Comparison of Grain Size and Delta Morphology East and West of the Elwha River Mouth

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Abstract

For almost 100 years sediment has been building up behind two dams on the Elwha River in Washington State (Warrick et al., 2009). It was determined that in order to restore the watershed, the most effective process would be the removal of the dams (Gelfenbaum et al., 2009). This study looks at the effects of the increased sediment budget on comparative grain-size and topographical and bathymetry profiles of two transect lines, east and west of the Elwha River mouth. We found a higher accumulation of sediment on the East transect versus the West transect which is likely due to the oblique wave angle on the delta and net alongshore transport to the east. The morphology of the East transect line after dam removal changed to a steeper slope which could be caused from the increased sediment being deposited faster than it can be eroded. Lastly, we found that the beach substrate within the troughs on the subaerial delta was finer while the berms consisted of coarser material, which is likely due to the relative exposure to wave energy.

1. Introduction

The morphology of river deltas is directly influenced by sediment supply being transported downstream (Warrick et al., 2009). Globally, the damming of rivers traps 80% of material that would naturally flow to coastal environments within reservoirs that form behind dams (Vörösmarty et al., 2003). This causes the sediment supply to the coast, shoreline and delta to be reduced, which increases the erosion rates as well as changes the morphology and grain-sizes of the delta (Warrick et al., 2009). When the physical dam structure is removed, the sediment that was built up behind the dam is released back into the system. This changes the grain size and morphology of the delta.

The Elwha River had two dams installed over 100 years ago that significantly reduced the amount of sediment flowing downstream, making it an excellent site to study the effects of dam removal (Kloehn et al., 2008). Within the reservoirs and on the delta, there are mixed grain sizes due to the influence of glaciers, making it a unique and understudied system that could increase the knowledge of areas similar to the Elwha (Buscombe and Masselink, 2006). Since the removal of the dams began, approximately 50% of the sediment in the reservoirs has moved downstream (Curren et al., 2012). Subsequently, the delta was prograding and the grain sizes have changed (Miller, 2013). The objective of this study is to investigate the differences in morphology and grain-size of a wave-dominated delta with mixed grain sizes after an increase in sediment budget. This is important to study future dam removal projects because it can be used to predict the effects of this type of restoration on small mountainous rivers.

2. Background

The Elwha River is located on the Olympic Peninsula of Washington, eight miles west of Port Angeles. The river is fed, in part, by glacial melt from the Olympic Mountains, and drains north into the Strait of Juan de Fuca. Waves move eastward through the Strait and hit the shore at an oblique angle causing a net shore drift of sediment to the east (Gelfenbaum et al., 2009). The waves dissipate as they move inland. However, they still play an important role in the Elwha's morphology and thus, it is classified as a wave dominated delta (Warrick et al., 2009). The delta itself is composed of two parts, the subaerial (above sea level) and the submarine (below sea level) (Duthier et al. 1995). It is believed that the submarine delta was created during the glacial retreat associated with the last glacial maximum (Duthier et al., 1995). At this time the sea level was 50 meters lower than at present, and the current submarine delta was probably subaerial (Glaster and Schwartz, 1990). When sea level rose to the current height, this delta was submerged and new subaerial delta was formed.

In 1912 and 1927, two dams were constructed on the Elwha River, changing the morphology of the delta as well as the amount of sediment delivered to the coastal ocean (Duda et al., 2011). The Elwha dam was built first, resulting in the accumulation of 5 million $m^3$of sediment (Duda et al., 2011). Farther upstream is the Glines Canyon Dam, which was built in 1927 and was estimated to have accumulated 13.5 million $m^3$of sediment as of 1995 (Duda et al., 2011) The sediment grain-sizes in the reservoirs was estimated to range between silt and cobble with an distribution of 52% silt and clay, 35% sand and 13% gravel and cobble (Gilbert and Link, 1995).

Because the sediment was being trapped behind the dams, the shoreline around the Elwha River delta became sediment starved and erosion of the finer sediment occurred, exposing the courser sands and cobbles (Gelfenbaum et al., 2009). On the west side of the river the beaches were steep and showed no long-term pattern of erosion (Warrick et al., 2009). However, on the east side of the river there was a steep foreshore and then a flat terrace that was constantly being eroded down to the coarse cobble and boulder lag (Gelfenbaum et al., 2009).

As of June 2014, the Elwha dam had been completely removed and over 50% of the Glines Canyon dam had been removed (NPS, 2014). Since the removal began it has been estimated that 31x10^6 m^3 of sediment have been transported downstream and about 12x10^6 m^3 has been deposited on the delta causing it to prograde (Curran et al., 2014).**3.**

Methods

In order to determine how grain size and morphology varied on the east versus the west sides of the Elwha river mouth, samples were collected along two transects. Each line begins within the backshore beach area and extended approximately 5,000 meters across the delta shoreface into deep water. These transects were selected to represent the general profile and grain sizes found on that side of the river.

Two different methods were used for collecting data in the intertidal and subtidal zones. Subaerial sediment samples were taken each time there was a visible and obvious change in grain size along the cross-shore transect. About 30 grams of sediment was collected from about an inch deep using a spoon. A Real Time Kinematic Differential Global Positioning System (RTK-DGPS) was used to record the sample location and elevation.

Once the samples were collected, we used a dry sieve technique for coarse sand and gravel to determine the grain-size distributions. Each sample was first weighed and then dried in the oven. The samples were placed in a sieve with mesh that ranged in size from -4 phi to 4 phi and shaken via Ro-tap for 10 minutes. From there the sub-samples for each grain-size fraction were weighed and the D50 grain size was calculated using Gradistat software.

For samples with a mix of grain sizes, a subsample was collected, weighed, and placed in a 4 phi sieve and washed with deionized water and $NaPo_4$ (dispersant) until the discharge ran clear. The sample remaining in the sieve was dried and then processed as a dry sieve sample as described above. The full sample was also dried and weighed to be used in calculations done by Gradistat.

The sediment that was able to run through the screen was added to a cylinder with dispersant solution that was filled to the one liter mark. It was then mixed for two minutes in order to suspend all the sediment. After, the cylinder was placed upright and left stationary, allowing the sediment to settle. Aliquots were taken at specific elevations and time intervals and dried (Buchanan, 1984). Once all five samples were taken the remaining liquid was placed in the oven to evaporate off the dispersant. The overall dry sample was weighed as well as the individual samples. Sediment size was then calculated using the settling velocity of the sediment (Buchanan 1984).

The GPS points from the RTK-DGPS were plotted on two graphs with distance from MHHW on the X-axis and elevation on the Y-axis, combined with data collected by the USGS in order to plot points within the subaqueous delta. This process was done for the East and the West transect in 2014 and in 2011. When comparing 2011 transects to 2014 transects the X-axis starts at the most landward point and the Y-axis is centered on sea level. The mean grain size of each sample taken in 2014 was determined through Gradistat and plotted along the graph from 2014 as the Z variable.

Figure 1: The East and West transect lines of the Elwha delta

4. Results

4.1. East and West Transect Before Dam Removal

Topography of both transect lines was mapped from data collected in 2011 (USGS) (fig 2). The lines intersect the Y axis at MHHW and start on shore and extend into the sub tidal, showing the full morphology of the beach. The subaerial delta on each graph is very similar. The East transect line has about 15 meters of mapped subaerial delta while the West has about 150 meters of recorded morphology above sea level. However, both share a similar berm that is about three meters tall. As the line moves into the subtidal zone, they share a very similar slope for the first 200 meters of the subaqueous delta. The two transects separate at about 200 meters and while the East transect line maintains its slope, the West transect line steepens and then levels out forming a terrace (fig. 2).

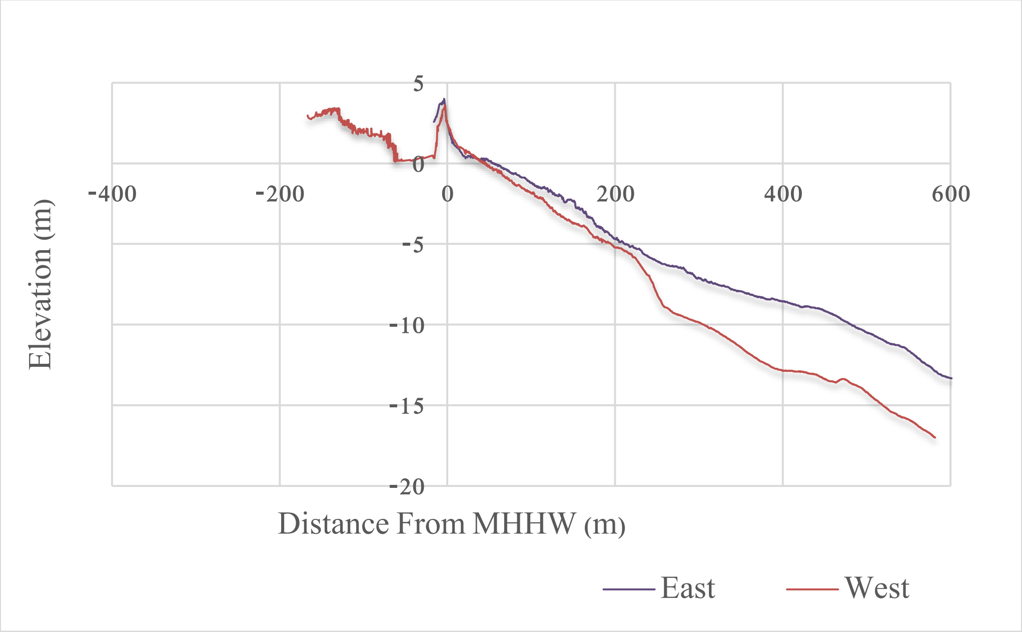

Figure 2: Topography of East and West transects before dam removal in 2011 from data collected by USGS

4.2. East and West Transects After Dam Removal

Each line extends about 500 meters out from the MHHW into the sub tidal zone to a depth of -17 meters (fig 3). The West transect line has about 200 meters of subaerial delta mapped above MHHW while the East transect line has about 350 meters of beach. The West beach consists of two berms and two troughs in the subaerial delta, while the east side has three berms and three troughs and extends farther landward. The berms on the East transect line have slightly lower elevation than the berms on the West transect line. Once the transect lines transition to the subaqueous delta, the two slopes decrease slightly for the first 100 meters of subtidal delta. After 100 meters, the slope increases and then slowly levels out, creating a second terrace (fig 3).

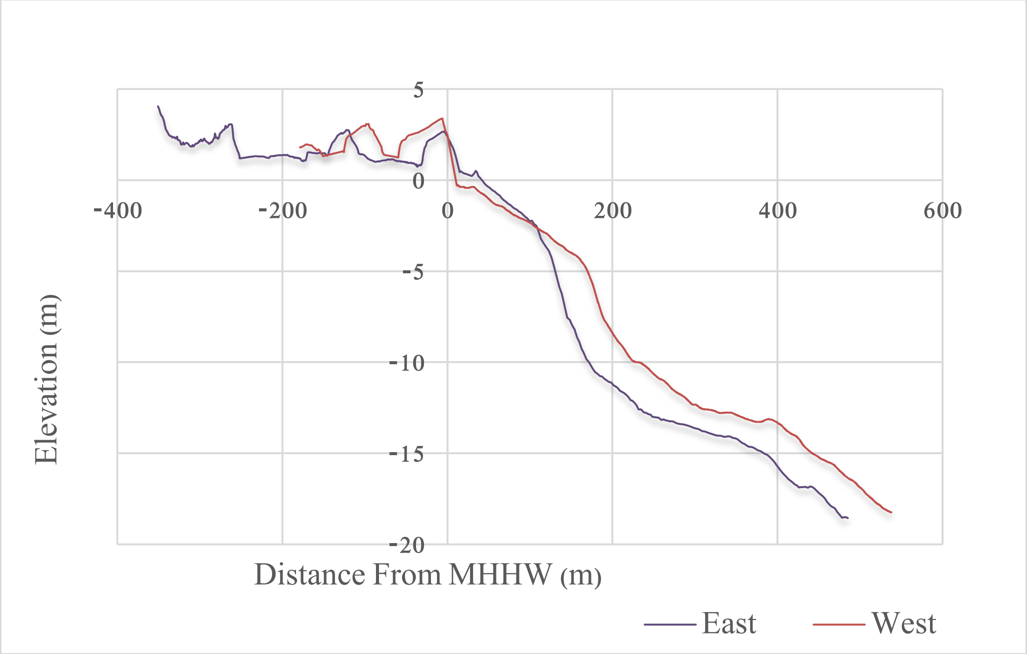

Figure 3: Topography of East and West transects after dam removal

4.3. West Transect Before and After Dam Removal

The profile is mapped for about 800 meters and reaches a maximum depth of -18 meters (fig 4). The line that depicts the topography of the pre-dam contains one trough and one berm while the post-dam profile has two troughs and two berms. The troughs are at a higher elevation than in the profile from 2011 however the berm height is about the same. There is visible accretion between the two transect lines that has a width of about 50 meters. The slopes of both transect lines run parallel to each other for about 150 meters and then return to the same elevation to the pre-dam removal (fig 4).

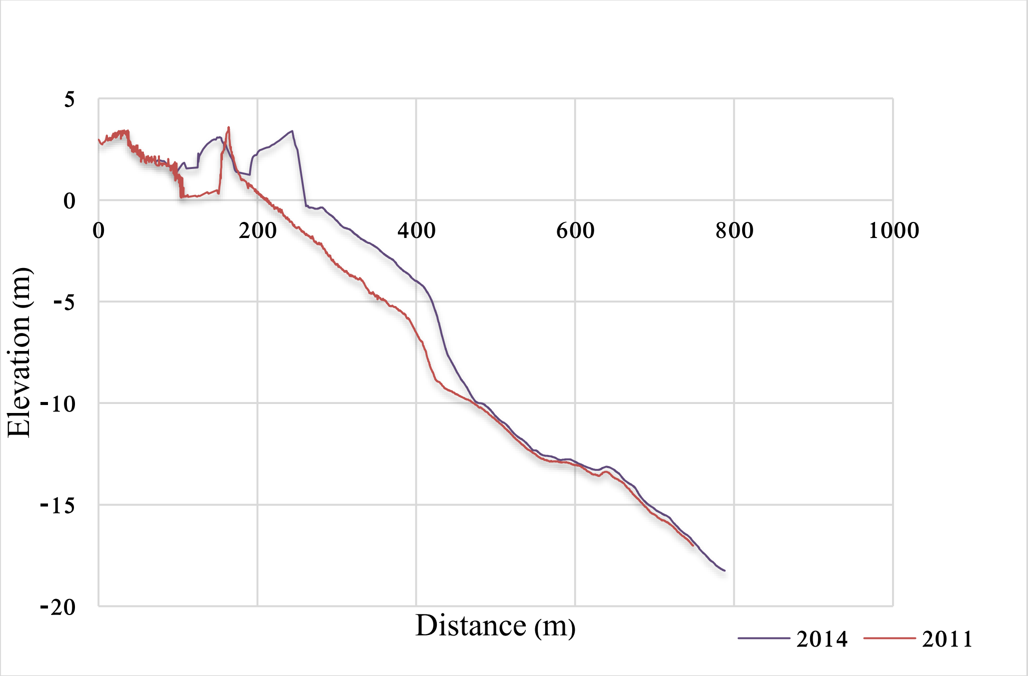

Figure 4: Topography of West transect before and after dam removal in 2011 and 2014

4.4. East Transect Before and After Dam Removal

The graph shows the profiles of the East transect before and after the dam removal process (fig 5). The purple line represent after the dam was removed and the red line is prior to dam removal. Each line is mapped for about 800 meters and has a maximum depth of 17 meters. Prior to dam removal only one berm is visible on the graph whereas after dam removal there are three berms and three troughs. The accretion is about 100 meters wide and extends about 450 meters before it returns to the pre-dam elevations (fig 5).

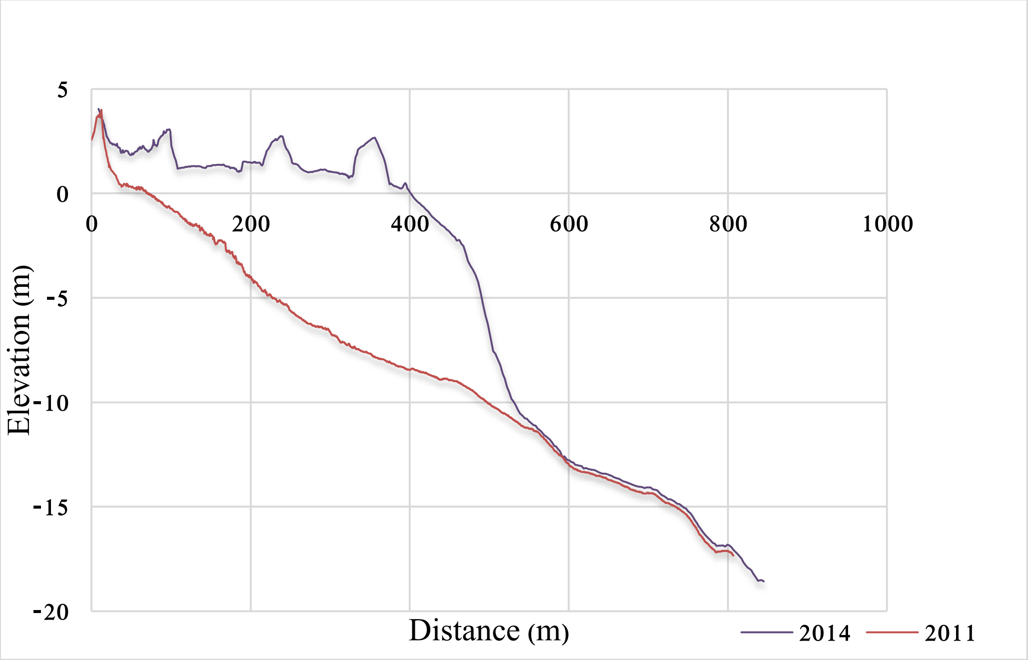

Figure 5: Topography of East transect before and after dam removal in 2011 and 2014

4.5. Grain-size Analysis of West and East Transect

On the West transect the sediment size ranges from 5.6 mm to .25mm on average (fig 6). The East transect line has a high D50 of 3.36 mm and a low D50 of .42mm (fig 7). In the lower elevations or troughs there is a smaller grain size on both graphs whereas on the berms the grain sizes are higher (Fig 6,7).

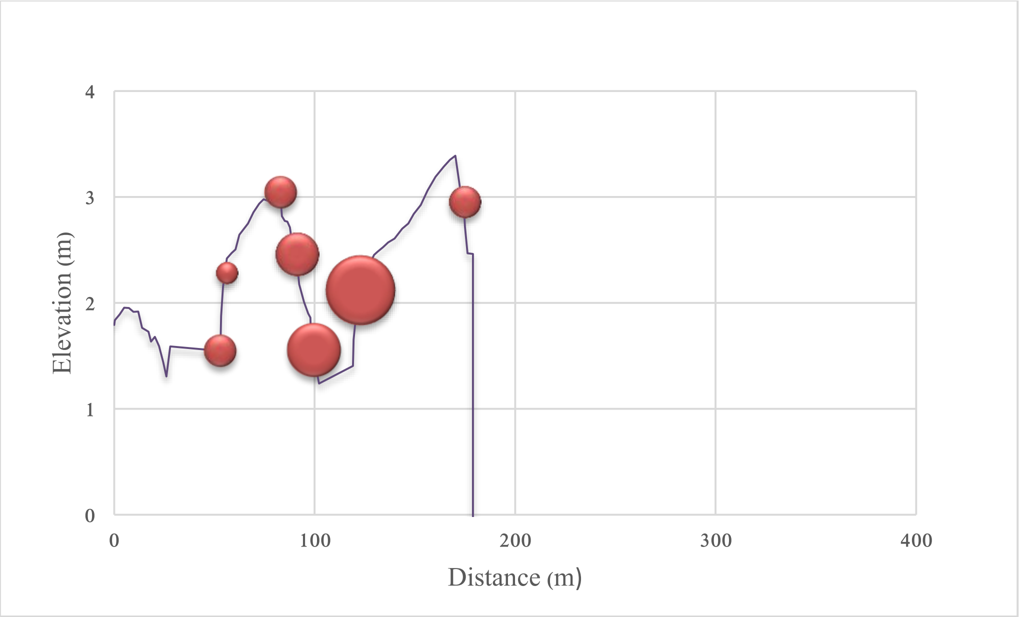

Figure 6: Grain size on West transect in 2014

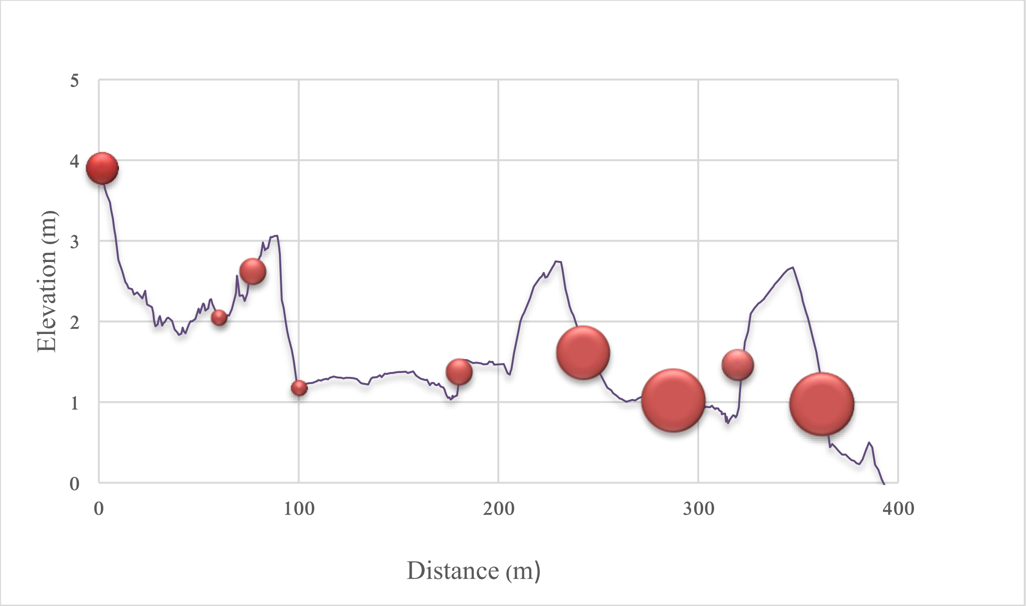

Figure 7: Grain size on East transect in 2014

5. Discussion

5.1. Sediment Accumulation

On the east side of the river there was more sediment deposited than the west, which confirms the hypotheses of Gelfenbaum et al., (2009). Approximately 3,000 m^3/m of sediment was deposited on the East transect line, while only about 800 m^3/m was deposited on the West transect line. This may be due to the oblique angle at which waves hit the shoreline, resulting in a net eastward flow. This supports the findings of Miller et al., (2011) who identified a pattern of eastward sediment transported to the east side of the river mouth, while on the west, sediment moved in both directions. This suggests the potential for sediment on the east to be transported faster than on the west, which results in the observed larger deposit.

5.2. Delta Profiles

Before the dam was removed, the West transect's profile was much steeper than that of the East (fig. 2). This is due to the higher erosion rates on the East transect from the oblique wave angle acting on the delta. There was not a significant source of sediment to replace what had been eroded and so it continued until it reached the boulder lag. We believe that this low flat terrace is a result of a sediment starved system (fig. 3). The West transect does not have this characteristic because it is located closer to the river mouth than the East and likely received more sediment. This combined with the slower erosion rate on the west side allows this transect to maintain a steeper slope.

Comparing these previous slopes to the profiles of the present-day beaches, one can note that the new East transect profile has steepened and has a similar morphology to that of the West transect line in 2011 (fig 3). It is thought that sediment is being added to the East transect at a rate faster than the delta can erode, causing a steeper slope to be formed.

5.3. Grain Size and Morphology

Previous research suggests that there would be a significant difference in the morphology and grain size between the East and the West transect lines. Gelfenbaum et al., (2009) predicted that following dam removal, sand would be deposited east of the river mouth while finer-grained material was predicted to settle to the west. This is due to the weaker currents on the west side that cannot transport the coarser material. Interestingly, we found similar grain-size distributions to the east and west with related to elevation. On both sides of the river, the average grain sizes were coarser on the berms, whereas the finer grain sizes were found at the base of the toughs.

Wave action is likely the process controlling grain size distribution on the delta. When a wave moves over the berm it deposits sediment. It is believed that the water and sediment becomes trapped within the trough allowing the sediment to settle. Different grain sizes have different settling velocities. Coarser grains have a higher settling velocity, while finer grains have a lower settling velocity. Due to this process, the finer materials settle after the coarser sediment has been deposited. When samples were taken on the surface, grain sizes were analyzed and it appeared that the troughs only contained fine grains. On the berms the grain sizes were coarser because the finer sediment did not have enough time to settle. Our findings show both wave action and delta morphology may be the determining factor of grain-size distribution.

6. Conclusion

In this study we created profiles of two transect lines on the east and west side of the river mouth. The study compared the present morphology to the morphology prior to dam removal, in order to determine how the delta has changed. What we found was that the amount of sediment deposited to the east was greater than that to the west due to the oblique wave angle hitting the delta. Furthermore, the slope of the West transect line prior to dam removal indicates that there was minimal long term erosion while the East transect line’s slope indicates that there was an insignificant amount of sediment being added as well as high erosion rates effecting the transect. After dam removal, sediment was being transported faster than it was being eroded, allowing a steeper slope to form. Profiles were also made from typography and bathymetry data collected in 2014 that had average grain sizes plotted in areas where changes in texture or color were noted. It was found that in the troughs, finer sediment sizes were observed, while on the berms the grain size was coarser. This is believed to be due to the lower settling velocity of finer grain sizes since they settle last. The findings of these studies suggest that dam removal results in sediment accretion to the shore as well as changes in grain sizes and the morphology of the delta.

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References

Buchanan, J. B. 1984. Sediment analysis. In ‘Methods for the Study of Marine Benthos’. Eds Holme, N. A. and A. D. McIntyre, editors. pp.41–65.Blackwell Scientific Publications. Boston, MA

Buscombe, D., Masselink, G., 2006. Concepts in gravel beach dynamics. Earth Science Reviews 79, 33–52.

Childers, D., D. L. Kresh, S. A. Gustafson, T. J. Randle, J. T. Melena, and B. Cluer. 2000. Hydrologic data collected during the 1994 Lake Mills drawdown experiment, Elwha River, Washington. U.S. Geological Survey Water-Resources Investigation Report 99-4215, Tacoma, WA.

Curran, C.A., Magirl, C.S., and Duda, J.J., 2014, Suspended-sediment concentrations during dam decommissioning in the Elwha River, Washington: U.S. Geological Data Set,http://wa.water.usgs.gov/pubs/misc/elwha/ssc/, doi:10.5066/F7M043DB.

Dethier, D. P., F. Pessel, R. F. Keuler, M. A. Balzarini, and D. R. Pevear. 1995. Late Wisconsinan glaciomarine deposition and isostatic rebound, northern Puget Lowland, Washington. Geological Society of America Bulletin 107:1288–1303.

Duda, J.J., Freilich, J.E., Schreiner, E.G., 2008. Baseline studies in the Elwha River ecosystem prior to dam removal: introduction to the special issue. Northwest

Science 82:1–12.

Duda, J.J., Warrick, J.A., Magirl, C.S., (Eds.), 2011. Coastal habitats of the Elwha River, Washington-biological and physical patterns and processes prior to dam removal, USGS Scientific Investigation Report, 5120:1-9.

Galster, R. W. and M. L. Schwartz. 1990. Ediz Hook—A case history of coastal erosion and rehabilitation. Journal of Coastal Research 6:103–113.

Gelfenbaum, G., Stevens, A., Elias, E., Warrick, J., 2009. Modeling sediment transport and delta morphology on the dammed Elwha River, Washington state USA. Coastal Dynamics, 109:1-15.

Kloehn, K.K., Beechie, T.J., Morley, S.A., Coe, H.J., Duda, J.J., 2008. Influence of dams on river-floodplain dynamics in the Elwha River, Washington. Northwest Science (Special Issue) 82, 224–235.

Mosher, D. C. and A. T. Hewitt. 2004. Late Quaternary deglaciation and sea-level history of eastern Juan de Fuca Strait, Cascadia. Quaternary International 121:23–39.

Warrick, J.A., George, D. A., Gelfenbaum, G., Ruggiero, P. 2009, Beach morphology and change along the mixed grain-size delta of the dammed Elwha River, Washington. Geomorphology 111: 136-148.

Vörösmarty, C.J. Meybeck, M. Fekete, B. Sharma, K Green, P. Syvitski J.P.M.

Anthropogenic sediment retention: major global impact from registered river impoundments Global and Planetary Change, 39 (1–2) (2003), pp. 169–190