

Effects Of Dam Removal On Macrobenthos In The Elwha Nearshore

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Abstract

The Elwha River dam removal project is expected to deliver fine grained sediment to the Elwha nearshore environment, thus potentially changing the substrate and affecting the macrobenthic invertebrate that inhabit it. This study looks at the relationship between grain size and macrobenthos. Grab samples were taken in April 2013 to evaluate for grain size and identify any invertebrates that were also picked up in the grab. The results were compared to those found prior to dam removal (2008) and that found in a similar study done spring 2012. Just outside of the river mouth, there were no benthos found and moving seaward numbers increased. Mud was found just outside the river mouth and to the west, and more sand was found in Freshwater Bay than had been prior to dam removal. Farther from the river mouth and to the east, there was mostly gravel and some sand, but little to no mud. It appears that in areas of higher gravel and sand fractions, there were more species found, as well as more total counts of benthos. In muddy areas there were little to no benthos found, which implies that the benthos are being smothered or migrating away from the areas with the most mud accumulation. This is an ongoing study and permanent effects on the benthic community are still unknown. However, this study concludes that during dam removal, the release of fine sediments will initially lower the presence of benthos near the river mouth.

1. Introduction

The Elwha River dam removal project is the largest dam removal projects that the United States has seen to date. With the removal, approximately one third of the total trapped sediment, mostly fine sand and mud, will be released into the nearshore area just outside of

the river mouth (Duda et al., 2011). This new sediment poses a problem for the macrobenthic invertebrate community because the substrate, and thus habitat, is starting to change.

Past studies have shown that disturbances to the habitat of the benthic community can have temporary effects on the invertebrates. However, in most studies, it has been found that the benthic community tends to recover (Shaffner, 2010). Based on past research, it can be assumed that with the initial input of new fine sediment, the benthic community near the mouth of the river will be decreased due to smothering (Shaffner, 2010; Airoidi and Hawkins, 2007; Morey et al., 2008). It is important to understand the changes happening during dam removal so that in the future there is data for comparison.

The goal of this study is to observe how the release of the sediment since the removal of the Elwha Dam and partial removal of the Glines Canyon Dam has changed the substrate and affected the benthic community. It is hypothesized that these findings will show an initial decrease in benthos found in muddy areas.

2. Background

2.1 Study Area

The Elwha River, Washington, U.S.A. flows from the Olympic Mountains to the Strait of Juan de Fuca (Fig. 1). In the early 1900s, the Elwha and Glines Canyon dams were built along the river creating two reservoirs, Lake Aldwell behind the Elwha Dam and Lake Mills further upstream behind the Glines Canyon Dam. Combined, the two reservoirs held approximately $26 \times 10^6 \text{ m}^3$ of sediment (NPS www.nps.gov/olymp). In 1992, the Elwha River Ecosystem and Fisheries Restoration Act was passed and led to plans for the two dams to be removed. It was projected that with the removals, approximately one third of the sediment

Sample Stations

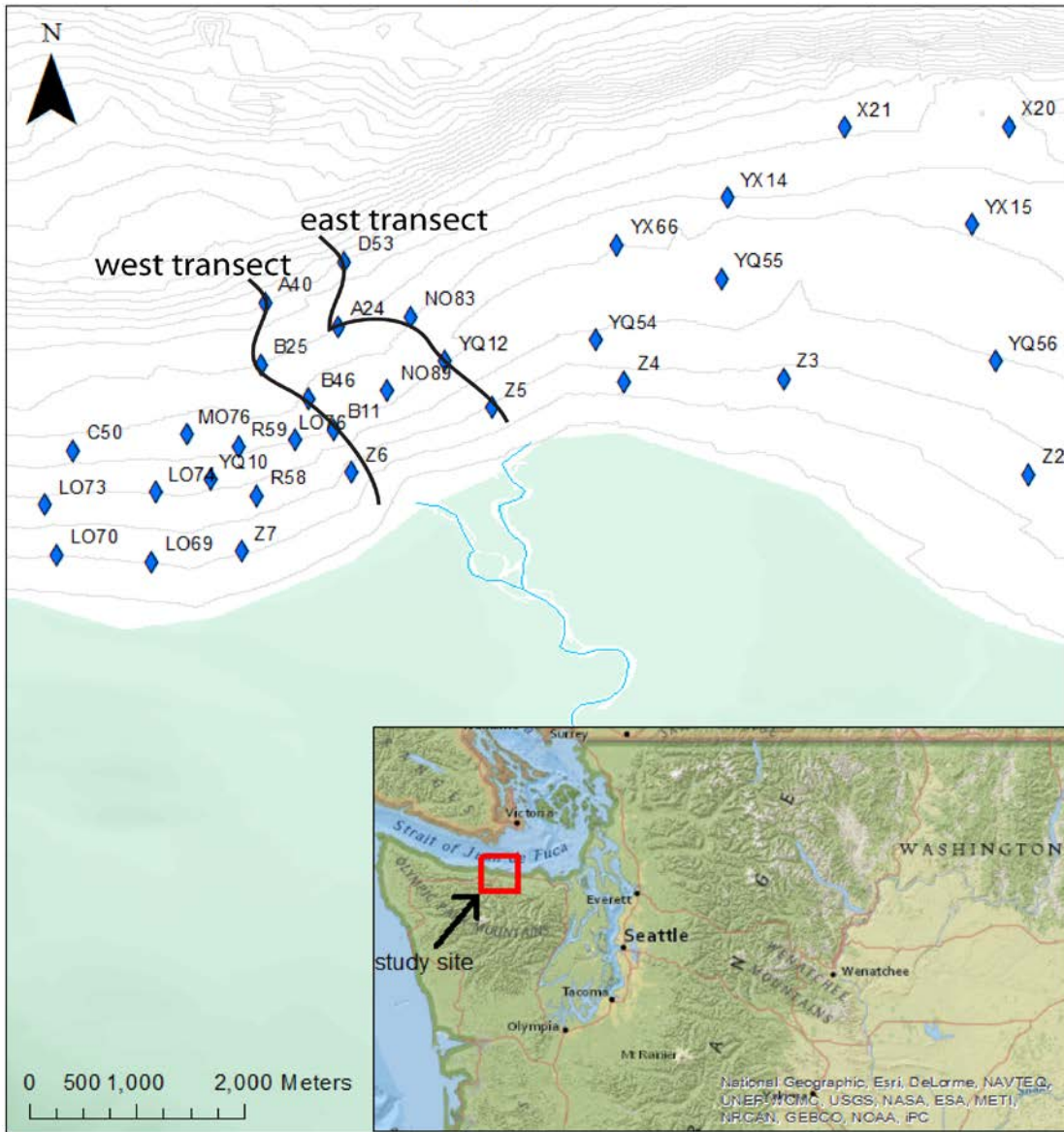


Figure 1. Station map where all of the grab samples were taken over the course of the two cruises. Each diamond represents a station, with its given station name to the upper right. Inset map is of Washington, U.S.A. with the arrow pointing to the study site. The east and west transects are along the two lines. Bathymetry lines from <http://www.ocean.washington.edu/data/pugetsound/> and Olympic Peninsula DEM from <http://deptweb.wvu.edu/huxley/huxweb/elwha/ElwhaWeb/>.

trapped behind the reservoirs would be released into the Strait of Juan de Fuca. The Elwha Dam was completely removed by spring 2012 and the Glines Canyon Dam is projected to be fully removed by summer 2013.

The physical processes that affect the Elwha Delta are responsible for the characteristics of the submarine substrate. The delta is affected by tidal currents (semidiurnal mixed tides) and wind generated waves (Shaffer et al., 2008). However, tides tend to be the dominant factor controlling the submarine substrate. In the Elwha nearshore prior to dam removal, there were coarse grains and high boulder abundance close to the mouth, and lower boulder abundance moving seaward (Warrick et al., 2008). There were sand bars found in Freshwater Bay (Warrick et al., 2008). Because of the dams, little to no fine sediment made it to the delta in the past 100 years (since the dams were built) and the strong tides helped maintain this coarse substrate.

2.2 Topical Background

To date, the coarse substrate has provided habitat to a large diversity of different benthic macrofauna. Some of the macrobenthos that were found in the Elwha nearshore were sea stars, sea cucumbers, sea urchins, crabs, clams, scallops, different species of worms, and more (Rubin et al., 2011). Other studies have also found that in coarser substrates, there are higher abundances and species diversity in the benthic community (Airoid, 2003; Morey et al., 2008). With dam removal, it is expected that more fine sediment will reach the Elwha nearshore, thus potentially creating a new benthic community that prefers finer grains.

Past studies have shown relationships between changes in substrate and its effects on the benthic community. The past studies examined here were based off anthropogenic changes to the community due to dredging (Shaffner, 2010) and hydrocarbon drilling (Gates

and Jones, 2012). Both these studies found that the initial deposit of fine sediments onto the seabed lowered the biomasses and species diversity of the benthic community (Gates and Jones, 2012; Shaffner, 2010). Both these studies also measured how long it took for the benthic community to recover after the disturbance was over and the substrate stabilized, and both concluded that the benthic community can recovery to almost original biomasses and species diversity in less than three years (Gates and Jones, 2012; Shaffner, 2010). Another study simulated rapid mud deposition onto benthos and concluded similar results as the above two studies, though recovery rates were not observed (Airoldi and Hawkins, 2007). Based on previous research, we hypothesize that there will be an initial decrease in the total amount of benthos and species found in areas of muddy substrates.

3. Methods

3.1 Data Collection

Data were collected on the *R/V Clifford A. Barnes* from 13-15 April 2013 and the *R/V Centennial* on 28 April 2013. A shipek grab sampler was used to take 31 grab samples (Fig. 1) from the *R/V Barnes*, and three more grab samples with a Van Veen at stations A24, B25 and YX13 from the *R/V Centennial*. The macrobenthos in each grab sample were removed and stored in 95% ethanol mixed with tap water prior to sediment collection. Sediment was then collected from the grab samples and stored in a refrigerator. If the first try for a grab was scant (smaller than 50g), a second grab was taken. Not all grab samples taken during this cruise were sampled for this project. Stations along the west and east transects (Fig. 1) were taken to do analysis moving seaward from both the east and west sides of the river mouth. Other stations were chosen based on whether or not benthos were present in the sample.

Some stations farther into the strait and to the east of the river were in waters that were too choppy for sampling to be possible.

3.2 Benthos Identification

The macrobenthos were identified with the help of Megan Dethier and the book *Whelks to Whales* (Harbo, 2011). They were identified by common name and the class in which they belong to (Table 1). For analysis purposes, they were then grouped based on which substrate they preferred for habitat (mud and fine sand, mixed: sand and some cobbles, or coarse: cobble with some boulders). The data from this study were compared with that found in 2008 (prior to dam removal) and 2012 (after the first dam was completely removed; Dunnell, 2012).

3.3 Grain Size Analysis

Sediment samples were first categorized into one of four groups: scant, heterogeneous, homogenous, and homogenous with few pebbles. Scant samples were weighed, dried, and weighed again with a detailed description of what the sample looked like. The heterogeneous samples were fully processed, first by wet sieving using a 4Φ sieve to separate the mud from the sand (based on phi sizes according to the Wentworth scale). Pipette analysis was used to find the mud fraction. The remainder sand and gravel was dried and sizes -4 to 4Φ were dry sieved in 1Φ increments (anything large than -4Φ was measured along its b-axis and then categorized by phi size and weighed). Approximately 30 g subsamples of homogenous samples were taken and then sieved using the technique described above. Homogenous samples with pebbles were analyzed similar to the homogenous ones, except prior to subsampling the rocks were taken out of the sample and dried along with the remaining sand portion and mud that was not subsampled.

Table 1. Classification of the different benthos found. Divided into substrates based on grain size data. Station names placed into category of substrate they fit into, and then under the organism if it was found there.

Class → Actual Substrate ↓	<i>Malacostraca</i>		<i>Polyplacophora</i>		<i>Gastropoda</i>		<i>Echinodermata</i>		<i>Maxillopoda</i>		<i>Polychaeta</i>		<i>Bivalvia</i>	
	shrimp	crab	chiton	limpet	snail	urchin	brittlestar	barnacle	Sea cucumber	Sabellariid-case	spiochaetop-ferous	scallop	clam	none
Fine	B11	YQ10		B11					B11	B11	B11			Z6
Medium	C50	B25	B25	B25	B46	B25			B25	LO69	LO69	B46	LO69	Z3
		B46	B46	B46	R58				LO69	R58	R58		R59	
		R59		LO69					R58	R59	R59			
				R58					R59					
Coarse	LO74	A24	A24	A24	A24	A40	A24	A24	YQ12	A24	LO73	A24	LO73	Z5
	X21	LO73	LO74	YQ55	A40	X20	X20		YQ15	LO73	A40	A40	X21	
	YQ55	X20	X20		X21	X21				X20			YQ15	
		YQ55	X21	YQ55		YQ12				X21			A40	
		YQ15	YQ12						A24					
			YQ55											

The grain size distribution was analyzed using the Folk and Ward method (1957) after running the results through GRADISTAT (Blott and Pye, 2001).

4. Results

4.1 Grain Size Distribution

Grain size distributions on the Elwha delta varied moving away from the river mouth. Moving seaward perpendicular to the mouth, the gravel percent increased (Fig. 2). However, when moving to the west of the river mouth into Freshwater Bay, the percent of gravel remained less than 50% (with the exceptions of stations LO73 and LO74) and some places were mostly sand (Fig. 2). The muddiest station was located in shallow water directly off the river mouth (Z6) and had 74.6% mud. Stations that did not have gradistat run on them were: D53, LO70, NO83, YQ54, YX13, YX14, YX66, and Z4 because they were all too scant (Fig. 2).

Some of the stations were bimodal, and thus had a mixed substrate of gravel, sand, and mud. Stations that had a gravel mode and a sand mode were LO73, YQ12, YX15, and Z3. Other bimodal stations had two modes that were both sand or silt. The gravel, sand, and mud fractions are representative of the substrate, and those where the fractions were similar for two different sediment sizes were also bimodal.

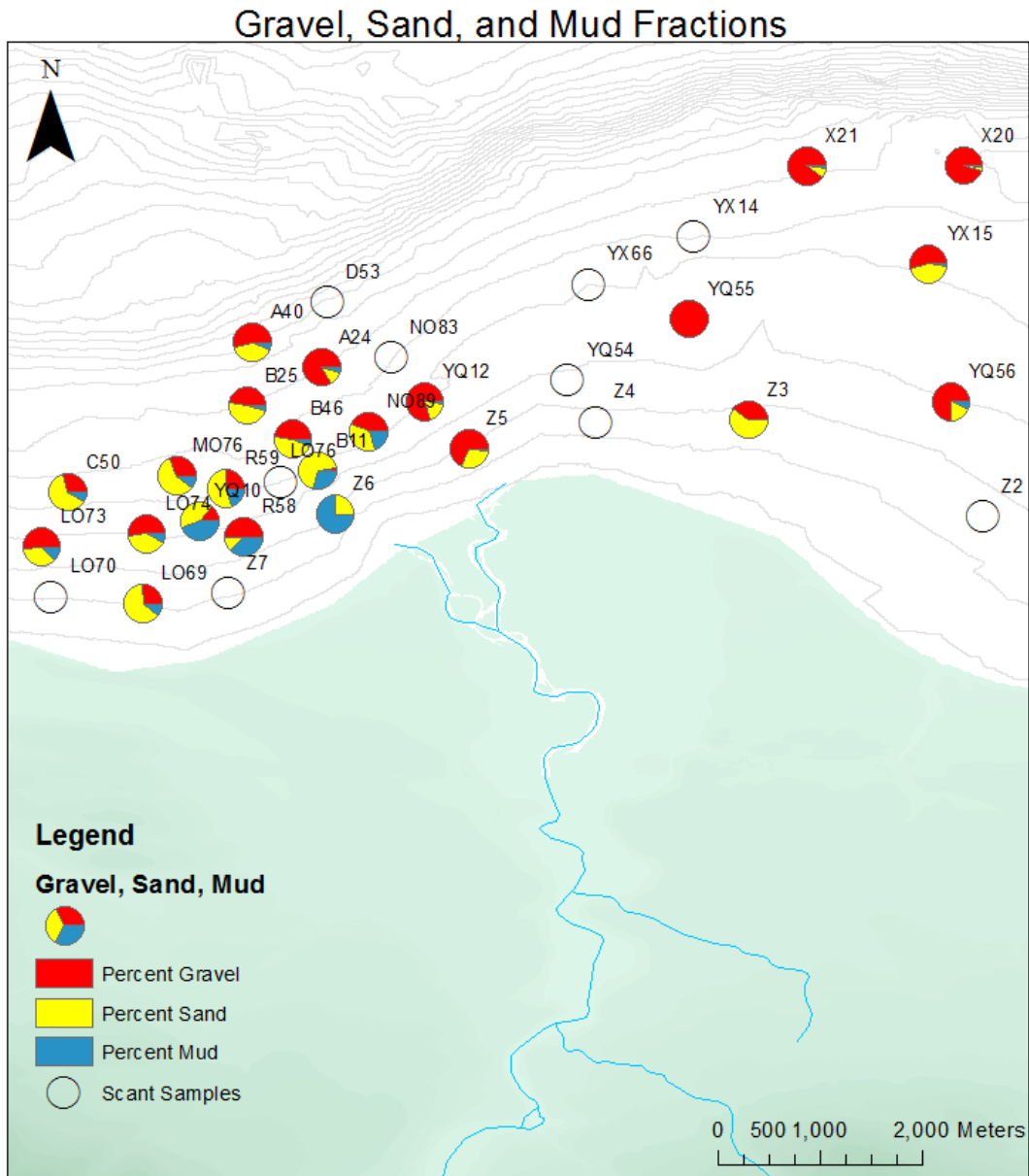


Figure 2. Grain-size distribution along the Elwha nearshore. Pie charts are divided into gravel, sand and mud fractions. Empty circles represent scant samples. Bathymetry lines from <http://www.ocean.washington.edu/data/pugetsound/> and Olympic Peninsula DEM from <http://deptweb.wvu.edu/huxley/huxweb/elwha/ElwhaWeb/>.

4.2 Benthos Analysis

Total counts of benthos varied throughout the Elwha nearshore. Within the sediment grab samples, there were a total of eleven different types of macrobenthos (identified using common name) found and two categories of worm casings that were also counted (Table 1). Of these eleven types of macrobenthos, there were seven different classifications of benthos found (Table 1). The station with the highest number of total macrobenthos was A24, which was perpendicular of the river mouth (Fig. 3). Stations that were closer to the river mouth had lower numbers of macrobenthos and farther from the mouth, more organisms were found (with the exceptions of C50, D53, YX15, YQ56; Fig. 3).

Up to six different types of macrobenthos were found at each site. Stations closest to the river mouth (Z6 and Z5) had zero organisms present (Fig. 4). The stations that had the most species were A24 and X21 (far out and east of the river mouth). From the river mouth seaward, amount of different species present increases (Fig. 4).

4.3 Transects

Two transects of benthos and grab samples were analyzed starting near the river mouth and extending seaward (Fig. 1). The point closest to the river mouth in the west transect (Z6) was 74.6% mud and the mud fraction decreased seaward (Fig. 5A). There were no organisms found at Z6. Station B11 had a substrate with 30% mud and had more benthos that preferred finer grain substrates whereas B25 had a substrate that was 5% mud and had more organisms that preferred cobble substrates (Fig. 5A). The total number of benthos found at a station generally increased seaward (Fig. 5A). Station A40 only had two benthos found, but both preferred cobble. Overall on the west transect, the gravel percentage increased and the amount of benthos that preferred mud and sand decreased

Total Counts of Macrobenthos

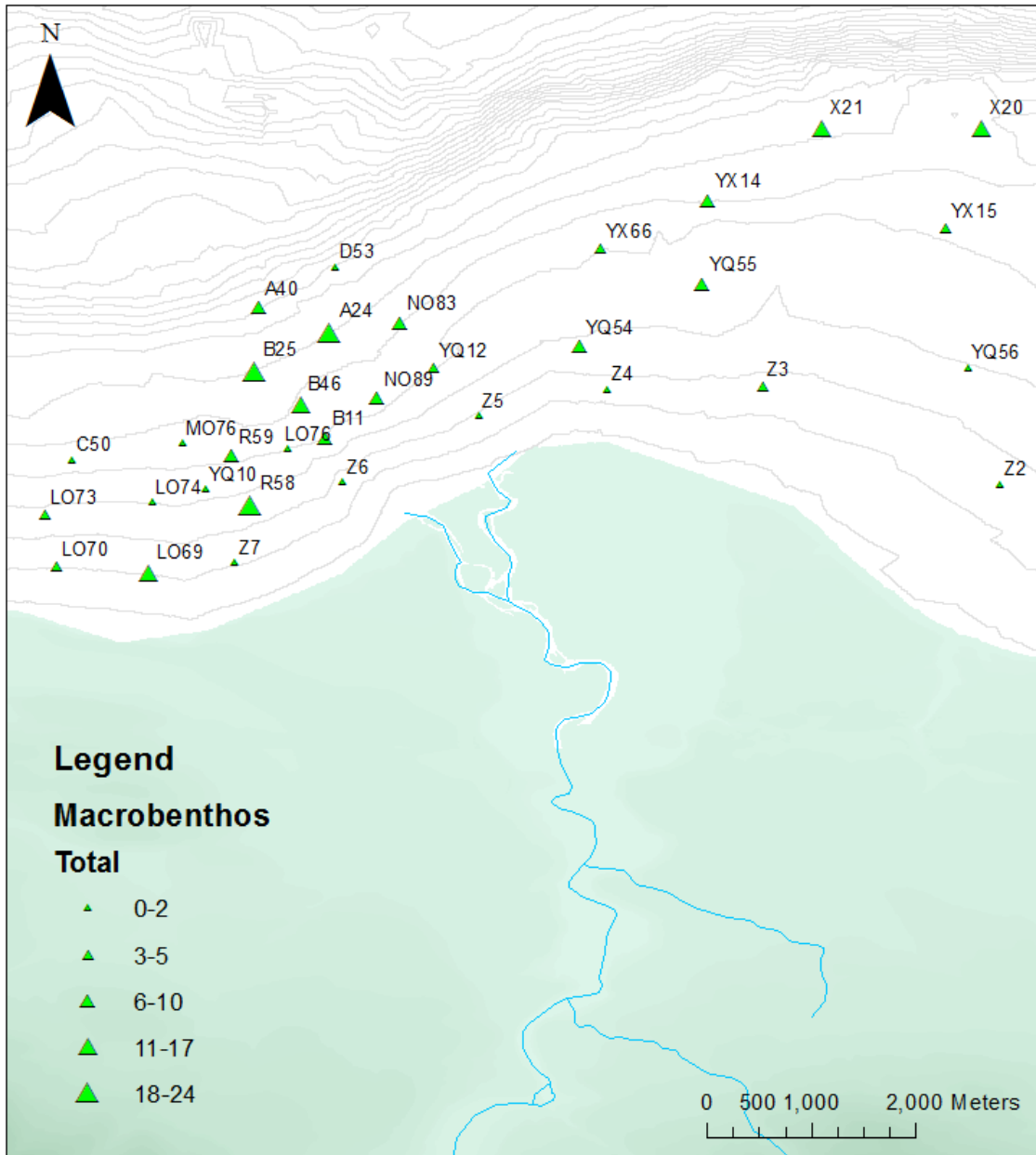


Figure 3. Total counts of macrobenthos found in the Elwha nearshore. Increasing size is equivalent to increasing total. Bathymetry lines from <http://www.ocean.washington.edu/data/pugetsound/> and Olympic Peninsula DEM from <http://deptweb.wvu.edu/huxley/huxweb/elwha/ElwhaWeb/>.

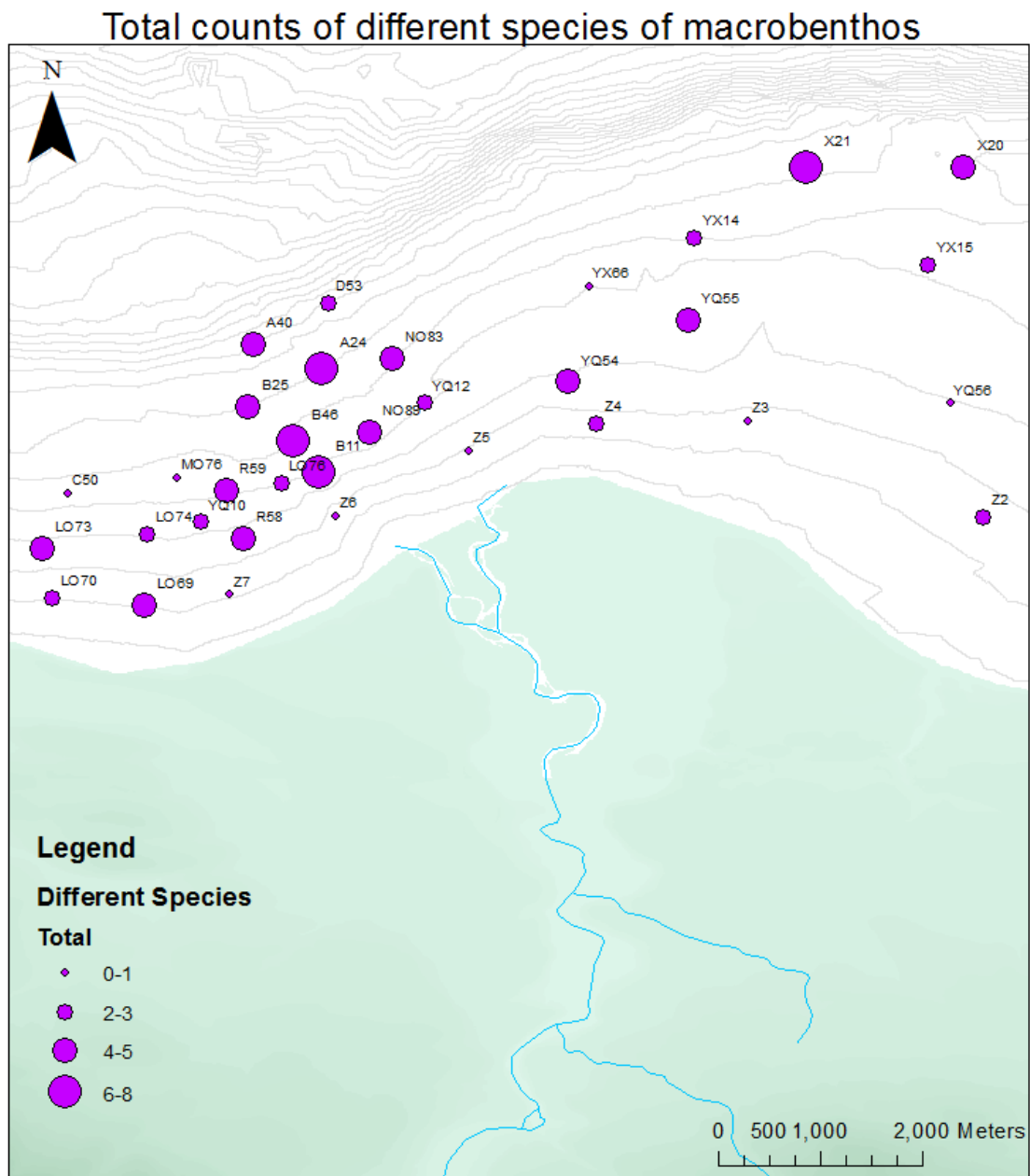
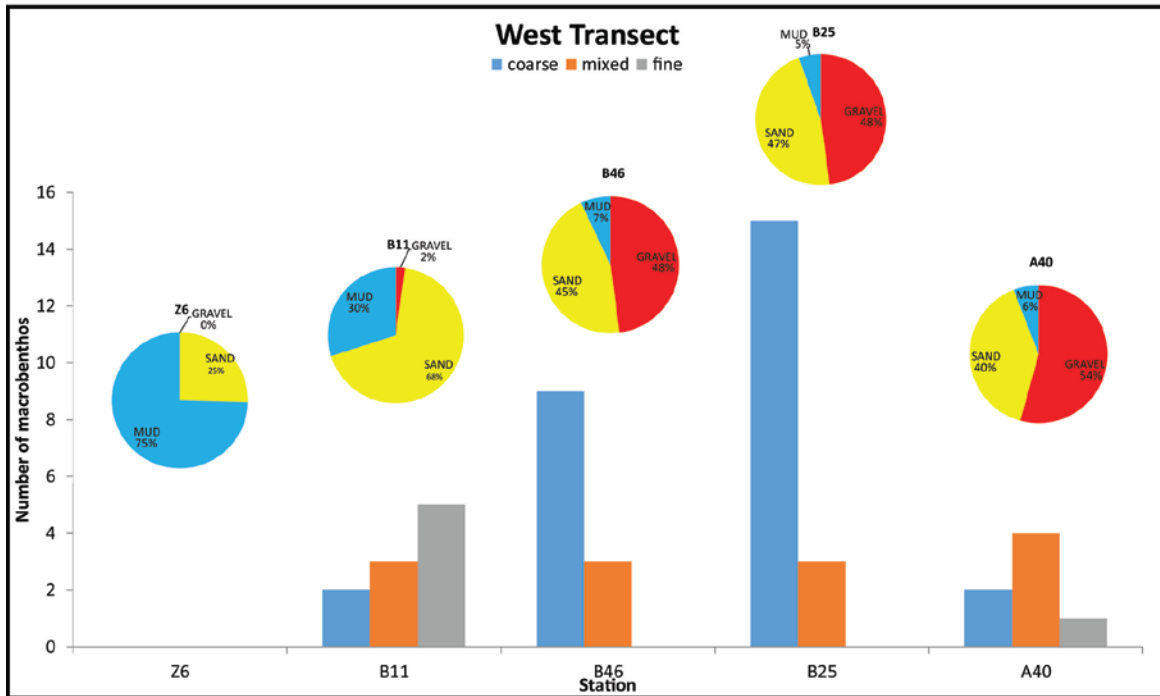


Figure 4. Total counts of different species found at each sample station in the Elwha nearshore. Increasing circle size is equivalent to increasing species count. Bathymetry lines from <http://www.ocean.washington.edu/data/pugetsound/> and Olympic Peninsula DEM from <http://deptweb.wvu.edu/huxley/huxweb/elwha/ElwhaWeb/>.

A



B

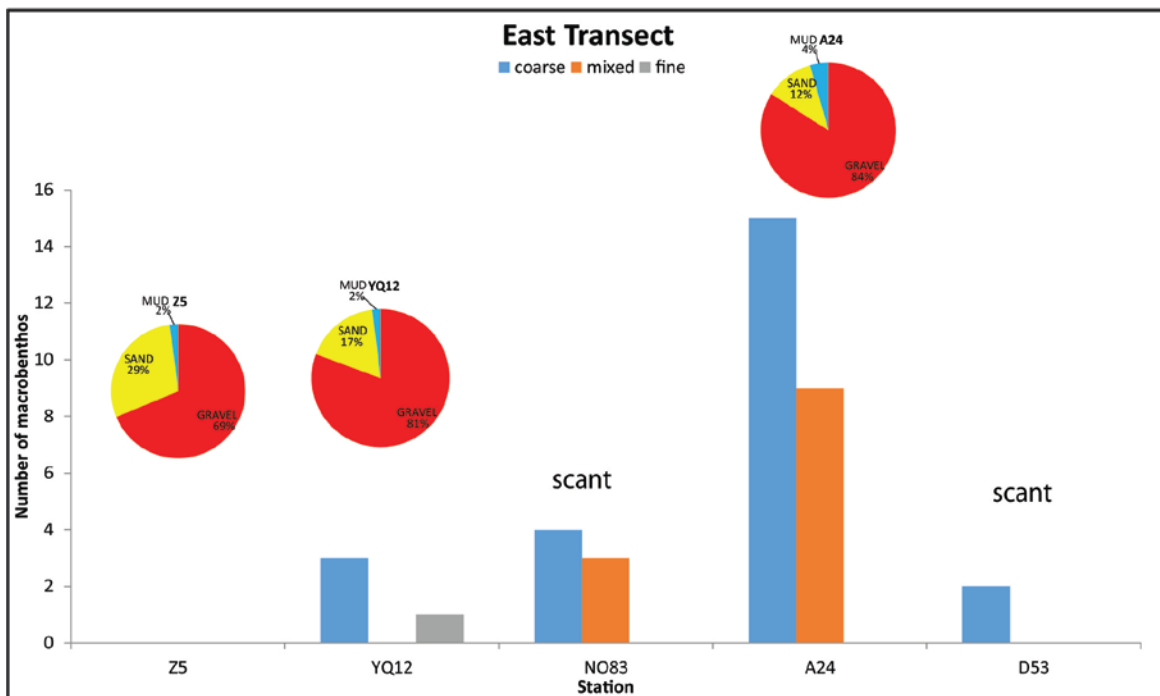


Figure 5. Transects of both the benthos counts and the substrate at five stations (along each transect) from the river mouth seaward. The pie charts are the gravel, sand, mud fractions at a particular station. The histogram is of total counts of macrobenthos found at a given site, separated into what substrate the benthos would prefer to inhabit (coarse, mixed or fine substrates). 5A is the west transect and 5B is the east transect.

while benthos that preferred cobble increased. On the east transect, zero organisms were found at the station closest to the river mouth (Z5, 31% mud) and 24 (15 that preferred cobble and 9 that preferred mixed) were found at station A24 (16% mud; Fig. 5B). Station D53, farthest from mouth, had two benthos (that preferred cobble) present and did not have grain size data because it was a scant sample. Station NO83 was also a scant sample, and thus did not have gradistat run on it. The mud percentage decreased moving seaward (Fig. 5B). The east transect had more gravel percent at all five stations than west transect.

5. Discussion

5.1 Grain-size distribution in Elwha nearshore

Changes to the grain-size distributions in the Elwha nearshore were present in this study. In general, to the west of the river mouth in Freshwater Bay, there was more mud and sand found than was in 2008 (Fig. 2; Warrick et al., 2008). It was expected that there would be more mud and sand in the nearshore area in 2013 because in 2008 both dams were still present. When comparing grain-size data from 2012 to that found in this study, there were not many significant differences. There were some minor differences, such as some stations nearest to the river mouth had higher mud fractions than in 2012, but it may not have been significant enough to rule out small-scale variability. Not all of the sediment being released from the river is settling just outside of the mouth, and it is still unclear as to where the rest of the fine sediments are moving. It is also unclear whether or not the fine sediment that has settled near the river mouth is permanent. However, as of this study, the overall trend is that

Freshwater Bay is getting sandier and just outside of the river mouth is getting muddier, which was different than what was seen in those areas prior to dam removal.

Stations that were scant were still important to note because they said something about the substrate. If the sample was scant, it was likely because the substrate was too coarse and had large cobbles that it made it difficult for the grab sampler to successfully grab enough sediment to analyze.

5.2 Macrobenthos distribution

Close to the river mouth there were lower counts of total macrobenthos present as well as lower counts of species found. In studies of the benthic community in 2008, there was a high diversity of macrobenthos found (Duda et al., 2011), whereas in this study, there were lower counts of different species, mainly near the river mouth (Fig. 4). In a study done in 2012 (Dunnell, 2012), the diversity of benthos was similar to that found in this study. One hypothesis is that the benthos were being smothered by the sediment coming from the river, as had been seen in past studies at other sites (Shaffner, 2010; Airolidi and Hawkins, 2007). Another hypothesis is that the benthos were migrating away from areas being covered by newly deposited sediments. It could be a combination of both, but at this time more data is needed to verify this. It is clear that fewer macrobenthos were found near the river mouth in this study than were found in 2008 (Fig. 3). It was expected that more benthic invertebrate would be found in areas of coarser substrates (Morey et al., 2008; Airolidi, 2003), which was the case in this study for most stations. Also, the data in this study support the hypothesis that in areas of higher gravel fractions and heterogeneity, there were higher species counts (Fig. 3; Airolidi, 2003).

In this initial phase of dam removal this study shows the benthic community diminishing near the river mouth, but this macrobenthic community has been recognized as resilient (Shaffner, 2010) and thus these present changes may not be permanent. Though the benthos were initially not thriving near the river mouth, it is likely that the benthos will either return, or new benthos will begin to thrive and there will be more clams and worms and other benthos that prefer muddy substrates (Shaffner 2010; Gates and Jones 2012). In past studies of macrobenthos, recovery rates for areas that were disturbed by major deposition of finer sediment recovered within 2 years after the disturbance was over (Shaffner 2010). Once the substrate of the Elwha nearshore stabilizes, it is possible that it will only take a few years for the benthic community to build up again. If different benthos than prior to dam removal begin to thrive in this area, then there could be a bottom up effect, changing the different types of predators that come to area. Further research could be done to better understand what would happen if the types of macrobenthos were to permanently change in the near river mouth area.

The results in this study were limited by the sampling techniques used. There were sometimes low counts of macrobenthos at places farther from river mouth where it was expected to see higher counts (Fig. 3). This was likely due to scant samples being collected with the grab sampler. On the contrary, some of the stations that had a lot of macrobenthos (e.g. B25) were grabbed with a van veen sampler, which was bigger than the shipek used on the first cruise.

5.3 Relating macrobenthos and grain-size distribution

The west transect had patterns between grain size and macrobenthos moving seaward. The station closest to the river mouth was 100% sand and mud; moving seaward, the mud

fraction decreased (Fig. 5A). Benthos that preferred cobble and mixed substrates increased seaward, as well as total benthos increased. This data was supportive of previous observations that more benthos will be found in coarse substrates than in finer substrates (Airoldi, 2003). In places where there was the most fine sediment, there were lower benthos counts. This conclusion is supported by past studies in which it was found that fewer benthic invertebrates were found in the areas most disturbed (Airoldi and Hawkins, 2007; Shaffner, 2010). The transect data here also support the previously stated conclusion that there was less mud found farther from the river mouth. Also, the data support the idea that more organisms are found farther from the river mouth where there was more cobble and gravel present. Overall, the patterns along this transect are supportive of past theories in relation to gravel sizes and total benthos present.

Similar patterns were found in the east transect as in the west (Fig. 5B). Gravel fraction and total benthos increased seaward. Also, benthos that preferred mud decreased seaward, while benthos that preferred cobble increased. At stations D53 and NO83, there was no grain-size data because both were scant samples (and thus probably coarse substrates; Fig, 5B). The east transect also supported that more benthos would be found in gravel substrates than in mud (Airoldi, 2003), however the east transect had greater gravel fractions overall.

Though both transects had similar patterns of benthic life and trends in grain size, the gravel fraction differed. The east transect had more gravel overall than the west (Fig. 5). This data supports the earlier stated hypothesis that more mud and sand is moving towards the west of the river mouth than to the east. Both had a general trend of increasing total benthos seaward (Fig. 5). Based on the gravel fractions only, it would have been expected that the benthos found at the east transect would have been significantly more than the west transect

(because more mud was found at the west than east transect). It is unclear why there were similar counts of benthos at both transects. To conclude, both transects supported earlier statements that more benthos are farther from river mouth and prefer gravel, also that more fine grains were deposited to the west rather than east.

6. Conclusion

This project helped to add data to the ongoing Elwha project, but also had some major conclusions of what has changed in the nearshore environment thus far. There were less macrobenthos found near the mouth of the river than at sites away from the river mouth. Similar patterns were observed in the species counts as well. Prior to dam removal there was no mud in the Elwha delta, however mud was found just outside of the river mouth in this study. The majority of the new sand and mud present was found to the west of the river mouth in Freshwater Bay. To the east of the river mouth it remained mostly gravel and some places had sand. In areas that were mostly gravel, there were more benthos than in areas that were mostly mud. This is an ongoing study, and the long-term effects of the new mud deposits are still unknown.

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