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# Quantifying Changes in Streambed Composition Following the Removal of the Elwha and Glines Canyon Dam on the Elwha River

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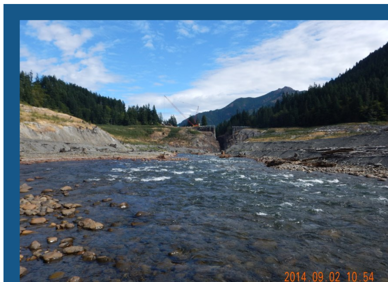




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# QUANTIFYING STREAMBED COMPOSITION OF THE ELWHA RIVER, 2014

Prepared for:

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## Abstract

Approximately 7.1 million $m^3$ of sediment was released during the first two years following dam removal (2011 and 2012) on the Elwha River, much of which has been transported and stored in river channels, floodplains, delta, and nearshore. Removal of Elwha and Glines Canyon Dams on the Elwha River was expected to eventually release a large proportion of the estimated 21 million $m^3$ (± 3 million $m^3$) of sediment stored behind the two dams. Nearly 50 percent of the estimated sediment release is classified as fine (silt and clay), which could have deleterious effects on downstream salmonid spawning habitats. The objectives of this project are to; 1) determine if fine sediment intrusion in spawning habitats of the mainstem and floodplain channels reaches levels likely to impact incubation survival, and 2) determine if the proportion of the substrate which is the appropriate size for spawning increases following dam removal. These objectives are being met through annual monitoring that was initiated prior to dam removal in 2010. Substrate was initially characterized at randomly selected riffle crests along the mainstem from just below Glines Canyon Dam to the river mouth. Floodplain substrates were characterized at upstream and downstream riffle crests in selected floodplain channels that coincided with other biological sampling (i.e., food web). Two (floodplain channels) or three (mainstem) bulk samples were collected behind a wood shield at each selected site to characterize sediment sizes. Water samples were collected before and after the bulk sampling to estimate the fine sediment content (i.e., <0.85 mm) that could not be captured in the bulk samples. These sediments affected mainstem and floodplain channels differently. Fine sediment concentrations at mainstem sites were less than six percent for the less than 0.85 mm fraction and less than 10 percent for the less than 3.35 mm fraction, except for one site which had 14.9 percent for the less than the 3.35 mm fraction. In contrast, fine sediment concentrations were generally greater than 90 percent in floodplain channels. Gravel made up a small percentage of most main channel and floodplain channel sites. Three of 22 main channels sites, all within 4 km of the former Elwha Dam site, were composed primarily of gravel. Mainstem sites consisted primarily of cobble. We recommend continuing the fine sediment sampling and initiation of streambed mobility monitoring in the mainstem.

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## INTRODUCTION

Large dam removal (dams greater than 10 m in height) has recently become a viable option to achieve numerous objectives such as the decommissioning of unnecessary or unsafe structures (Doyle et al. 2008, Warrick et al. 2015) and the recovery of aquatic ecosystems (Heinz Center 2002, Stanley and Doyle 2003, Service 2011). One of the main issues surrounding large dam removal is the large volumes of sediment that can be released because many such dams have been in place for decades, accumulating sediment in the reservoir areas (Minear and Kondolf, 2009; Sawaske and Freyberg, 2012; Merritts et al. 2013). Regardless of how long it takes to remove dams, there is typically a massive increase in sediment supply that can lead to a 3 to 20 times the average increase in the annual amount of transported sediment in a river (Warrick et al. 2015, East et al. 2015, Magirl et al. 2015, Major et al. 2012; Wilcox et al. 2014). The composition of sediment being released during dam removal will vary, but in most cases will be substantially finer grained than most of the pre-dam- removal riverbed (Kibler et al. 2011, Tullos et al. 2014, East et al. 2015). However, it is not clear how this change in sediment supply translates into changes to the aquatic ecosystem (Tullos et al, 2014).

Streambed and associated aquatic habitat responses to sediment pulses associated with dam removal can vary considerably in both temporal and spatial extent, with responses ranging from minimal and temporary, to large and persistent (Kibler et al. 2011, East et al. 2015, Tullos et al. 2014). Change in downstream aquatic habitats in the main stem, associated floodplains, and delta areas typically varies as a function of stream channel slope, stream power, sediment supply, and peak flow history (Warrick et al, 2015, East et al. 2015, Magirl et al. 2015, Stanley and Doyle, 2002, Ahearn and Dahlgren 2005, Doyle et al. 2005, Riggsbee et al. 2007, Major et al. 2012, Merritts et al. 2013, Wilcox et al. 2014).

Downstream response of streambed and aquatic habitat has already been identified in larger dam removals. Immediately after the Condit Dam removal on the White Salmon River, Washington, bed material transport increased and subsequent deposition filled pools and channel margins, aggrading the channel between 1 to 2 meters over 2 kilometers downstream (Wilcox et al. 2014). However, the channel incised 5 days later because of the diminished sediment supply exiting the reservoir and small size of the sediment transported downstream, which inhibited streambed armoring (Wilcox et al. 2014). The Marmot Dam removal on the Sandy River, Oregon resulted in immediate and persistent deposition immediately downstream of the dam four years after removal; however, there was a lack of deposition and change 7 to 12 km downstream (Cui et al. 2014). After the Milltown Dam removal in the Clark Fork River, Montana, deposition of fine sediment (<2mm) and intrusion of fines into the streambed pore space was minimal in reaches that were dominated by complex channel features, high sediment supply, and mobile streambeds (Evans and Wilcox 2013) These dam removal projects differ from Elwha dam removals in that they were instantaneous, while dam removals on the Elwha were staged. In addition, the amount and type of sediment differed from the Elwha River dams.

Newly deposited sediment from dam removal in the Elwha River, Washington resulted in a 2 to 10-fold change in bed elevation relative to the previous four years, significant channel changes (gravel bars, channel avulsion, floodplain channel aggradation), and a significant reduction in streambed particle size over the entire course of the river below the dams (East et al. 2015). The geomorphic alterations and changing bed sediment grain size along the Elwha River has important ecological implications, affecting aquatic habitat structure, benthic fauna, and in particular salmonid fish spawning and rearing potential (East et al. 2015).

Our study focuses on two questions related to these changes in the Elwha River. First, how have sediment releases from dam removal and subsequent mainstem and floodplain channel deposition altered the quality of salmonid spawning habitat in the Elwha River? Second, how has fine sediment (< 2mm) released from dam removal impacted salmonid spawning gravels? This report summarizes data collected during 2014.

## Study Area

The Elwha River is an 833 km$^2$ watershed that begins at an elevation of 1,300 m in the Olympic Mountains of Washington State's Olympic Peninsula. The Elwha flows north for 72 km emptying into the Strait of Juan de Fuca. The mountains are composed of metasedimentary rocks, with frequent landslides supplying relative large volumes of sediment (Acker et al. 2008). The Elwha is situated in a maritime climate with dry summers and cool, wet winters. The average annual precipitation is 550 cm in the headwaters and 100 cm near the river mouth (Duda et al. 2008). Peak discharges are driven by both winter rain-on-snow events and late spring/early summer snow melt. Average annual discharge in the Elwha is 42 cms, the median (two-year) peak discharge is 400 cms (Curran et al. 2009).

Construction of two dams, Elwha Dam (Rkm 7.9) and Glines Canyon Dam (Rkm 21.6) was completed in the early 1900's and blocked anadromous fish access to about 90% of the watershed (Pess et al. 2008). The dams impounded approximately 21 million m$^3$ (± 3 million m$^3$) of sediment (Warrick et al. 2015). The former Mills Reservoir, formed by Glines Canyon Dam had approximately 16 million m$^3$ (± 1.2 million m$^3$) of sediment of which less than half (44%) was composed of silt and clay (<0.063 mm) and over half (56%) was coarse (Warrick et al. 2015). The former Aldwell Reservoir, formed by Elwha dam, had ~5 million m$^3$ (± 1.4 million m$^3$) of sediment less than half of which (47%) was composed of silt and clay and over half (53%) was coarse (Warrick et al. 2015).

The Elwha River is composed of several alluvial valleys. The alluvial lower Elwha River, below former Elwha dam, has an average slope of 0.4%. The middle Elwha River, between the former Elwha and Glines Canyon dams, has a slope of 0.7-0.8% (East et al. 2015). Before dam removal, the streambed in the Lower and Middle Elwha was armored with predominately cobble sized material (64 - 256 mm; Childers et al. 2000, Pohl 2004; Draut et al. 2011).

The removal of both dams, which began in 2011, has resulted in an estimated release of ~7.1 million m$^3$ (~9.2 Mt) of sediment being released during the first two years, 6 million m$^3$ (~7.8 Mt) of which had been impounded behind Glines Canyon Dam (~37% of stored sediments) and 1.1 million m$^3$ (~1.4 Mt) behind Elwha Dam (~23% of stored sediment) (Warrick et al. 2015). The release represents a decade's worth of sediment since normal release during the period would be approximately 147,000-500,000 m$^3$ (217,000-513,000) metric tons (Curran et al., 2009; Czuba et al., 2011). Bedload transport during the second year after dam removal was about an order of magnitude greater than the first year (Magirl et al 2015). Sand and gravel began flowing over Glines Canyon Dam in October of 2012 (Randle et al. 2015). Large-scale river incision (~0.4 m) occurred at in the Lake Aldwell reservoir delta sediments behind former Elwha Dam by November 2012 (Randle et al. 2015). As of September 2013 there was an estimated 580,000 $m^3$ of new sediment stored in the lower 18 kilometers of the Elwha River (East et al. 2015).

## METHODS

### *Field Methods*

The proportion of fine sediment and spawning gravel in the Elwha River below the former Glines Canyon Dam were quantified by sampling 20 of 46 (in 2010) selected riffle crest sites in the mainstem, and 18 floodplain channel sites in the Middle and Lower Elwha during August and September of 2014. The 20-mainstem sampling sites sampled were randomly selected from the 46-riffle crests available in 2010 from Glines Canyon Dam downstream to the river mouth. The sites were randomly selected to ensure that they would be distributed from Glines Canyon to the river mouth (Figure 1). Floodplain channels were generally sampled at their upstream and downstream ends and were selected to coincide with on-going biological sampling efforts (e.g. Morley et al. 2008). Three sub-samples were collected at each mainstem site and two sub-samples at narrower (<5 m wetted width) floodplain channels. When possible we sampled across the entire riffle crest, one in the center and two closer to each bank at mainstem locations and two closer to each bank in floodplain channels. Where this was not possible due to water depth and/or velocity, we sampled on one side or the other, sampling at the upstream, downstream and mid riffle crest portion of the site. Results from the subsamples were combined to calculate the metrics evaluated as described below.

A plywood shield modified from the design presented by Bunte and Abt (2001) was used to define a sampling area of approximately 0.10 $m^2$. The shield was placed on the streambed with the open end downstream, to provide a protected area for sampling (Figure 2). We then collected a depth-integrated water sample from the sampling location to get a quantitative estimate of the proportion of suspended sediments in the water column prior to sampling. We measured five water depths within the sampling area at equidistant points with a ruler to calculate an average water depth. Three to five of the largest surface layer rocks, which we thought represented the 84th percentile streambed particle size (D84), were removed, measured and weighed on-site. Water depths in the voids left by the removed particles were measured to determine an average depth of excavation. The surface layer was defined as the material lying between the original channel bottom and the average depth of the voids left by the rocks removed (Figure 3). The surface layer was then uniformly excavated and placed into a canvas bag using gloved hands, cupped to avoid losing the fine sediment fraction. Each sample was marked with the date, study site, and within site, location (i.e. left bank, right bank, middle). Once the sample was completely removed we collected a second depth-integrated water sample while the water was still turbid from the removal of the surface layer to assess the volume of fines dislodged into suspension during sampling.

We recorded the length, width, and original and final depths of the excavated area and used this to calculate the volume of water within the sampling area, which was used to calculate the weight of fines suspended in the water column (see below). In some cases, the site had large particles that were difficult to transport back to the lab (generally, 90 mm or larger). We measured the intermediate- or b-axis (Bunte and Abt 2001) and weight of each of these particles in the field. Smaller rocks were weighed with a platform scale accurate to 0.001 kg, while larger rocks were placed in a sample bag and weighed using a spring scale accurate to 0.1 kg.

Bulk samples were taken to the lab, dried, and sieved following standard procedures (Bunte and Abt 2001). Sieves having openings of 75, 26.5, 13.2, 9.5, 3.35, 2, 0.85, 0.106 mm were used to characterize sediments. Particles in each sieve were weighed using a platform scale accurate to the nearest 0.001 kg. The concentration of suspended sediments (mg/l) in the water samples associated with each bulk sample collected was determined by lab filtration using a modified standard methods approach (Franson 1985). Ninety- mm-diameter fiberglass filters were washed (using 30 ml distilled water) and dried (103-105 $^{o}$C for 4 hrs) two separate times to remove dust and loose fibers. Filters were weighed to 0.0001 mg at the beginning and end of each wash/dry cycle. Suspended sediment samples were shaken for 5 minutes using an electric sediment shaker fitted with a bottle holder attachment. Once shaken, 200 to 300 ml of the sample was quickly poured into a graduate cylinder and the volume noted. This sub-sample was slowly poured onto the glass filter to allow the water to be sucked through the filter by a vacuum pump. Once the entire subsample was processed, the graduated cylinder was washed three times using 20 ml of distilled water, which was also poured onto the filter. The funnel supporting the glass filter was washed three consecutive times and allowed to drain completely. The filter was then removed and dried in an oven overnight at 103-105 $^{o}$C. The filter was weighed after drying overnight and placed in a muffle furnace at 550 $^{o}$C for 15 minutes at to burn off any organic matter. After cooling, the filter was weighed again.

The suspended sediment concentration behind the shield after the sample was collected was calculated by dividing the difference in weight of the filter after ignition at high temperatures in the muffle furnace and the original, clean, washed and dried filter, by the volume of water filtered. The background concentrations obtained from the water sample collected before the substrate sample was collected was subtracted to calculate the actual concentration suspended during the sampling activity. The total weight of non-organic solids stirred up into the water column during sampling was computed using the volume of water within the shield as determined from the dimensions of the sampling area and water depth. The estimated fine sediment weight determined from this procedure was included in the <0.106 mm size fraction in the sample analysis.

Data were summarized by main channel and floodplain channels for percent less than 0.85 mm, percent less than 3.35 mm, percent gravel (>3.35 mm, < 75 mm), and percent cobble (>75 mm). Data were summarized as percent less than 0.85 mm because this substrate size has been shown to have the greatest impact on salmonid egg survival (Jensen et al. 2009). The percentage less than 3.35 mm size fraction was used since it was similar to the sizes reviewed by Jensen et al. (2009). Percent less than 0.85 mm and 3.35 mm were calculated based on the total weight of the sample less than 75 mm to reduce the potential bias caused by extremely large particles making up a large proportion of the sample.

## RESULTS

The response of floodplain and mainstem channels to sediment releases from the removal of Elwha and Glines Canyon dams differed for the fine sediment and cobble size fractions, but not for gravel (Figure 4 and 5). Fine sediment less than 0.85 mm ranged from 0 to 5.8 percent in main channels and 1.9 to 100 percent in floodplain channels. None of the 22 mainstem sites had <0.85 mm concentrations greater than 10 percent, while 11 of 13 floodplain channel sites had concentrations greater than 10 percent. The concentrations of the less than 3.35 mm fraction ranged from 0 to 14.9 percent in the main channel sites, with one of the 22 sites having a concentration greater than 10 percent. In contrast, the 3.35 mm fraction ranged from 4.3 to 100 percent, with 12 of the 13 sites having concentrations greater than 10%.

Percent gravel observed in main channel and floodplain channel sites were generally similar (Figures 4 and 5). Percent gravel varied from 0 to 88.9 percent in main channel sites, while those in floodplain channels varied from 0 to 82.9 percent. Only two of the 22 main channel sites and two of 13 floodplain channel sites had greater than 50 percent gravel. Thus, gravel made up a relatively small proportion of the overall substrate in both main and floodplain channel sites.

In contrast to floodplain channel sites that were composed primarily of fine sediments, main channel sites were composed primarily of cobble (Figures 4 and 5). Percent cobble varied from 6.7 to 100 percent in the main channel sites and from 0 to 99.8 in the floodplain channel sites. Nineteen of the 22 mainstem sites had greater than 90 percent cobble. In contrast, only two of the 13-floodplain channel sites had more than 90 percent cobble.

## DISCUSSION

The removal of Elwha and Glines Canyon Dams has resulted in the release of approximately 7.1 million $m^3$ (10.5 million Mt) of sediment during the first two years of dam removal and much of this was fine sediment (Randle et al. 2015). This sediment has been transported throughout the Elwha River to the near-shore environment (Warrick et al. 2015) and therefore has the potential to impact salmonid spawning habitat (Peters et al. 2014). Mainstem and floodplain channel substrates have been influenced differently by this sediment release. Potential spawning habitat in floodplain channels has been almost completely covered with fine sediment, while mainstem spawning habitat has relatively low percentages of fine sediment present. However, only a few main channel sites are composed primarily of gravel, with the remaining main channels sites composed primarily of cobble.

In general, fine sediment levels in floodplain channels exceeded 90%, while fine sediment levels in the main channel sites were on average less than 6%. This has several potential effects on salmonids of all life stages. First spawning salmonids will likely not utilize the floodplain habitats due the high proportion of finer sediment, while salmonids will likely utilize the mainstem sites due to the higher proportion of spawnable material. Salmonids that spawn in floodplain channels conversely also have a higher likelihood of deleterious effects at other life stages such as the egg to fry life stage due to elevated fine levels (Jensen et al. 2009). Mainstem sites will have a higher likelihood of being utilized at the spawning life stage and a lower likelihood of deleterious effects at the egg to fry life stage resulting from fine sediment impacts because of the lower levels of fine sediment (Jensen et al. 2009).

Although fine sediment concentrations were low in the mainstem, the results should be viewed cautiously. Our sampling method resulted in a relatively small sample being collected from the large riffle crests of the mainstem Elwha and represents conditions during a single point in time; summer low flow conditions. When combined, the three sub-samples from each riffle represented an average area of about 1.25 $m^2$. Diplas and Fripp (1992) recommend that areal samples should be a minimum of 100 times the area of the largest particle, while Fripp and Diplas (1993) recommend 400 times the largest particle to obtain precise estimates of all particle sizes. Individual particles with surface areas of 0.15 $m^2$ were common during sediment sampling in the Elwha River from 2010-2013 (Peters, unpublished data). Given this, sampling areas of 15 $m^2$ to 60 $m^2$ would be required to obtain an unbiased sample based on these areal methods. Sampling this area is logistically impractical and environmentally undesirable. Thus, the total area sampled during our sampling efforts was small relative to that required to obtain an unbiased sample. To counteract this potential bias, we calculated percent fine sediment (both <0.85 and 3.35 mm) based on the overall sample weight of particles less than 75 mm – the largest sieve used to characterize particle size in this study. This should have limited the potential bias associated with very large particles.

Although much less common due to the generally smaller substrate size in floodplain channels prior to dam removal (Peters, unpublished data), and the small size of substrates observed, data for the floodplain channels also have potential bias. We collected two sub-samples in floodplain channels, so the area sampled was about 0.8 $m^2$. However, particles up to 190 mm (~0.04$m^2$) were present, requiring a sample area of approximately 4 $m^2$ to obtain unbiased estimates. This potential bias existed for only five of the 13 floodplain sites we sampled. However, with the exception of two of these sites, concentrations of the less than 0.85 mm particles were greater than 10 percent, a level reported to result in increased incubation mortality (Jensen et al. 2009). Thus, even with this potential bias against fine sediment concentrations, the concentration of 0.85 mm particles was sufficient to potentially impact incubation survival of salmonids, assuming any salmonids spawned in these channels. In addition, our result are similar to those reported by Pess et al. (2015), who reported significant fine sediment (< 2 mm) accumulations in floodplain channels from the lower and middle Elwha River. Finally, by calculating percent fine sediment based on the total weight of sediment less than 75 mm we limited the potential for this bias.

Data from 2014 suggest similar results to those observed from 2010-2013 (Peters, Unpublished data). It appears that fine sediments (i.e., <0.85 mm and <3.35 mm) have been declining since 2012 in main channel sites and that levels are still below levels reported to reduce incubation survival. In addition, the bed appears to be degrading back to its original elevation and re-exposing previous cobble substrates, an observation that is supported by East et al. (2015). The somewhat reduced deposition in floodplain channels between 2013 and 2014 (Pess et al. 2015) has resulted in increased substrate size in several of the floodplain sites we sampled.

We recommend that yearly sampling continue as long as sediment transport substantially greater than normal is observed. Based on this, we plan to sample these sites again in 2015. We plan to sample at least three additional floodplain channels to overlap with new food web sampling planned for 2015 (Sarah Morley, NOAA, personal communication). In addition, main channel and floodplain channel pebble counts will be summarized in the future. Pebble counts were collected in floodplain channel during 2014, but could not be safely collected in the main channel due to higher flows. We expect to be able to collect main channel pebble counts in 2015 and will summarize that data in future reports.

Increased salmonid redd scour is another mechanism that could lead to decreased incubation survival for salmonids. Redd scour is known to increase in channels where sediment loads increase drastically above background levels (Tripp and Poulin 1986; Frissell et al. 1996), which is occurring in the Elwha River (East et al. 2015). However, this variable is not being measured in the Elwha River. We recommend that scour monitoring be initiated in the mainstem if possible to assess the influence of increased sediment transport on salmonid spawning habitat below the former Glines Canyon Dam site. This area represents nearly 21 km of mainstem river and has been the primary spawning area for Chinook salmon in recent years (McHenry et al. 2015).

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## LITERATURE CITED

Acker, S.A., Beechie, T.J., Shafroth, P.B., 2008. Effects of a natural dam-break flood on geomorphology and vegetation on the Elwha River, Washington, U.S.A. Northwest Science 82 (Special Issue):210–223.

Ahearn, D.S., Dahlgren, R.A. 2005. Sediment and nutrient dynamics following a low-head dam removal at Murphy Creek, California. Limnology and Oceanography 50:1752

Bunte, K., and S.R. Abt. 2001. Sampling surface and subsurface particle-size distributions in wadable gravel- and cobble-bed streams for analysis in sediment transport, hydraulics, and streambed monitoring. General Technical Report RMRS-GTR-74. USDA, Forest Service, Rocky Mountain Research Station, Fort Collins, Colorado.

Childers, D., Kresch, D.L., Gustafson, S.A., Randle, T.J., Melena, J.T., Cluer, B., 2000. Hydrologic data collected during the 1994 Lake Mills Drawdown Experiment, Elwha River, Washington. U.S. Geological Survey Water-Resources Investigation Report 99-4215 (115 pp.).

Cui, Y., Wooster, J.K., Braudrick, C.A., Orr, B.K., 2014. Lessons learned from sediment transport model predictions and long-term postremoval monitoring: Marmot Dam removal project on the Sandy River in Oregon. Journal of Hydraulic Engineering http://dx.doi.org/10. 1061/(ASCE)HY.1943-7900.0000894, 04014044.

Curran, C.A., Konrad, C.P., Higgins, J.L., Bryant, M.K., 2009. Estimates of sediment load prior to dam removal in the Elwha River, Clallam County, Washington. US Geol. Surv. Sci. Investig. Rep. 2009–5221, 18.

Czuba, C.R., Randle, T.J., Bountry, J.A., Magirl, C.S., Czuba, J.A., Curran, C.A., Konrad, C.P. 2011. Anticipated sediment delivery to the lower Elwha River during and following dam removal. In: Duda, J.J., Warrick, J.A., Magirl, C.S. (Eds.), Coastal Habitats of the Elwha River, Washington—Biological and Physical Patterns and Processes Prior to Dam Removal. U.S. Geological Survey Scientific Investigations Report 2011-5120, pp. 27–46.

Diplas, P. and J. Fripp, 1991. Bed material sampling: issues and answers. Pages 281-288 *in* Proceedings of the Fifth Federal Interagency Sedimentation Conference, Las Vegas, Nev., Subcommittee on Sedimentation of the Interagency Advisory Committee on Water Data.

Doyle, M.W., Stanley, E.H., Orr, C.H., Selle, A.R., Sethi, S.A., Harbor, J.M., 2005. Stream ecosystem response to small dam removal: lessons from the Heartland. Geomorphology 71:227–244.

Doyle, M.W., Stanley, E.H., Havlick, D.G., Kaiser, M.J., Steinbeck, G., Graf, W.L., Galloway, G.E., Riggsbee, J.A., 2008. Aging infrastructure and ecosystem restoration. Science 319:286–287.

Draut, A.E., Logan, J.B., Mastin, M.C., 2011. Channel evolution on the dammed Elwha River, Washington, USA. Geomorphology 127:71–87.

Duda, J.J., Freilich, J.E., Schreiner, E.G., 2008. Baseline studies in the Elwha River ecosystem prior to dam removal. Northwest Science 82 (Special Issue):1–12.

East, A.E., Pess, G.R., Bountry, J.A., Magirl, C.S., Ritchie, A.C., Logan, J.B., Randle, T.J., Mastin, M.C., Duda, J.J., Liermann, M.C., McHenry, M.L., Beechie, T.J., Shafroth, P.B., 2015. Large-scale dam removal on the Elwha River, Washington, USA: river channel and floodplain geomorphic change. Geomorphology 228:765-786. http://dx.doi.org/10.1016/ jgeomorph.2014.08.028.

Evans, E., Wilcox, A.C. 2013. Fine sediment infiltration dynamics in a gravel-bed river following a sediment pulse. River Research and Application 30:372–384.

Franson, M. A., 1985. Standard methods for the examination of water and wastewater, 16th ed. American Public Health Association, Washington, D.C. 1268 pp.

Fripp, J.B. and Diplas, P., 1993. Surface sampling in gravel streams. Journal of Hydraulic Engineering 119(4):473-490.

Frissell, C.A., W.J. Liss, R.E. Gresswell, R.K. Nawa, and J.L. Ebersole. 1996. A resource in crisis: changing the measure of salmon management . Pages 411-444 *in* D. Stouder, P. Bisson, and R. Naiman, editors. Pacific salmon and their ecosystems: status and future options. Chapman and Hall, New York.

Heinz Center. 2002. Dam removal: science and decision making. H. John Heinz III Center for Science Economics and the Environment, Washington, D.C. (221 pp.).

Jensen, D.W., Steel, E.A., Fullerton, A.H. and Pess, G.R. 2009. Impact of fine sediment on egg-to-fry survival of Pacific salmon: A meta-analysis of published studies, Reviews in Fisheries Science,17(3):348-359. DOI: 10.1080/10641260902716954

Kibler, K., Tullos, D., & Kondolf, M. 2011. Evolving expectations of dam removal outcomes: Downstream geomorphic effects following removal of a small, gravel-filled Dam1. JAWRA Journal of the American Water Resources Association, 47:408-423.

Magirl, C.S., Hilldale, R.C., Curran, C.A., Duda, J.J., Straub, T.D., Domanski, M., Foreman, J.R.. 2015. Large-scale dam removal on the Elwha River, Washington, USA: Fluvial sediment load. Geomorphology 228:xxx-xxx. doi:10.1016/j.geomorph.2014.12.032.

Major, J.J., O'Connor, J.E., Podolak, C.J., Keith, M.K., Grant, G.E., Spicer, K.R., Pittman, S., Bragg, H.M.,Wallick, J.R., Tanner, D.Q., Rhode, A.,Wilcock, P.R., 2012. Geomorphic response of the Sandy River, Oregon, to removal of Marmot Dam. U.S. Geological Survey Professional Paper 1792 (64 pp.).

McHenry, M. G. Pess, R. Moses, S. Brenkman, P. Crain, and J. Anderson. 2015. Spawning distribution of Chinook salmon (Oncorhynchus tshawytscha) in the Elwha River, Washington State during dam removal from 2012 to 2014. Lower Elwha Tribe Report, Port Angeles, WA.

Merritts, D.,W., R., Rahnis, M., Cox, S., Hartranft, J., Scheid, C., Potter, N., Jenschke, M., Reed, A., Matuszewski, D., Kratz, L., Manion, L., Shilling, A., Datin, K., 2013. The rise and fall of Mid-Atlantic streams: millpond sedimentation, milldam breaching, channel incision, and stream bank erosion. In: De Graff, J.V., Evans, J.E. (Eds.), The Challenges of Dam Removal and River Restoration: Geological Society of America Reviews in Engineering Geology XXI, pp. 183–203.

Minear, J.T., Kondolf, G.M. 2009. Estimating reservoir sedimentation rates at large spatial and temporal scales: a case study of California. Water Resource Research 45:W12502.

Morley, S. A., Duda, J. J., Coe, H. J., Kloehn, K. K., & McHenry, M. L. 2008. Benthic invertebrates and periphyton in the Elwha River basin: current conditions and predicted response to dam removal. Northwest Science, 82(sp1):179-196.

Pess, G.R., McHenry, M.L., Beechie, T.J., Davies, J., 2008. Biological impacts of the Elwha River dams and potential salmonid responses to dam removal. Northwest Sci. 82 (Special Issue):72–90.

Pess, G.R. M.C. Liermann, T.R. Bennett, and T.J. Beechie. 2015. Longitudinal profiles in floodplain channels of the Middle and Lower Elwha River – 2012 and 2014. Northwest Fisheries Science Center (NWFSC), National Oceanic and Atmospheric Administration (NOAA), Seattle, WA

Peters, R.J., J.J Duda, G.R. Pess, M. Zimmerman, P. Crain, Z. Hughes, A. Wilson, M.C. Liermann, S.A. Morley, J.R. McMillan, K. Denton, D. Morrill, and K. Warheit. 2014. Guidelines for Monitoring and Adpatively Manageing Restoration of Chinook Salmon (*Oncorhynchus tshawytscha*) and Steelhead (*O. Mykiss*) on the Elwha River. U.S. Fish and Wildlife Service, Olympia.

Pohl, M., 2004. Channel bed mobility downstream from the Elwha dams, Washington. Professional Geographer 56:422–431.

Randle, T.J., Bountry, J.A., Ritchie, A., Wille, K., 2015. Large-scale dam removal on the Elwha River, Washington, USA: erosion of reservoir sediment. Geomorphology 228: xxx-xxx. doi:10.1016/j.geomorph.2014.12.045.

Riggsbee, J.A., Julian, J.P., Doyle, M.W.,Wetzel, R.G., 2007. Suspended sediment, dissolved organic carbon, and dissolved nitrogen export during the dam removal process. Water Resources Research 43:W09414.

Sawaske, S.R., and Freyberg, D.L., 2012. A comparison of past small dam removals in highly sediment-impacted systems in the US. Geomorphology 151:50–58

Service, R.F. 2011. Will busting dams boost salmon? Science 334 (6058):888–892.

Stanley, E.H., and M.W. Doyle, 2003. Trading off: the ecological effects of dam removal. Frontiers in Ecology and the Environment 1:15–22.

Tripp, D.B., and V.A. Poulin. 1986. The effects of logging and mass wasting on salmonid spawning habitat in streams on the Queen Charlotte Islands. Ministry of Forest and Lands, Research Branch, Land Management Report 50, Victoria, British Columbia.

Tullos, D., Wang, H. W., 2014. Morphological responses and sediment processes following a typhoon-induced dam failure, Dahan River, Taiwan. Earth Surface Processes and Landform 39:245–258.

Warrick, J.A., Bountry, J.A., East, A.E., Magirl, C.S., Randle, T.J., Gelfenbaum, G.R., Ritchie, A.C., Pess, G.R., Leung, V., Duda, J.J., 2015. Large-scale dam removal on the Elwha River, Washington, USA: source-to-sink sediment budget and synthesis. Geomorphology 228: xxx-xxx. doi:10.1016/j.geomorph.2015.01.010.

Wilcox, A.C., O'Connor, J.E., Major, J.J., 2014. Rapid reservoir erosion, hyper concentrated flow, and downstream deposition triggered by breaching of 38 m tall Condit Dam, White Salmon River, Washington. Journal of Geophysical Research - Earth Surfaces 119. http://dx.doi.org/10.1002/2013JF003073.

## FIGURES

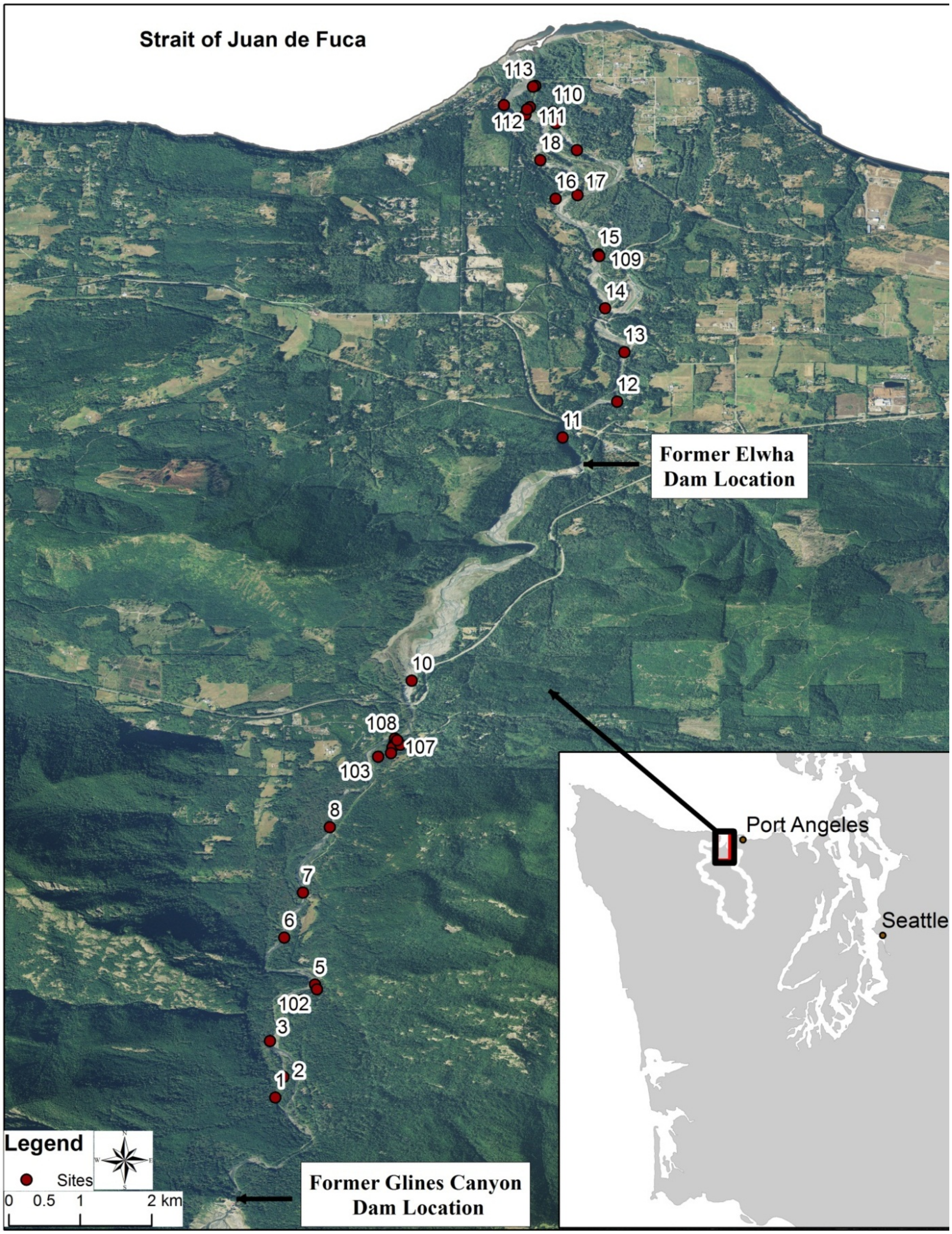


Figure 1. Elwha study area and sites sampled during late summer 2014


Figure 2. Photograph showing the shield used to provide a calm area where fine sediment samples could be collected.

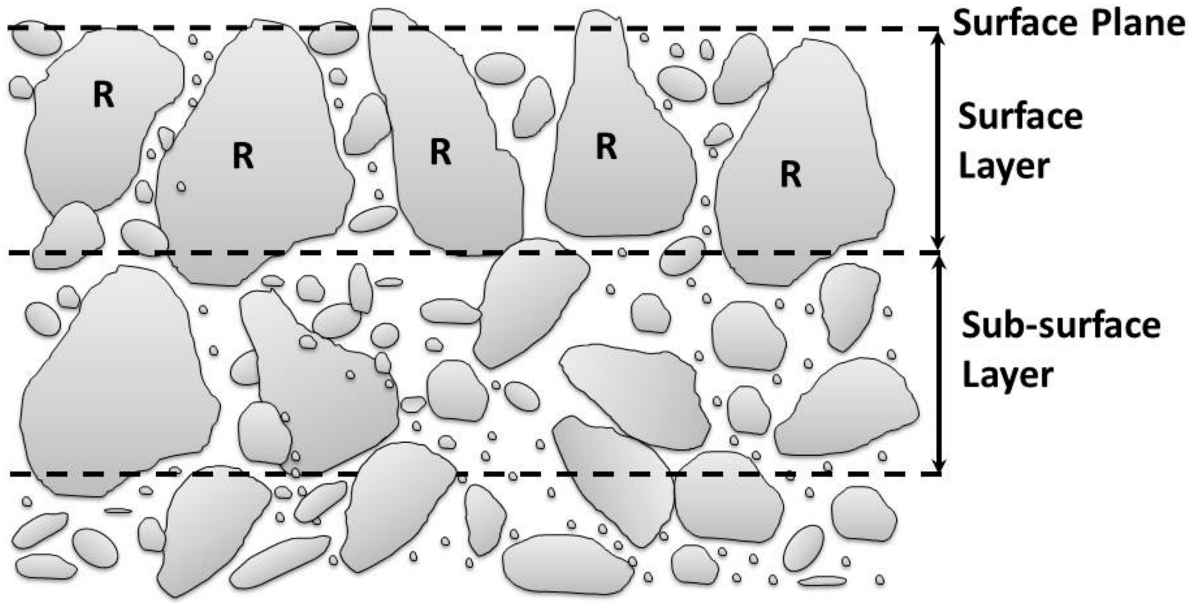


Figure 3. The surface layer for sediment removal and analysis during this project was defined by removing three to five rocks representing the 84$^{th}$ percentile streambed particle size (marked with an 'R' in this figure. The surface layer extended to the average depth of the void left by removing these rocks (adapted from Bunte and Abt 2001).

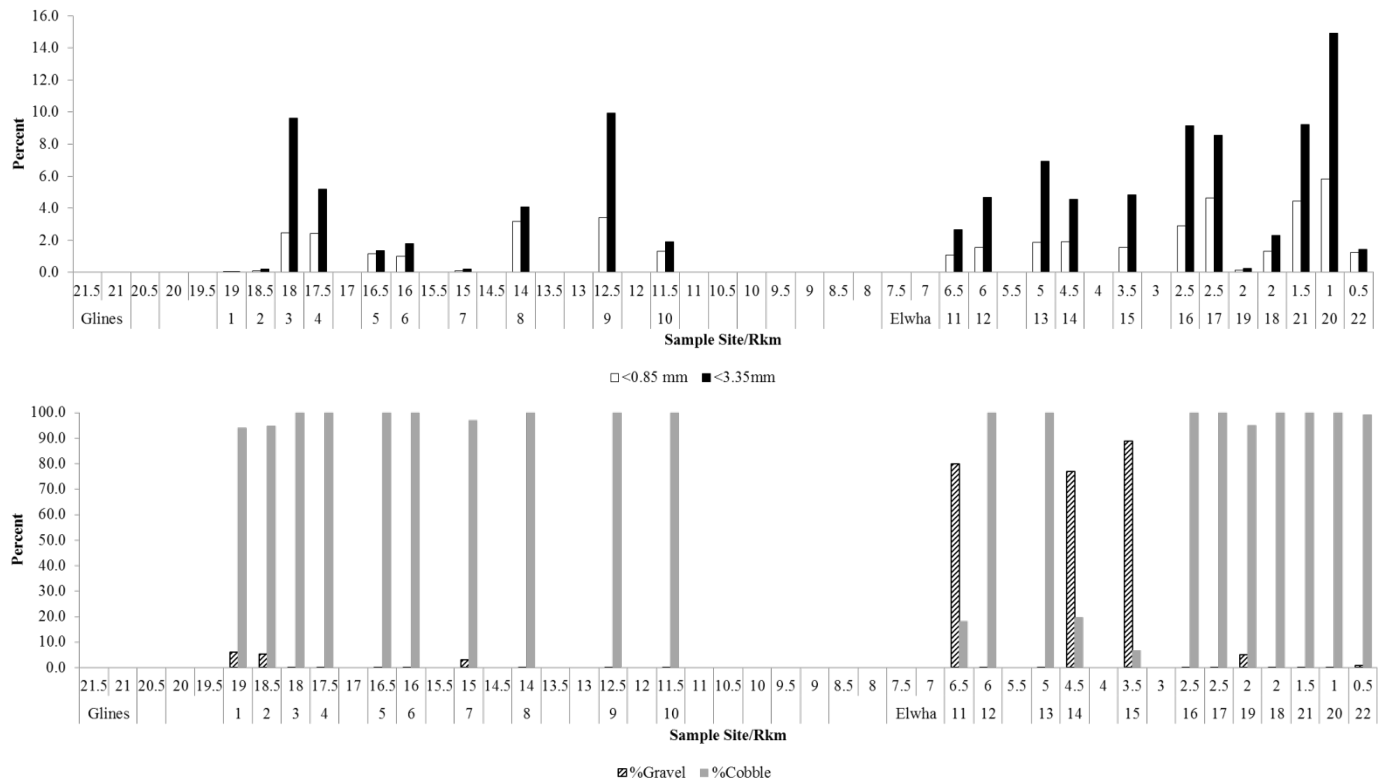


Figure 4. Percent fine sediment less than 0.85 mm, 3.35 mm, gravel and cobble observed in bulk samples from mainstem sample sites. River kilometer (top row) and site names (bottom row) are both listed on the x-axis. Percent gravel and cobble is based on total sample weight; percent fine sediment is based on total weight less than 75 mm. No samples were collected if no site names are listed. This was done to show the relative position of the sampling sites. The location of the former Glines Canyon dam (Glines) and Elwha Dam (Elwha) are noted on the site name line. Note that the scales for the y-axis are different in the two charts.

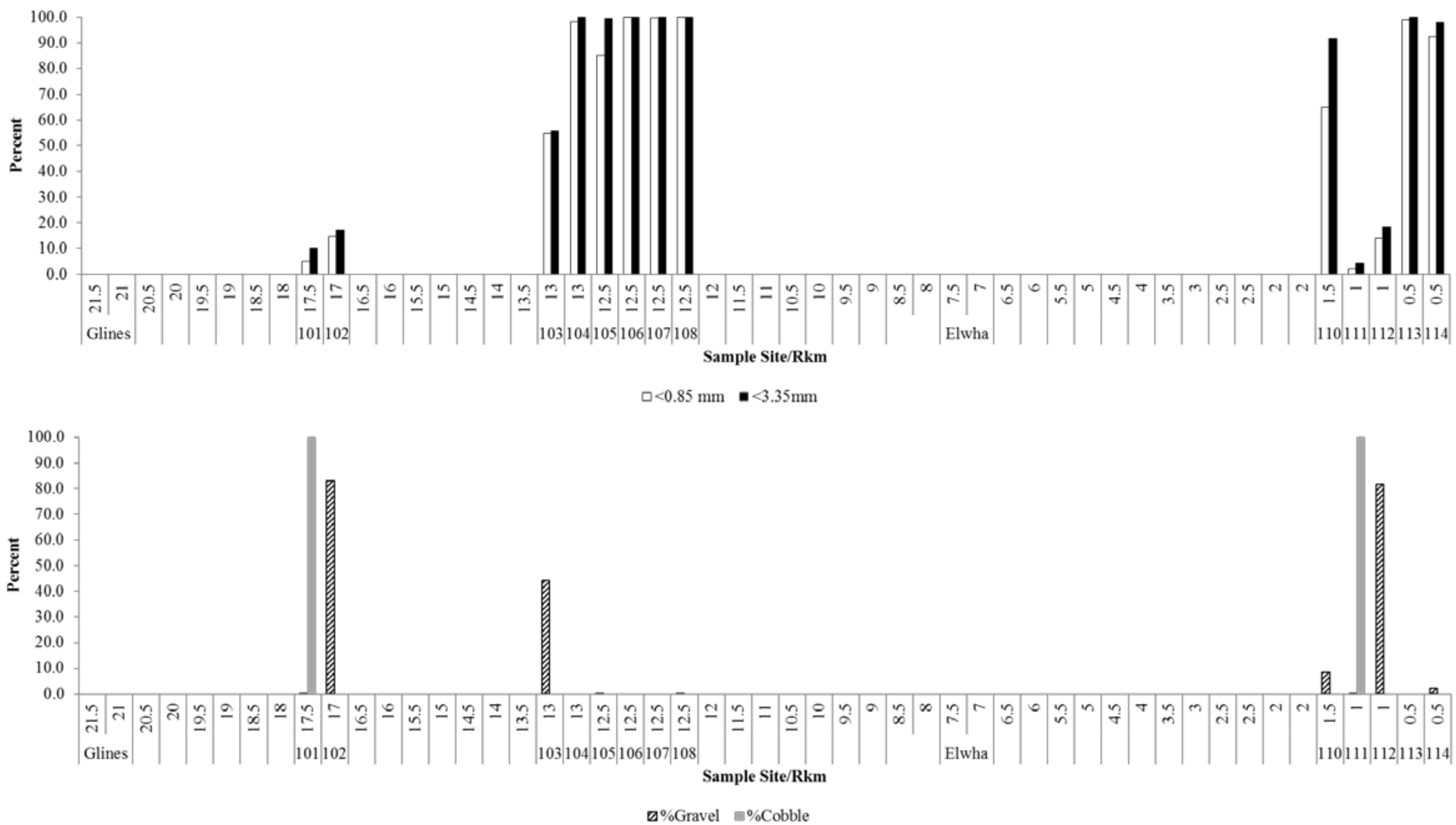


Figure 5. Percent fine sediment less than 0.85 mm, 3.35 mm, gravel and cobble observed in bulk samples from floodplain sample sites. Percent gravel and cobble is based on total sample weight; percent fine sediment is based on total weight less than 75 mm. River kilometer (top row) and site names (bottom row) are both listed on the x-axis. No samples were collected if no site names are listed. This was done to show the relative position of the sampling sites. The location of the former Glines Canyon dam (Glines) and Elwha Dam (Elwha) are noted on the site name line.

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