. Repeating photographs at photopoints of sand/gravel experiments and documenting fine sediment deposition in the Upper Preston Falls, Mystery Bar, Albino Pool, Early Intake Calibration Pool, and Early Intake Boulder Garden reaches;
2. Repeating large wood surveys in the Upper Preston (1 and 2), Albino Pool, and Early Intake subreaches;
3. Repeating topographic surveys in areas of localized sand deposition; and
4. Field reconnaissance of sand bars that have formed since the Rim Fire to evaluate how deposition and emerging riparian establishment is influencing aquatic habitat and physical conditions at Mystery Bar, Albino Pool, Calibration Pool, and Boulder Garden riparian study sites.

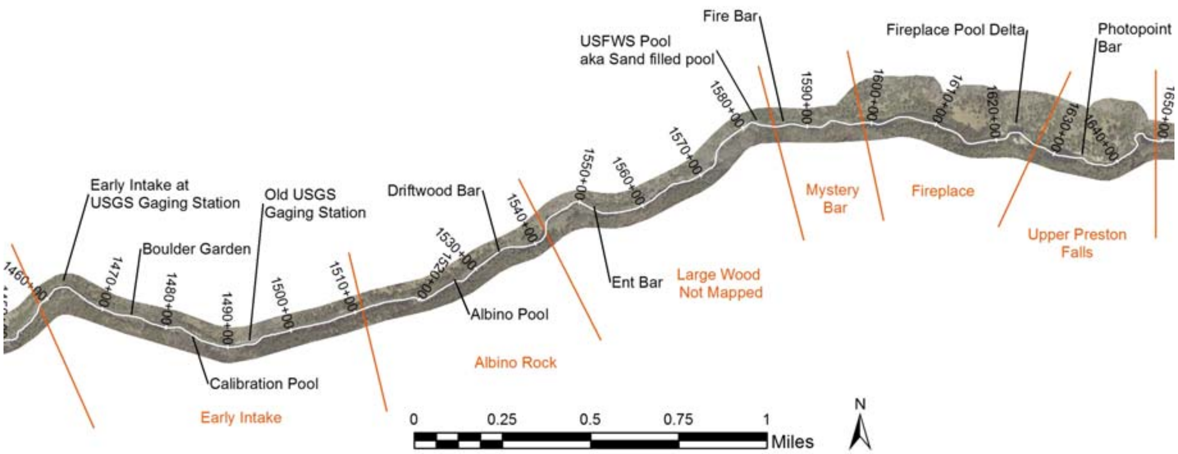

Figure 2. The lower Hetch Hetchy Reach on the Tuolumne River, from Early Intake to Preston Falls, showing study subreaches (orange), monitoring sites (black), and longitudinal stationing (feet).

Table 1. Post-Rim Fire monitoring conducted since 2013.

Monitoring Date	Photopoints	Large wood storage	Cross section	Topographic survey	Riparian assessment
November 2013	Yes	Yes	Yes	No	No
July 2014	Yes	Yes	No	No	No
October 2015	Yes	No	Yes	Yes	Yes
July 2016	Yes	Yes	Yes	Yes	Yes

In addition to photo monitoring, cross section surveys and large wood mapping, monitoring was expanded in October 2015 to include more focused study of six fine sediment deposits in different geomorphic settings in response to the Rim Fire. Six sand bars distributed from Preston Falls to Albino Rock were sampled. Four deposits were sand bars that had formed at the base of gullies and two had formed in the lee deposits of boulders. Vegetation establishment patterns were quantified and described on the selected fine sediment deposits in October 2015 and again in July 2016. Tasks included locating sand bars that had become more pronounced after the fire, sampling the plant species cover and woody plant age, and documenting the deposits with fixed photopoints. Two of the deposits were selected for detailed topographic surveys.

Water years (WY) 2013 through 2015 were all below normal water yields and high flow releases from O'Shaughnessy Dam (OSD) did not occur during these years. Thus, there were no significant fine sediment flushing events within the Hetch Hetchy Reach during this period (Figure 3). Daily average streamflow above Early Intake at USGS Station #11276600 in 2013 and 2014 did not exceed 250 cfs in either year.

The WY 2016 winter was wetter than the three previous winters. Recommendations for releasing streamflows to mobilize fine sediment and scour away sand bars were developed from post-Rim Fire UTREP monitoring data. Based on the age of woody plants sampled in October 2015, it was estimated that streamflows greater than 8,000 cfs would be needed to scour establishing vegetation on sand bars. A managed flow release of 7,200 cfs was made from O'Shaughnessy Dam on May 11, 2016, as part of reservoir operations and to test fine sediment flushing in the main channel. During July 2016, the six fine sediment locations were revisited, the topography resurveyed, and plant species cover and location sampled.

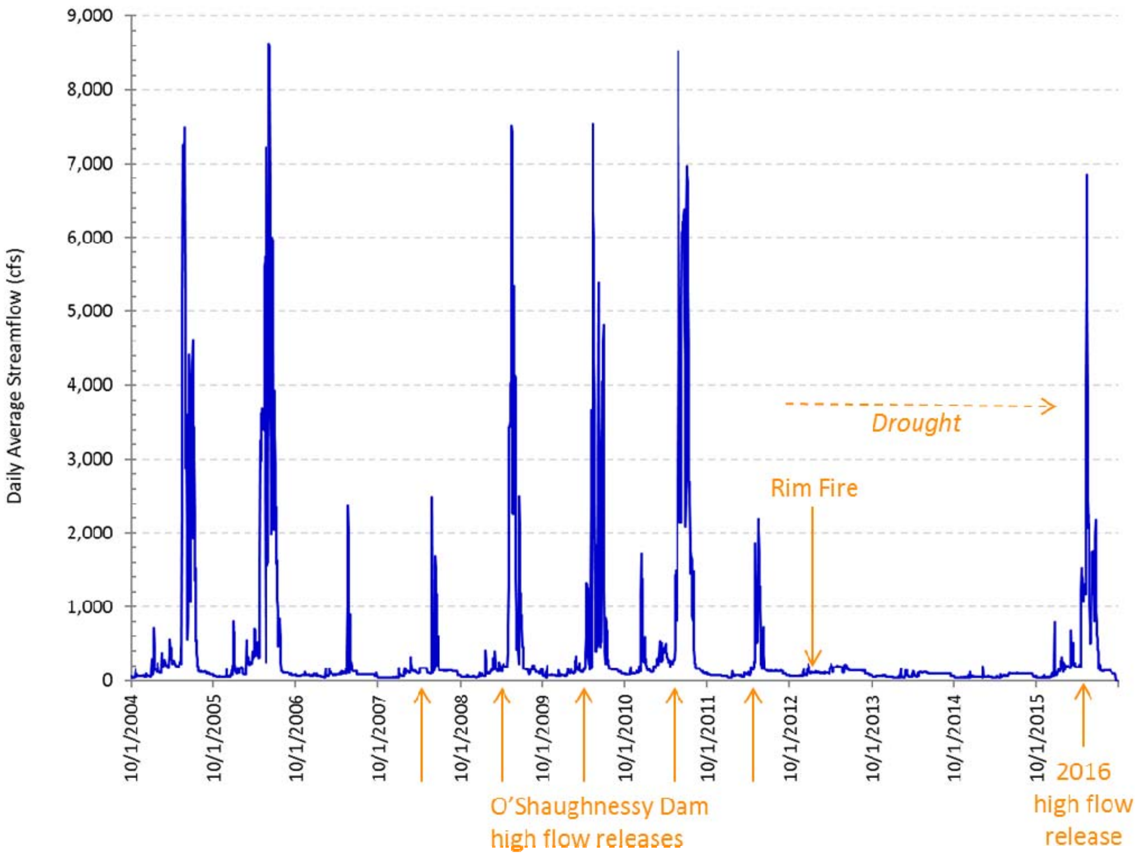

Figure 3. Upper Tuolumne River daily average streamflow discharge at Tuolumne River above Early Intake (USGS gage # 11276600) between 2004 and 2016. Arrows below the x axis represent high flow releases from O'Shaughnessy Dam. Sand accumulation and riparian colonization occurred during the drought period.

2 PHOTO MONITORING

Photo monitoring was conducted to document sediment contribution and the physical and vegetative changes to the mainstem upper Tuolumne River after the Rim Fire. The first type was an established photo monitoring network, which allowed documentation of the systemic extent of deposition related to the Rim Fire and the outcome of managed releases across a wide range of physical settings without having a large data investment at any one location. In May 2008, a photo monitoring network of 18 photopoints was installed throughout the Hetch Hetchy Reach to support the instream flow management plan and initially to photo-document flows that ranged from 80 cfs to 6,250 cfs. Photopoints were identified using the longitudinal distance in feet upstream of Wards Ferry Bridge. Photopoints were monumented using a 1-inch washer epoxied to a boulder or bedrock outcrop with photopoint stationing stamped on it (SFPUC 2014). During the instream fish habitat assessment in 2009 and 2010, 17 additional habitat-specific photopoints were selected to ensure overlapping panoramic photomosaics within all study sites and accessibility at all flows. This existing photopoint monitoring network was reoccupied during post-Rim Fire monitoring.

Photographs of previously established sand and gravel experiments were repeated, which allowed documentation of changes in aerial extend and sediment recruitment, mobilization, and size. Work conducted under the UTREP documented pulses of sand entering and transporting through study sites below Preston Falls. Between 2008 and 2010, scour nests were used to qualitatively assess bed scour and deposition at the Early Intake, Albino Pool, and Mystery Bar subreaches (SFPUC 2014). Scour nests are piles of tracer material set in natural boulder and bedrock lee or obstruction deposits. Deposits were previously photo documented in boulder lee deposits, pools, and pool tails and were originally composed of sand and gravel. The deposits were revisited and re-photographed during post-Rim Fire monitoring.

2.1 Methods

In November 2013, immediately following the Rim Fire, the 35 photopoints between Upper Preston Falls and Early Intake in the existing photopoint network were reoccupied to document fire related changes in aquatic and terrestrial habitats. Additional photos were taken along the river where substantial wood loading and sediment delivery were occurring as a result of the fire, but no new permanent monuments were established. A total of 60 photomosaics were taken in the fall of 2013 to provide a baseline for documenting fire-related changes to the riverine environment and evaluate future changes in response to wind, runoff, and flow releases from OSD. A Nikon D90 DSLR with a polarizing lens filter minimized solar glare off the water surface. Photomosaics were typically 180° upstream to downstream panoramas of complete mesohabitat units. In July 2014, all 35 photopoints were reoccupied to document changes in wood loading and hillslope sediment delivery caused by winter/spring rain surface runoff. The number of photopoints monitored has gradually increased since November 2013 to a total of 104 photopoints in October 2015. Photo mosaics were repeated at all 104 photopoints during July 2016.

In November 2013, July 2014, and October 2015, the scour nest experiments were relocated and photographed to note any changes in sediment size and quantity resulting from sediment introduction due to the Rim Fire and to provide a readily repeatable source of observations over the long term. Photo monitoring gravel and sand experiment locations may be an easier way to manage information about the effects of the fire in the mainstem. Our underlying hypothesis is that these deposits may fill with more sand given the increased sand supply resulting from the Rim Fire, and that managed high flows could be an important tool for fine sediment management in the mainstem. In the July 2016, photographs of scour nest experiments were not repeated due to time constraints.

2.2 Results

Photo monitoring, field reconnaissance, and SFPUC staff observations indicated that fine sand and silt had steadily increased near and in-channel since 2013 (Figure 4). In 2014 and 2015, evidence of debris flows was observed in two gullies upstream of lower Preston Falls (Figure 5). Upslope surface erosion and overland flow deposited sand and fine silts on surfaces adjacent to the channel upstream at the Albino Rock site and at locations above lower Preston Falls. Fine sand and silts from hillslope surface erosion filled interstitial spaces on a boulder bar at the Albino Pool site (Figure 6). On the mainstem at longitudinal station 1581+50 upstream of lower Preston Falls, a location that had been previously classified as a pool by USFWS in 1991 was documented in summer 2014 to be filling with fine sediment, and by 2015, was less than 1 ft deep and full of sand (Figure 7). A run mesohabitat unit at Mystery Bar was also documented to be filling in with fine sediments at longitudinal station 1592+25 (Figure 8).

Photo monitoring was used to document the colonization and growth of woody riparian plants rooted in interstitial spaces of larger grain sizes (large cobbles and boulders). In-channel boulder pockets were identified as being prone to the permanent establishment of woody riparian vegetation if flood peaks did not exceed 5,000 cfs for three years or more. Fine sediment deposited in boulder pockets created conditions where seeds could germinate and establish (Figure 9).

Photo monitoring and field observations suggested that fine sediment did not necessarily occur at cross section locations or in previously monitored pools, making estimation of the sediment volume delivered at a specific location in 2014 difficult. By October 2015, fine sediments delivered to the mainstem had visibly affected fish and FYLF habitat conditions, and created new riparian vegetation seedbeds in lee deposits of boulders and on sand bars. Overall fine sediment delivery since November 2013 had reduced exposed gravel storage in the Early Intake Reach and led to undesirable riparian vegetation establishment and fossilization of these in-channel deposits. Photo monitoring documented that the May 2016 streamflow release from OSD greatly reduced in-channel fine sediment storage below Preston Falls.

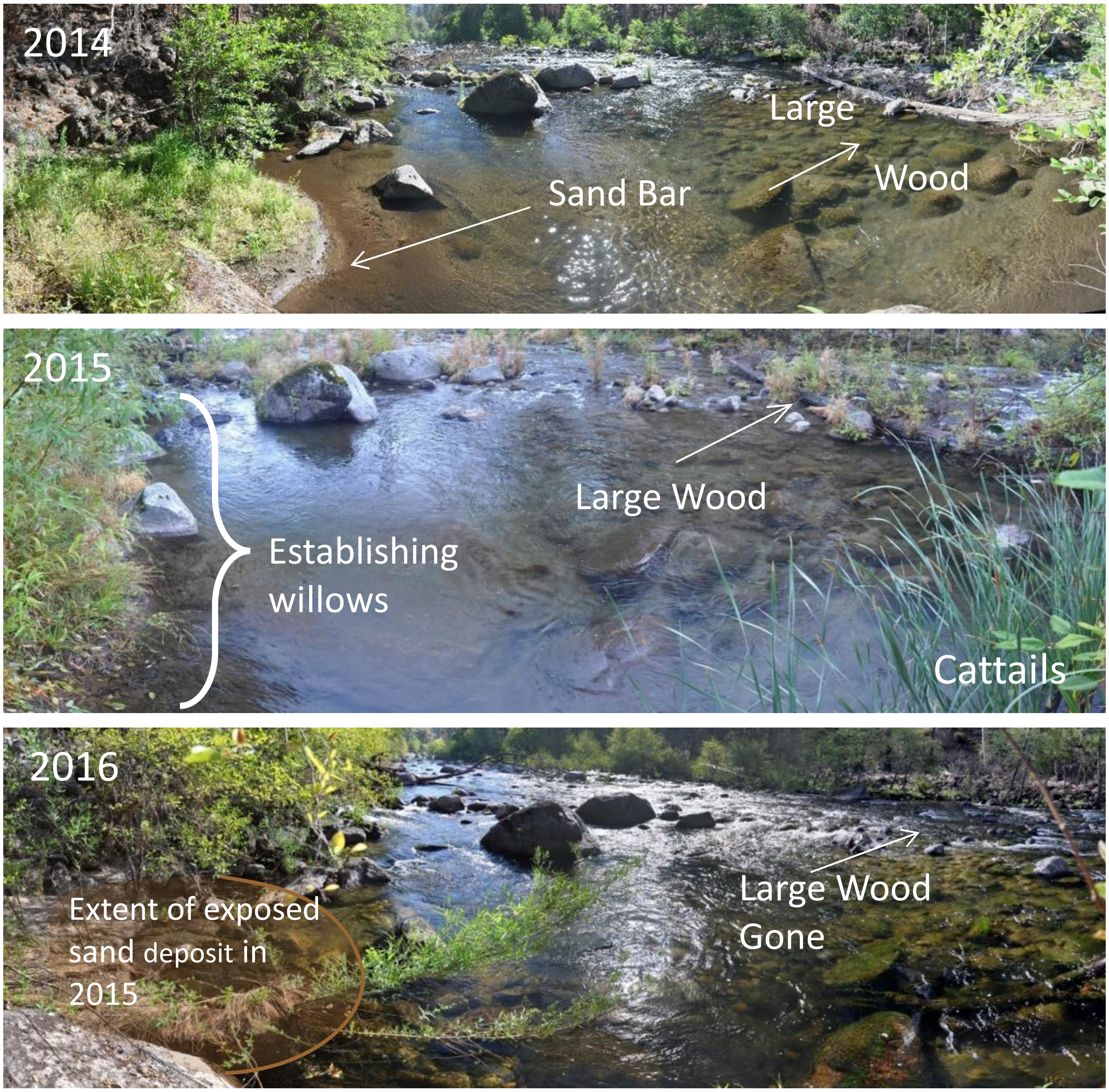

Figure 4. Photopoint 1529+80 comparison between 2014 and 2016 was used to document the evolution of a fine sediment delta that had been colonized with riparian plants and subsequently scoured.

Figure 5. A gully that contributed enough sand to build a bar in the Tuolumne River which was colonized by riparian plants, and subsequently scoured by the 7,200 cfs OSD release in May 2016 (shown in Figure 4). Changes in sand bar area were documented at photopoint 1529+80 upstream of lower Preston Falls. Top photo is from the top of the gully looking down toward the mainstem Tuolumne River in July 2014; bottom photo is from the mainstem Tuolumne River looking upstream where the gully enters.

Figure 6. Boulder bar at Albino Pool station 1528+50 in July 2014, showing the interstitial spaces between boulders filled in with fine sediments.

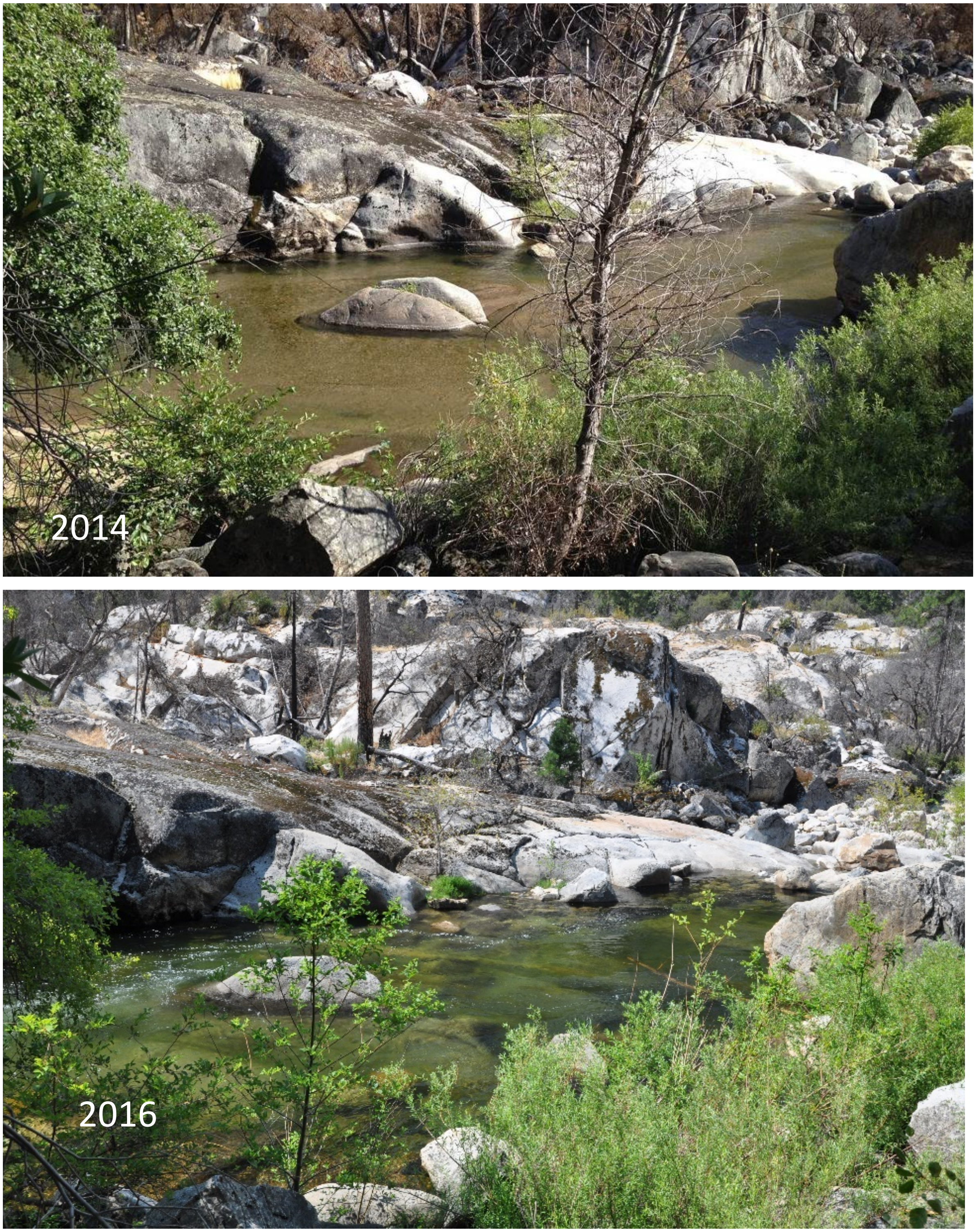

Figure 7. Photopoint 1581+50 comparison between July 2014 and July 2016 at a location on the mainstem Tuolumne River that had been previously classified as a pool by USFWS in 1991 and was less than 1 ft deep and full of sand in summer 2015. The 7,200 cfs OSD release in May 2016 substantially scoured the sand from the pool.

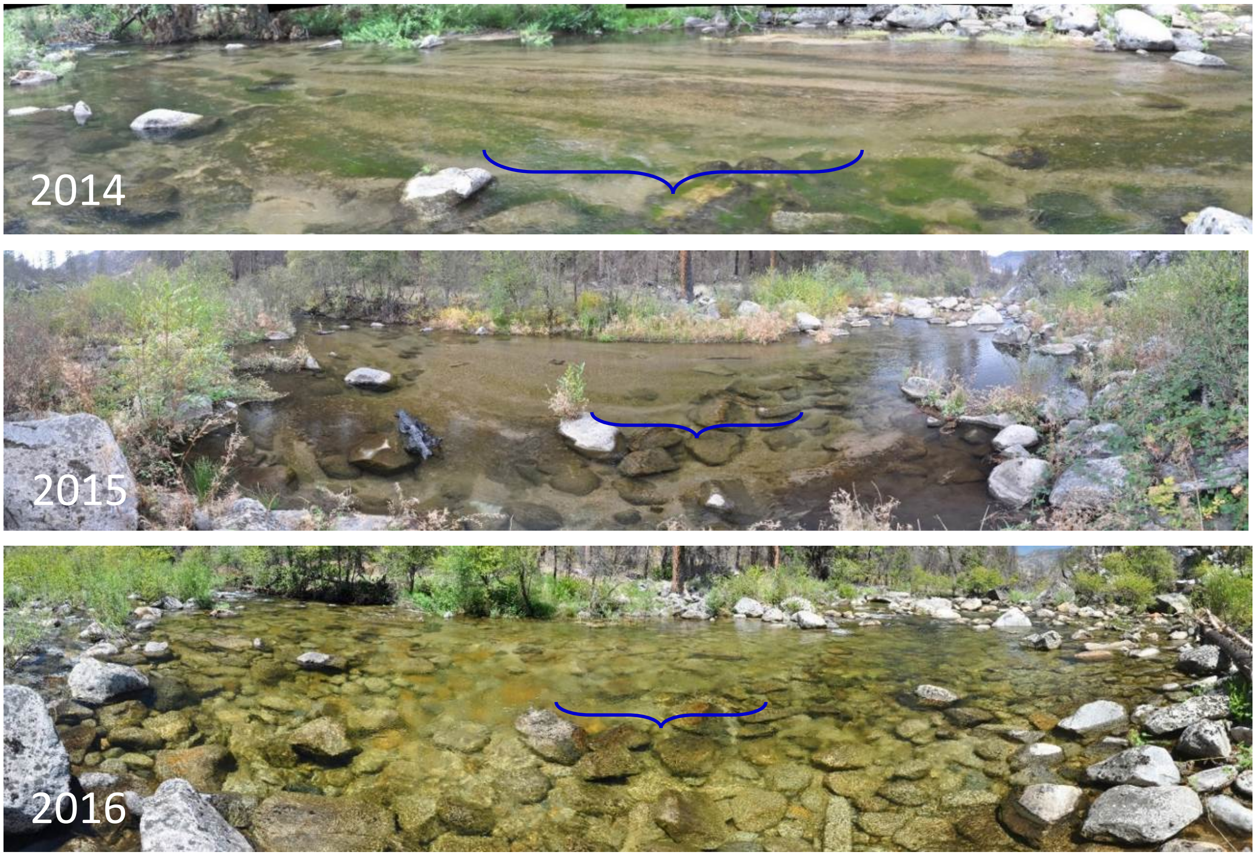

Figure 8. Photopoint 1592+25 comparison between July 2014 and July 2016 at a run mesohabitat unit at Mystery Bar. The large sand deposit was unchanged between July 2014 and October 2015. The 7,200 cfs streamflow in May 2016 scoured most of the sand.

Figure 9. Photopoint 1469+50 comparison between May 2009 and July 2016 at the downstream end of the Early Intake Boulder Garden Reach. No woody plants can be seen the wetted channel area in 2009. By October 2015, alders had encroached the wetted channel and established within the accumulating sand/silt. The 7,200 cfs streamflow in May 2016 scoured most of the woody plants from the wetted channel.

3 CROSS SECTION SURVEYS, POOL RECONNAISSANCE, AND TOPOGRAPHIC SURVEYS

Topographic surveys were performed at selected sand deposition sites on the mainstem Tuolumne River to document local sand deposition and scour evolution after the Rim Fire (deposition), and after high flow releases from O'Shaughnessy Dam (scour).

3.1 Methods

In November 2013, cross section 1623+00 at the Fireplace Bar site and cross section 1589+50 at the Mystery Bar site were surveyed just after the Rim Fire. During the 2014 summer field reconnaissance, five previously established cross sections and pools (the USGS gaging station below Hetch Hetchy, Mystery Bar, Albino Pool, Calibration Pool, and Boulder Garden riparian study sites) were evaluated for deposition that could have occurred since the Rim Fire and whether repeat topographic surveys were warranted. Mystery Bar cross section 1589+50 was surveyed again in November 2015 and July 2016.

Topographic surveys were conducted at four localized sand deposition areas in the Hetch Hetchy study reach in October 2015 and July 2016 at Mystery Bar, Fire Bar, and Driftwood Bar. Additional areas around pools were surveyed in August 2016 and added to a July 2016 survey conducted by Meridian to ensure maximum overlap and coverage between the November 2015 and July 2016 surveys.

Topographic change analysis was used to evaluate sediment volumes in 2015 and changes to pool volume resulting from spring 2016 managed releases (7,200 cfs). Digital terrain models (DTM) were developed from the topographic surveys in AutoCAD Civil 3D. DTMs were sampled to 1ft raster digital elevation models and exported to ArcGIS format for geomorphic change detection (GCD) analysis (Wheaton 2008). A minimum level of detection (MinLOD) of ± 0.2 ft was applied to the change detection to filter out topographic uncertainty due to survey methods (prism pole tilt). The GCD analysis output included estimates of erosion, deposition and net volumetric change between the October 2015 and July 2016 surveys.

3.1 Results

Geomorphic Change Detection (GCD) analyses at the four topographic survey locations showed that 7,200 cfs was effective at scouring fine sediments out of the mainstem channel. Mystery Bar downstream (the delta area) showed the greatest amount of deposition with some areas exceeding 2.1 ft of deposition (Figure 10, Table 2). The upstream end of Mystery Bar upstream (longitudinal station 1592+25) was scoured of sand and the run restored (Figure 8). Mystery Bar cross section 1589+50 just downstream of the delta area has continued to slowly aggrade since initial surveys in 2010 (Figure 11). Fire Bar had the greatest maximum scour of over 6 ft and averaged 2.6 ft (Figure 12, Figure 2). Driftwood Bar had very similar scour patterns as Fire Bar and little deposition (Figure 13). The maximum scour at Driftwood Bar exceeded 5 ft and had an average scour of 2.7 ft, which was a higher average scour than at Fire Bar (Table 2). The May 2016 releases scoured the highest volume of sediment at Driftwood Bar, of the four locations analyzed (Table 3).

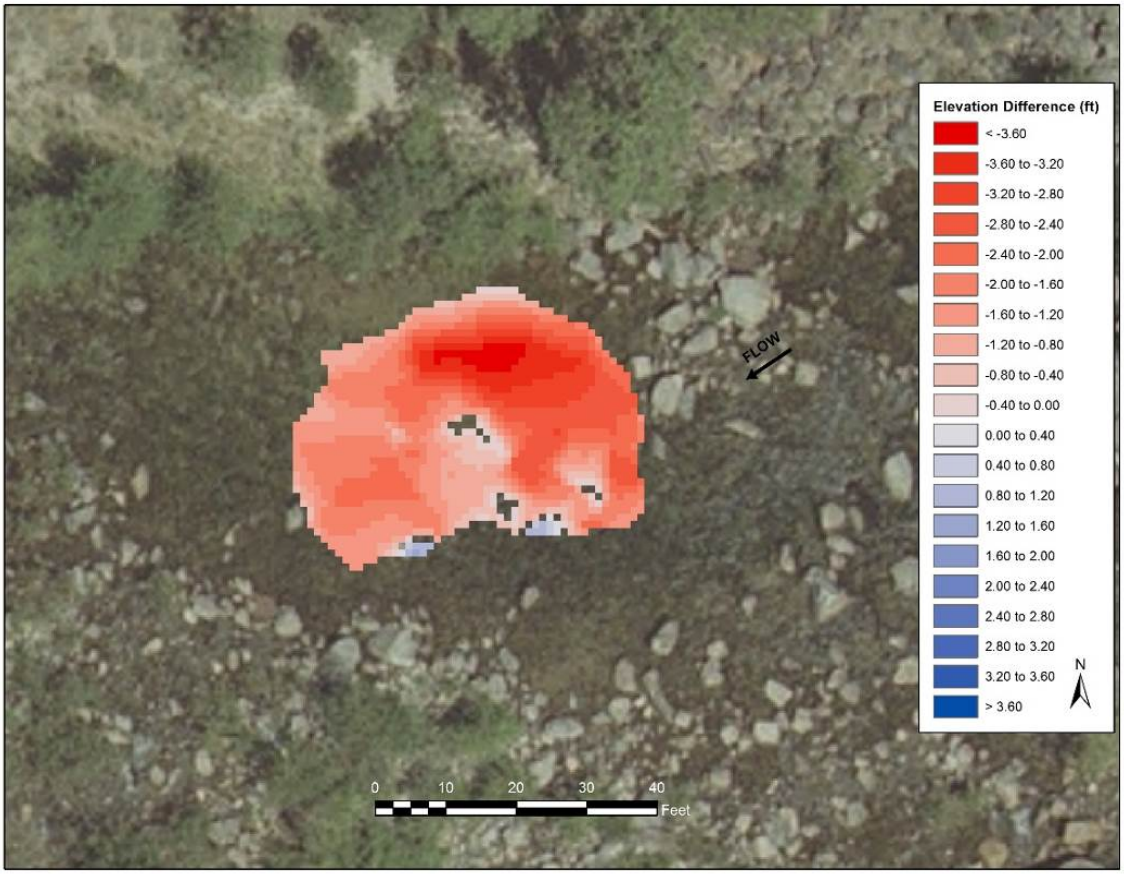

Figure 10. GCD analysis for the period between October 2015 and July 2016 at upstream Mystery Bar station 1592+25 (Figure 8), showing that most of the site was scoured (red), with small areas of deposition (blue).

Table 2. Summary of scour and deposition at four study sites below Preston Falls between November 2015 and July 2016 using a minimum level of detection of 0.2 ft.

	Erosion			Deposition		
Site	**Min**	**Ave**	**Max**	**Min**	**Ave**	**Max**
Driftwood Bar	−0.2	−2.7	−5	0.2	0.4	0.6
Fire Bar	−0.2	−2.6	−6.1	0.2	0.7	1.4
Mystery Bar downstream	−0.2	−1.9	−4.7	0.2	0.7	2.1
Mystery Bar upstream	−0.2	−1.9	−4	0.2	0.8	1.3

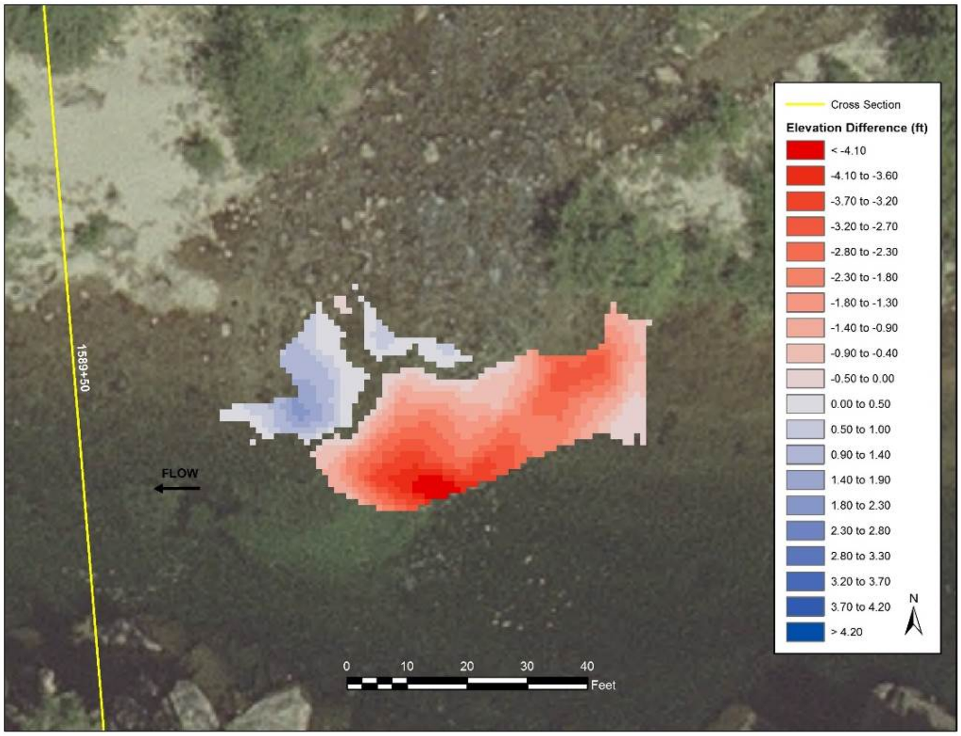

Figure 11. GCD analysis for the period between October 2015 and July 2016 at downstream Mystery Bar station 1590+00, showing areas of deposition (blue) and scour (red) and Mystery Bar cross section 1589+50 (yellow line).

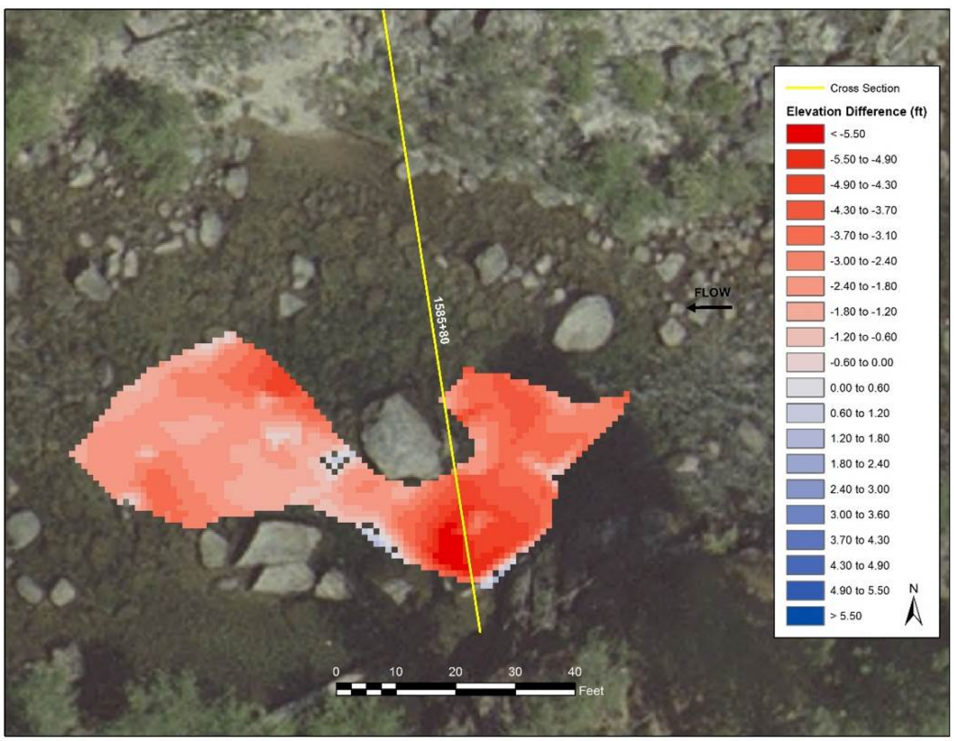

Figure 12. GCD analysis for the period between November 2015 and July 2016 at Fire Bar cross section 1585+80 (Figure 19), showing scour throughout the site (red) with a localized scour pool between a large boulder and exposed bedrock. Small areas of deposition (blue) can also be seen.

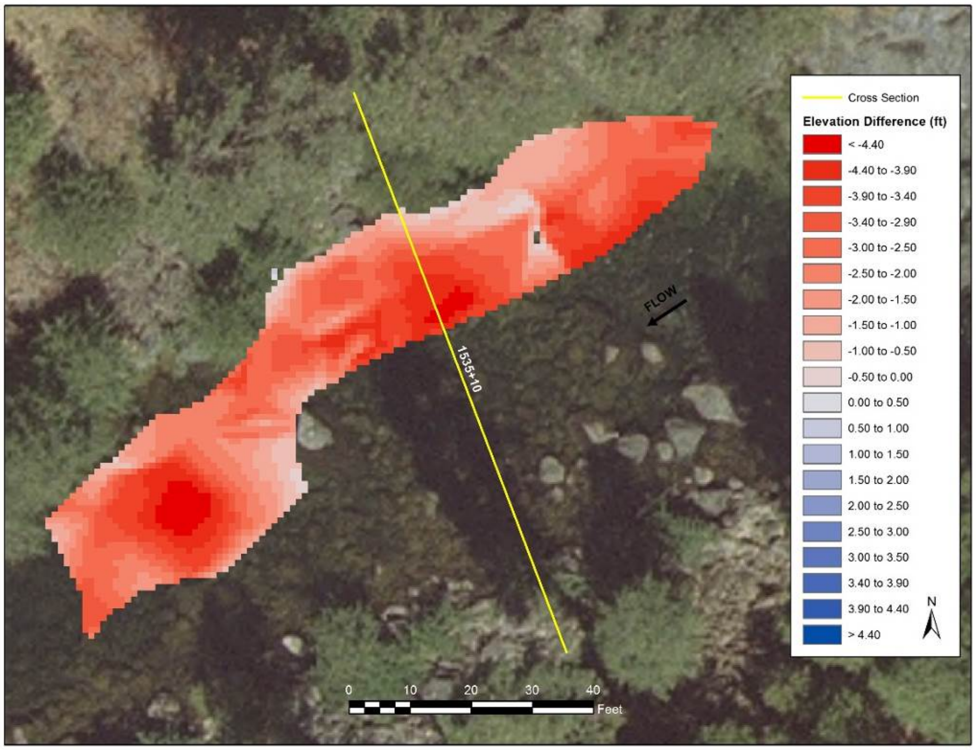

Figure 13. GCD analysis for the period between October 2015 and July 2016 at Driftwood Bar station 1535+10 (Figure 21), showing scour (red) throughout the site.

Table 3. Volumetric changes at four study sites below Preston Falls between October 2015 and July 2016 using a minimum level of detection of 0.2 ft.

Site	**Total net volume difference (yd^3)**
Driftwood Bar	−250.6
Fire Bar	−178.6
Mystery Bar Downstream	−58.8
Mystery Bar Upstream	−98.6

4 RIPARIAN COLONIZATION AND ESTABLISHMENT MONITORING

During July 2014 monitoring, exposed fine sediment deposits near the summer low water channel were opportunistically visited and riparian colonization observed. Seedlings were surveyed using intuitive controlled searches (BLM 2012), which rely on plants' affinity for particular environments and common plant associates to constrain the search to those areas where seedlings were likely to occur.

4.1 Methods

Plant species cover was estimated on six fine sediment deposits distributed between Preston Falls and Albino Rock during October 015 and repeated in July 2016. All the sediment deposits where plant cover was sampled were visible on the May 26, 2014 (post-Rim Fire), Google Earth aerial photographs. At one site (Fire Bar) where topography surveys were conducted, plants were sampled along a cross section in fall 2015 and summer 2016. The species, proportional area of the deposit covered, hardwood root collar diameter, height, age, and location were documented.

4.2 Results

Overall observations downstream of Preston Falls suggested that alder seedling recruitment has been particularly high since 2013 (Figure 14). Riparian plants rapidly colonized eddy deposits and fine sediment bars at delivery points, presumably due to their long exposure above water during dry years, readily available soil moisture, and fine textured sediment (Figure 4, Figure 5). Seeds have also germinated in fine organic debris caught on the woody debris and on shoreline silts (Figure 15).

Figure 14. Freshly deposited sand bar colonized with riparian seedlings in July 2014 at station 1529+30.

Figure 15. Floating alder seeds (foreground) were deposited and germinated in fine silts/sand and organic debris deposited on the shoreline July 2014.

In fall 2015, a red willow on a sand bar was cut down and the bottom section of the stem near the root collar aged. The red willow stem was 6 years old, indicating that the willow had colonized the sand bar in 2009 and that the bar pre-dated the Rim Fire. The ages of woody plants on most of the bars suggested that the sand bars may have formed before the Rim Fire, but the rate of bar growth was likely limited by sand contribution before the fire. Post-Rim Fire, the rate of bar growth and the area available for woody plant establishment increased as sand routed into the channel from burned hillslopes. Based on the results of previously conducted riparian scour analyses conducted in 2010 and 2011 (SFPUC 2014) and the age of woody plants sampled in fall 2015, it was predicted that streamflows greater than 8,000 cfs would be needed to scour the vegetation establishing on the sand bars.

Generally, the new sand bars were covered with established woody and herbaceous plants in 2015. Young-of-year seedlings ranging to 6-year old saplings of red willow, white alder, and arroyo willow were sampled in fall 2015. Woody plant cover was typically 20 to 40 percent of the bar area for each woody plant species observed. The 2015 understory was composed of sedges, rushes, and emergent herbaceous plants.

All six sand bars were inundated and the vegetation substantially scoured during the peak streamflow in May 2016 (7,200 cfs). The amount of plants scoured away by the 2016 peak streamflow varied depending on geomorphic setting where the deposit occurred. Four of the six sand bars where riparian vegetation was sampled in 2015 were completely scoured away during the release (Figure 18, Figure 19, Figure 20, and Figure 21). Two sand bars were not scoured away by the release (Figure 16 and Figure 17). The sand bar located at station 1634+50 was in the lee side of a large boulder and was protected by the hydraulic shadow created by the boulders. The sand bar located at 1623+00 was located along the right side of the Fireplace pool where the mainstem channel splits and is very wide.

Changes at each sand bar are described below.

4.2.1 Photopoint Bar

Photopoint Bar formed on the lee side of boulders along the right bank channel margin at longitudinal station 1634+50 (Figure 16). The 7,200 cfs streamflow did not change the bar area and vegetative cover substantially. Changes in the area associated with herbaceous species were small Between October 2015 and July 2016; however, plants were sampled much earlier in the growing season in 2016. The bar area was estimated at 50 ft^2 in November 2015 and 40 ft^2 in July 2016.

4.2.2 Fireplace Bar and Fireplace Pool

A sand delta formed along the right bank of Fireplace pool and is located within the Fireplace site. The sand delta was observed in November 2013 and had grown larger by July 2014 (Figure 17). Cross section 1623+00 at the fireplace site bisects a large pool, Fireplace Bar and the sand delta. The 7,200 cfs streamflow did not change the bar area and vegetative cover substantially. The channel is wide at Fireplace Pool, and velocities and scour along the pool margin during the May 2016 event would have been low, which likely protected the bar from any significant scour during high flows.

4.2.3 Bar Above Mystery Bar

This bar is located on the right bank of a broad pool upstream of Mystery Bar at longitudinal station 1595+50. A sand delta from a hillslope gully forms this bar on the right bank. The bar was initially observed during 2014 field reconnaissance. In October 2015, the bar was hardly discernable, and was initially thought to be eroded. However, further inspection revealed it was heavily vegetated (Figure 18). The 7,200 cfs streamflow completely scoured the bar and removed all plants that were sampled in October 2015. The bar area was 150 ft^2 in 2015 and 0 ft^2 in 2016.

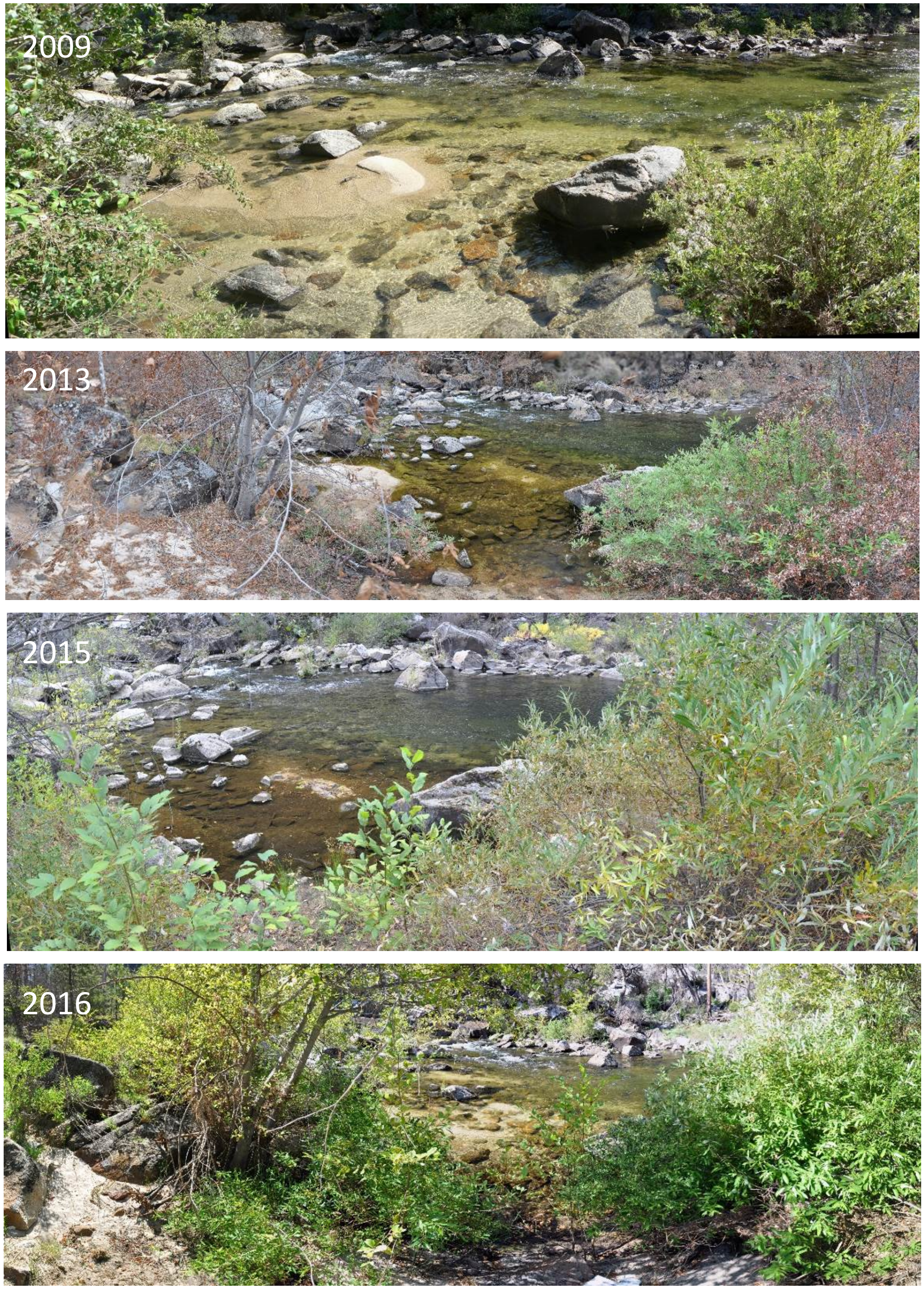

Figure 16. Photopoint 1634+50 comparison between May 2009 and July 2016 at Photopoint Bar downstream of Preston Falls. The sand bar is located to the left of center. The 7,200 cfs OSD release in May 2016 did not substantially change the bar area and vegetative cover.

Figure 17. Photopoint 1623+00 comparison between October 2015 and July 2016 at Fireplace Bar within the Fireplace site. The 7,200 cfs OSD release in May 2016 did not change the bar area and vegetative cover substantially. The channel is wide at Fireplace Pool, and velocities and scour along the pool margin during the 7,200 cfs streamflow event would have been low, which likely protected the bar from any significant scour during high flows.

Figure 18. Photopoint 1595+50 comparison between July 2014 and July 2016 at the bar above Mystery Bar, upstream of the Mystery Bar site. The bar was initially observed during 2014 field reconnaissance. In October 2015, the bar was hardly discernable, and was initially thought to be eroded. However, further inspection revealed it was heavily vegetated. The 7,200 cfs OSD release in May 2016 completely scoured the bar and removed all plants that were sampled in October 2015.

4.2.4 Fire Bar

Fire Bar was the largest of the sand bars sampled and is located at longitudinal station 1585+80. Sediment delivered to the river had formed a large sand bar that had been colonized by riparian vegetation (Figure 19). The 7,200 cfs streamflow scoured the bar and establishing plants to the edge of existing mature vegetation. The bar area was not noted in 2015 and was 0 ft^2 in 2016.

4.2.1 Ent Bar

Ent Bar was on the right bank at the upstream end of the long riffle captured in photopoint 1548+80 (Figure 20). A sand delta from a hillslope gully forms the bar. The river channel around Ent Bar was very complex with a slack water area on the left bank. One hundred feet upstream of Ent Bar, a large 28-inch DBH alder (the "Ent tree") grows on the right bank. The alder is old enough to have established before the Canyon Tunnel was completed in 1967. The 7,200 cfs streamflow completely scoured the bar and removed all plants that were sampled in October 2015. The bar area was 150 ft^2 in 2015 and 0 ft^2 in 2016. After the spring high flows, the Ent tree and other mature alder trees, and some 3-year-old alders remained in the zone of previously established plants, but the bar itself was gone.

4.2.2 Driftwood Bar

The delta that forms Driftwood Bar comes into the mainstem channel on the right bank at longitudinal station 1535+10. The pool complex ends in the riffle that drops into the Albino Rock study site downstream. The observed deposition patterns were highly localized with minimal sand deposition observed downstream (Figure 21). The 7,200 cfs streamflow completely scoured Driftwood Bar and removed all plants that were sampled in October 2015. The bar area was 2,000 ft^2 in 2015 and 0 ft^2 in 2016. Similar to other bars formed from sediment deltas, some 3 year-old alders remained in the zone of previously established plants, but the bar itself was gone.

Figure 19. Photopoint 1585+80 comparison between 2015 and 2016 at Fire Bar downstream of the Mystery Bar site. The 7,200 cfs OSD release in May 2016 eroded the bar and establishing plants to the edge of existing mature vegetation. After the spring high flows, some 3 year-old alders remained in the zone of previously established plants, but the bar itself was gone.

Figure 20. Photopoint 1552+25 (left bank) comparison between 2015 and 2016 at Ent Bar downstream of Lower Preston Falls. The 7,200 cfs OSD release in May 2016 completely eroded the bar shown inside the red oval and removed all plants that were sampled in October 2015.

Figure 21. Photopoint 1534+75 comparison between 2015 and 2016 at Driftwood Bar upstream of Albino Rock. The 7,200 cfs OSD release in May 2016 completely scoured Driftwood Bar and removed all plants that were sampled in fall 2015. Similar to other bars formed from sediment deltas, some 3-year-old alders remained in the zone of previously established plants, but the bar itself was gone.

5 LARGE WOOD MAPPING

Large wood mapping was conducted immediately after the Rim Fire to establish a post fire baseline condition. Large wood mapping has been repeated in July 2014 and July 2016 to track how large wood storage downstream of Preston Falls has changed since November 2013 immediately after the Rim Fire. The survey was conducted from Preston Falls to Early Intake, with one sub-seach between Lower Preston Falls (longitudinal station 1588+92) and Albino Rock (longitudinal station 1540+80) excluded due to poor access and low wood storage.

5.1 Methods

Large wood monitoring was conducted in the Upper Preston, Albino Pool, and Early Intake subreaches within the Hetch Hetchy Reach in November 2013, July 2014, and July 2016. Monitoring included mapping each piece of wood with a diameter greater than 8 inches within the active channel, post-field data processing, and preliminary analysis. Locations of large wood pieces were recorded using a Trimble GeoXH handheld GPS with external Zephyr antennae capable of achieving 2-ft accuracy.

Attributes of each piece of wood, such as species and stem diameter, were recorded. Debris piles were mapped as a single point, and the most prevalent size class of debris was noted, as well as general number (e.g., > 20 pieces). However, the precise number of wood pieces within each debris pile was not always counted, particularly for larger accumulations.

When each large wood piece was surveyed, the location was entered into a data logger and attributes were assigned that described the piece of wood. This method only focused on changes in large wood storage in a subreach and did not necessarily assess large wood recruitment, routing, or budgeting throughout the subreaches (i.e., individual large wood pieces were not tagged or tracked to see if they mobilized from the site and routed downstream). Data processing was conducted using GPS Pathfinder Office (Trimble), ArcMap (ESRI), and Excel (Microsoft) software. Survey attributes included:

- Subreach name;
- A unique identification number for individual large wood pieces;
- Date;
- Origin (i.e., natural, fire-fall, wind-fall, unknown);
- Location of wood relative to stream bank;
- Diameter measured at root collar (DRC), assigned to one of six size classes (8–12 in, 12–18 in, 18–24 in, 24–36 in, 36–48 in, and >48 in);
- Root wad width (i.e., total and wet widths; measured at widest point of root wad, ft);
- Stem length total and wetted lengths measured from root collar to tip of stem, ft;
- Orientation of stem relative to magnetic north measured with compass from root collar;
- Species;
- Status of large wood decay (using criteria adapted from Wohl et al. 2011);
- Additional comments or ancillary information.

5.2 Results

Each mapped piece of wood was assigned a longitudinal stationing and the cumulative number of pieces was plotted through the three subreaches and compared between years (Figure 22). An evaluation of whether large wood storage in the active channel is increasing, decreasing, or being maintained was conducted for each subreach between fall 2013 and summer 2016 (Table 4). The Early Intake subreach had the greatest increase in large wood loading. The decrease of large wood pieces mapped in the Fireplace subreach was likely due to the decrease in water clarity within the deep backwater. Overall, the increase of wood loading between winter 2013 and summer 2016 mapping efforts was 36 pieces. Large wood storage increased in the mapped reaches from 27.8 pieces/mi in 2013 to 32.9 pieces/mi in 2016.

Since the initial large wood surveys began in 2013, the Rim Fire and subsequent wind-throw and routing has increased the number of wood pieces from 192 to 228 in the mapped portion of the Early Intake subreach from 2013–2016, as well as increased the wood density from 27.8 to 32.9 pieces/mi.

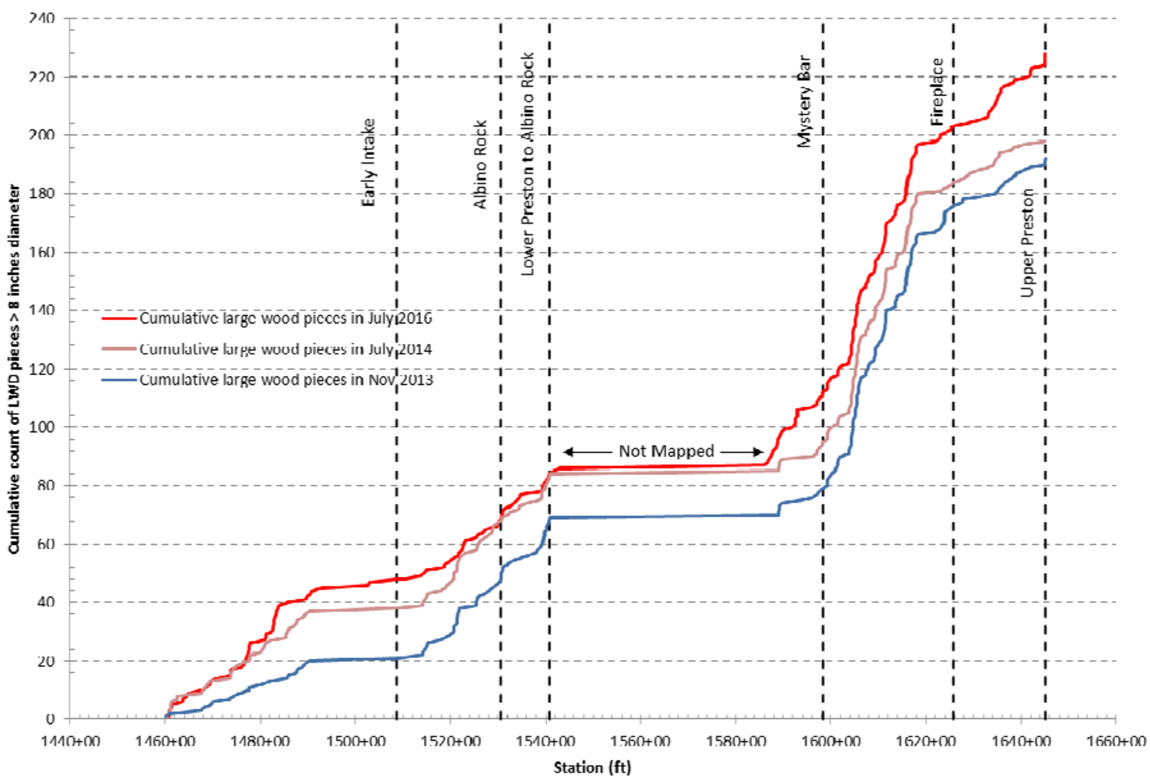

Figure 22. Cumulative count of large wood pieces by longitudinal stationing, showing comparison between winter 2013 and summer 2014 and 2016.

Table 4. Summary of number of large wood pieces mapped within each subreach between 2013 and 2016.

Date	Early Intake	Albino Rock	Mystery Bar	Fireplace	Preston Falls	Grand Total
Nov 2013	21	48	10	97	16	192
Jul 2014	38	46	11	89	14	198
Jul 2016	48	38	26	91	25	228
2013–2016	+27	−10	+16	−6	+9	+36

6 DISCUSSION AND RECOMMENDATIONS

Rim Fire-related fine sediment was being deposited and stored in-channel within the Hetch Hetchy Reach between 2013 and 2015 during sequential dry water year conditions. Although fine sediment was being contributed and stored in-channel before the Rim Fire, the in-channel sand accumulation after the Rim Fire and during the drought was more pronounced and rapid than pre-Rim Fire. In 2016, pulse flows from OSD were used to manage these fine sediment deposits and provide some aquatic ecological benefits. The results of the July 2016 monitoring suggested that short-duration, high magnitude releases can be effective tools for "resetting" fine sediment deposits within the active channel after a series of drier years. The 7,200 cfs OSD release in May 2016 flow did not mobilize large cobble and boulder deposits (nor was it expected to based on prior studies); however, it did flush large quantities of sand and removed accumulated fine sediment in the active channel at various scales (surficial storage, lee deposits, bars, deltas).

Riparian plant colonization of fine sediment deposits (i.e., lee deposits, bars and deltas) after the Rim Fire and during the drought was rapid between 2013 and 2015. However, the July 2016 results indicated that short-duration, high magnitude releases were an effective tool for "resetting" riparian vegetation established on these fine sediment deposits after a series of drier water years, but less so on deposits of larger grain sizes (cobbles and boulders). This is consistent with earlier observations in 2006–2013 as part of the instream flow management plan (SFPUC 2014). The 7,200 cfs removed established vegetation on larger sandy surfaces (new sand bars and deltas that were scoured). The 7,200 cfs release did not substantially remove riparian vegetation rooted in interstitial spaces of larger grain sizes (large cobbles and boulders).

Several of the gullies that had contributed sand into the mainstem Tuolumne River were visited in the summer of 2016. Herbaceous and woody plants colonized and presumably have stabilized most of the exposed sand deposits in the gullies. The amount of sand reaching the mainstem Tuolumne River should continue to decline as vegetation reestablishes on hillslopes and fire related hillslope sand and fine sediment supply is exhausted based on July 2016 observations. Continued photo monitoring would help document future sand introduction and deposition, should it occur.

Future monitoring could be used to quantify active channel large wood storage and routing, confirm a reduction in fine sediment contribution and vegetation establishment on active channel sand bars, and adaptively manage future high flow releases from OSD. If overall fine sediment storage decreases over time, sand bar location, number, and size are expected to fluctuate as fine sediment delivery decreases and periodic high flow releases occur from OSD. It is hypothesized that the largest volumes of sand have already been delivered and flushed from the river, and that the sand volume reaching and being stored in the mainstem will decline in the coming years. Based on 2014–2016 field observations, large wood loading, storage, and transport are expected to continue slowly increasing in the coming years as standing dead wood falls into the river, then perhaps decrease with reduced supply, wood deterioration, and wood transport during periodic high flow releases from OSD.

Future Rim Fire monitoring tasks should focus on evaluating the efficacy of management actions (primarily flows). Periodic photo monitoring should be continued, as well as monitoring large wood storage, and fine sediment storage Hillslope sand introduction and in-channel deposition should be assessed in wet or extremely wet water years. Riparian woody plant colonization of sand bars in the mainstem should be documented and monitored for the first three years after sand bar formation has been detected, or three successive below normal water year types occur. Additional analysis to consider:

- Quantify the Fireplace Pool area change over time using air photos, and/or re-survey the Fireplace Pool cross section. The bar area was estimated to be 500 ft^2 in 2015 and 300–500 ft^2 in 2016.

- Evaluate channel width (using an index high flow of 8,000 cfs), channel gradient, and other hydraulic and geomorphic indicators to help explain why some bars did not change while others were removed or changed dramatically as a result of the 2016 flows.
- If field reconnaissance detects fine sediment accumulation in the low flow channel, use drone flights to map surficial fine sediment storage.

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