

Impacts of Dam Removal on the Macrobenthos of the Elwha River Delta

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Abstract

For almost a century, the Elwha River has been constrained by the Elwha and Glines Canyon dams, which have severely restricted the transport of fine sediment downriver. The dams are currently undergoing removal; it is the largest such project ever attempted in the United States. The purposes of this experiment were to identify the macrobenthos currently living on the subaqueous delta and determine the potential impacts of dam removal, and the ensuing sediment influx, on macrobenthic diversity. Samples of benthic organisms and sediment were collected from the delta floor, inventoried and analyzed, and the results mapped to find correlations between the two. The results showed patterns suggesting a correlation between grain size and diversity, with the greatest diversity at sites with high percentages of gravel, and the lowest diversity at sites with high percentages of mud. These findings demonstrate the importance of sediment size and sorting on the diversity of the Elwha delta. Given that the sediment in Lake Aldwell and Lake Mills is expected to continue traveling downstream, this information can be used to predict how the dam removal will impact macrobenthic communities on the delta, including economically important species such as clams, geoducks and crabs.

1. Introduction

The Elwha River, which originates in the Olympic Mountains of Washington and flows north to the Strait of Juan de Fuca, is currently undergoing the removal of two dams that have been in place for almost a century. Aside from the intended consequence of making the river accessible to spawning salmon for the first time since dam construction, the removal of the dams will release millions of cubic meters of sediment

downriver and into the ocean. Scientists can only guess the impacts that this sediment will have on the subaqueous Elwha delta and nearby shorelines, though many hope it will slow coastal erosion (Duda et al., 2011b). However, the potential deposition of vast amounts of sediment on the delta itself could alter the benthic habitats and thus the types of organisms that live there (Rubin et al., 2011; Airoidi, 2003). The type and diversity of organisms that inhabit the Elwha delta floor are important for many reasons. The delta and Elwha River estuary, as areas where fresh and saltwater mix, are critical to the lifecycle of migrating salmon; therefore their productivity and health may be significant to the recovery and vitality of the Elwha salmon runs (Duda et al., 2011a). Additionally, shellfish and other organisms are harvested from the southern coast of the strait, and sedimentation to the delta may alter the species composition of the benthos, with economic repercussions (Nyblade, 1979).

In this study, we will be looking at benthic communities rather than individual species, and attempting to gauge the effects of dam removal on the assemblages as a whole. The dam removal represents a possible disturbance of the delta habitat which is different, and probably much more intense, than those to which the organisms on the delta are typically exposed. As has been demonstrated in previous studies, disturbance severity is important in determining rates of recovery of communities (Shaffner, 2010), therefore we can expect dam removal to have a more extreme impact than normal, non-anthropogenic disturbance events.

The purpose of this experiment is to predict the effects of sedimentation due to dam removal on the benthic organisms of the Elwha delta by analyzing the relationship between the existing benthic communities and the grain-size distribution of the delta

substrate, and using tidal current information to predict where sediment from the river plume will deposit. This experiment will consist of surveying the types of organisms living on the delta floor during dam removal and, by examining grain-size distributions and tidal conditions, predict where sediment will be deposited along the delta, and how this may change the diversity of benthic communities.

2. Background

2.1 Physical Setting

The Elwha River is relatively untouched by man, with 83% of its watershed located within the protected Olympic National Park (Duda et al., 2011b). However, for the past century, the presence of the Elwha and Glines Canyon Dams on the river has altered the substrate of the subaqueous delta, which extends several kilometers offshore into the Strait. Trapping of sediment by the reservoirs, Lake Aldwell and Lake Mills, has resulted in coarsening of the delta bed; surveys found that the substrate prior to dam removal was composed of coarse sand to boulders (Warrick et al., 2011). The dams are currently being removed, which is expected to release 7 to 8 million cubic meters of mostly fine-grained sediment downriver, potentially changing the nature of the delta floor, thereby altering the habitat of benthic organisms (Czuba et al., 2011).

The position of the Elwha delta in the Strait of Juan de Fuca means that it is subject to both locally generated waves and swell from the Pacific Ocean. During the winter, storms are capable of raising sea level up to half a meter. The coastal currents are tidally dominated due to the exchange of water between the Pacific and the Salish Sea, and tides are semi-diurnal. The form of the delta causes currents to split as they pass over

it, creating eddies that result in different current conditions on either side of the delta. These eddies direct coastal currents toward the delta tip, and these dominant northeast currents in turn drive the Elwha River plume toward the east (Warrick et al., 2011). Models of the Elwha plume show that the plume is directed toward the east about 50% of the time, but toward the west less than 10% of the time (Warrick and Stevens, 2011). The model also predicted that during dam removal, at least half of fine sediment in the plume, meaning silt and clay, would settle out of the plume within one kilometer of the river mouth; though due to the broad range of settling velocities of fine particles, sediment from the plume is expected to be observed up to 10 km offshore (Warrick and Stevens, 2011). Our sampling region is within several kilometers of the river mouth (Fig. 1), therefore we can expect to see impacts of dam removal within the study area.

2.2 Topical background

The deconstruction of the Elwha dams presents a unique opportunity to study the effects of sedimentation on benthic habitats in the field. Sedimentation is an umbrella term that encompasses the many physical processes by which sediment may affect benthic organisms, such as burial, scouring, or turbidity. The effect of sedimentation on benthic communities is dependent on the interplay of physical factors like currents, and also biological feedback. Though lab experiments on the subject are common, field studies are rare and often have conflicting results. This is because sediment deposition rates depend on factors such as substrate type, the kinds of organisms living on the substrate, and exposure to oceanographic processes. Sedimentation can directly affect organisms negatively by three mechanisms: burial or smothering, which may limit the availability of oxygen, light, or nutrients, scour, in which moving sediments damage

organisms, and alteration of the substrate, which can prevent certain organisms from colonizing by covering solid substrate with unstable particles (Airoldi, 2003).

Sedimentation can also have indirect effects, such as altering predator/prey interactions or lowering diversity by favoring “sand-tolerant” species at the expense of non-tolerant species (Airoldi, 2003). Studies have shown that species with certain traits do well despite sedimentation; for example, algae that reproduce vegetatively rather than sexually are easily able to overcome disturbance from sedimentation (Airoldi, 2003). In her review of papers on the effects of sedimentation on rocky coast communities, Laura Airoldi found that while many studies concluded that sediment deposition tended to decrease biological diversity, she noted that variable patterns of sedimentation could increase diversity by creating habitat heterogeneity (Airoldi, 2003).

Rubin et al., 2011, conducted a survey prior to the commencement of dam removal of the benthos of the Elwha delta and nearby coastline at depths of 3-18 m. They found that most habitats at these depths could be divided into four types of substrate: bedrock/boulder reefs, mixed sand and gravel with boulders, mixed sand and gravel without boulders, and sandy habitats. Each of these habitats had different organism density and diversity; those with the poorest sediment sorting (i.e. mixed sand and gravel with boulder relief) had the greatest diversity of both kelp and invertebrates, whereas well-sorted habitats (i.e. sand only) had the lowest diversity (Rubin et al., 2011).

3. Methods and Materials

3.1 Field Work

Seabed samples were collected along the Elwha River delta on two separate cruises in April 2012 (Figure 1). On the first cruise, which occurred between April 3rd and 5th, Shipek grab samples were taken at (#) stations. From each Shipek grab, two types of samples were taken; first, benthic macrofauna were removed by hand and placed in jars containing two parts seawater to one part alcohol for preservation. Next, a homogenized sediment sample was removed. The sizes of these samples varied depending on the amount of sediment actually picked up by the Shipek. Additionally, only 26 samples of macrobenthos were obtained, since not every grab sample had organisms in it. Video of the seabed was also taken by lowering a camera overboard; each recording lasted approximately (#) minutes. Samples were taken in a similar way of the second cruise, which took place April 17th, with the exception that a Van Veen was used to grab seabed samples rather than a Shipek.

3.2 Lab Work

Samples of macrobenthic organisms were identified to the level of family whenever possible, and the numbers per sample recorded. To analyze the video of each station, the film was paused at 10-second intervals and the number and type of organisms present recorded. If other particularly large or interesting organisms were seen throughout the course of the recording, those were also recorded regardless of the point in the video they were seen.

Video was also used to look at grain size and sorting of the delta floor, using the same method as that for tallying benthic organisms (every 10 seconds the frame was frozen, and approximate grain size and sorting were recorded). The sediment grab samples of the seabed were sorted using a combination of wet and dry sieving.

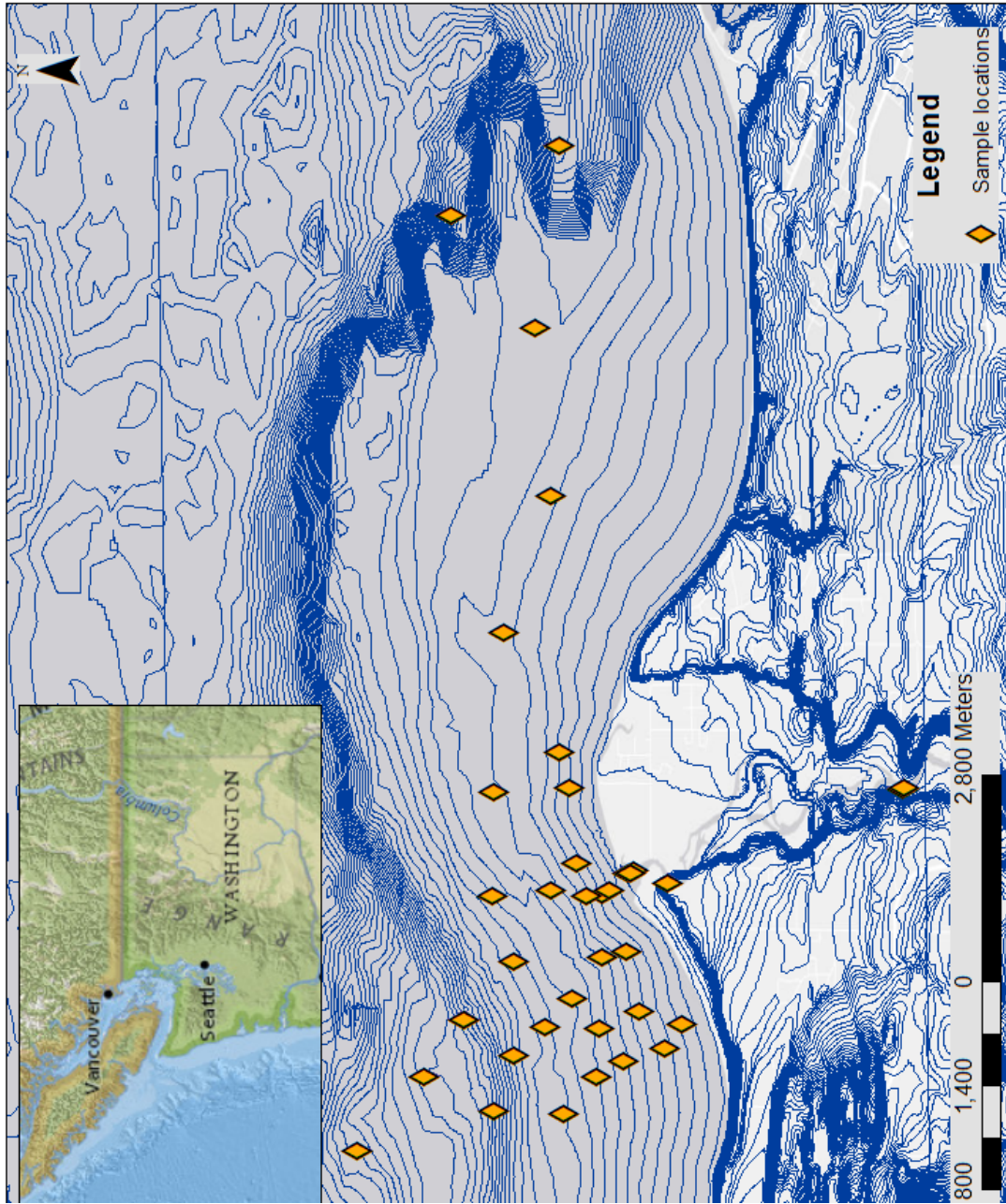


Figure 1. Location of sampling stations along the Elwha River delta. The inset map depicts the location within Washington State. Bathymetry basemap created by USGS (walrus.wr.usgs.gov)

Sediments larger than 4 phi were separated from the mud and sorted at 1-phi intervals (-4 through 4) and weighed. Sediments smaller than 4 phi were washed away from larger grains and pipette analysis performed to determine the proportions of silt and clay.

3.3 Statistical Analysis

Analysis of grain size was performed with the Folk and Ward method using the program GRADISTAT (Folk and Ward, 1957) (Blott, 2010). Due to the quantitative nature of macrobenthos samples, visual interpretation rather than statistical analysis was used to find patterns.

4. Results

4.1 Grain Size Analysis

Grain size and other characteristics of the grab samples from the delta substrate were determined. Mean grain diameter (D_{50}), and percentages of gravel, sand and mud were mapped (Figs. 2 and 3). While high amounts of gravel occur across the delta, it is most concentrated just northwest of the river mouth (Fig. 3). Sediment farther west and north of the river mouth is composed mostly of sand (Fig. 3). Mud, however, seems to be most concentrated close to the mouth of the river, with similar percentages to the east, but not to the west (Fig. 3). These trends are also reflected by D_{50} , which was smallest in front of the river mouth and to the east, and largest to the northwest (Fig. 2).

Grain sorting was also calculated. The majority of samples were very poorly or poorly sorted, and only one was very well or well sorted (Fig. 3). Although there is some variation, sediment on the west side of the delta tends to be very poorly sorted farther from the river mouth, but becomes increasingly well sorted with decreasing distance from

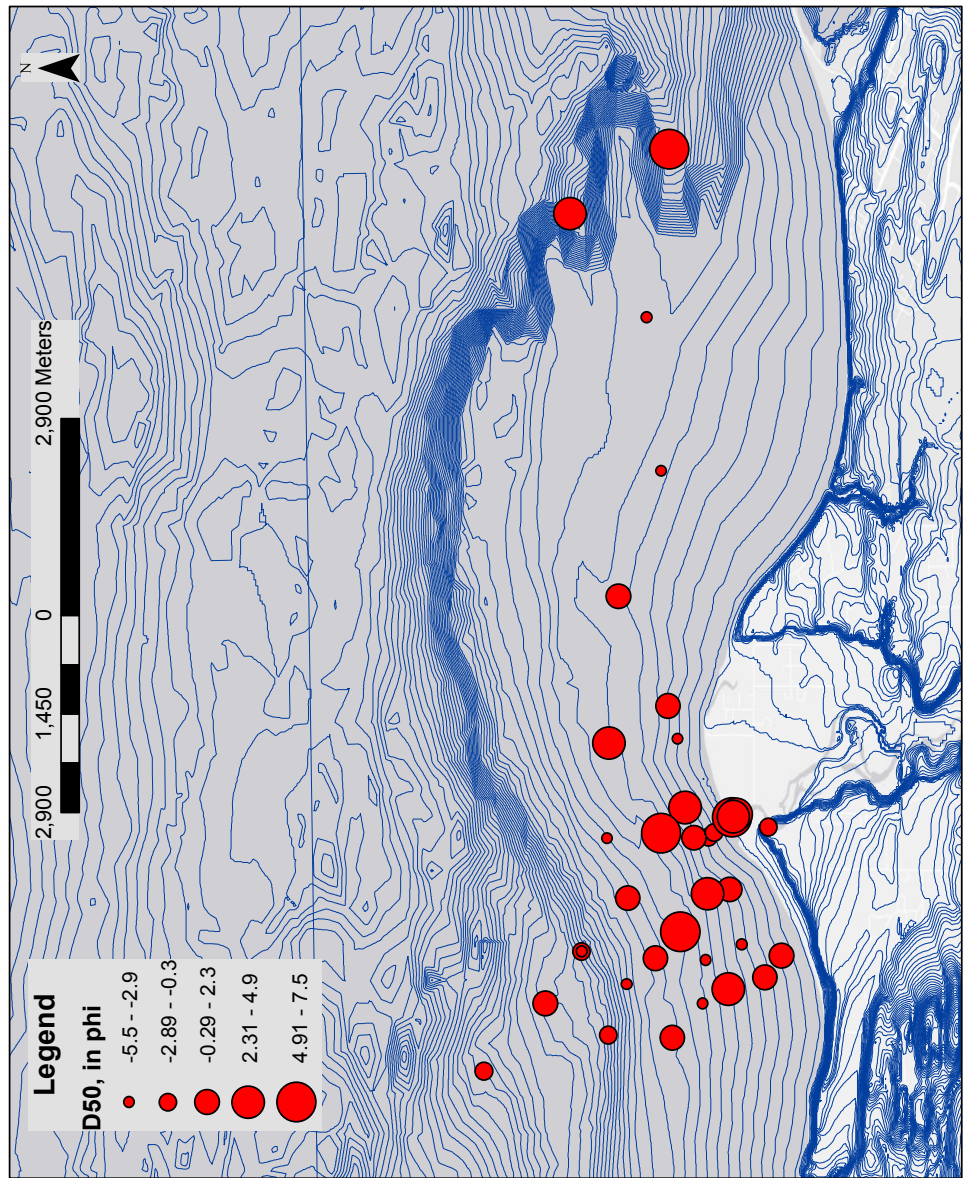


Figure 2. Grain-size distribution along the Elwha delta. Each size of symbol represents a range of phi sizes of D_{50} . Bathymetry basemap created by USGS (walrus.wr.usgs.gov)

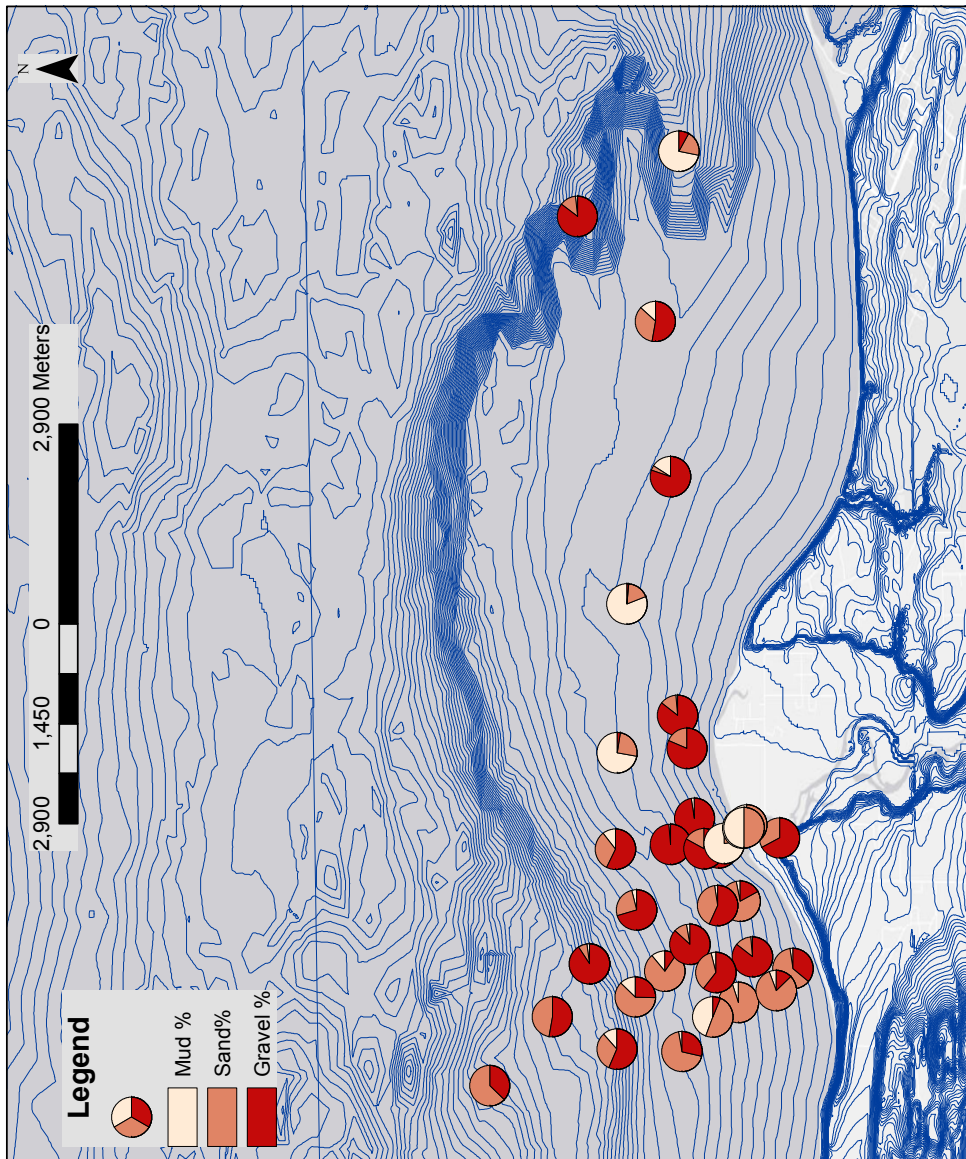


Figure 3. Percentages of gravel, sand, and mud at stations along the Elwha delta. The symbols are pie charts representing the fractions of the types of sediment found at each station. Bathymetry basemap created by USGS (walrus.wr.usgs.gov).

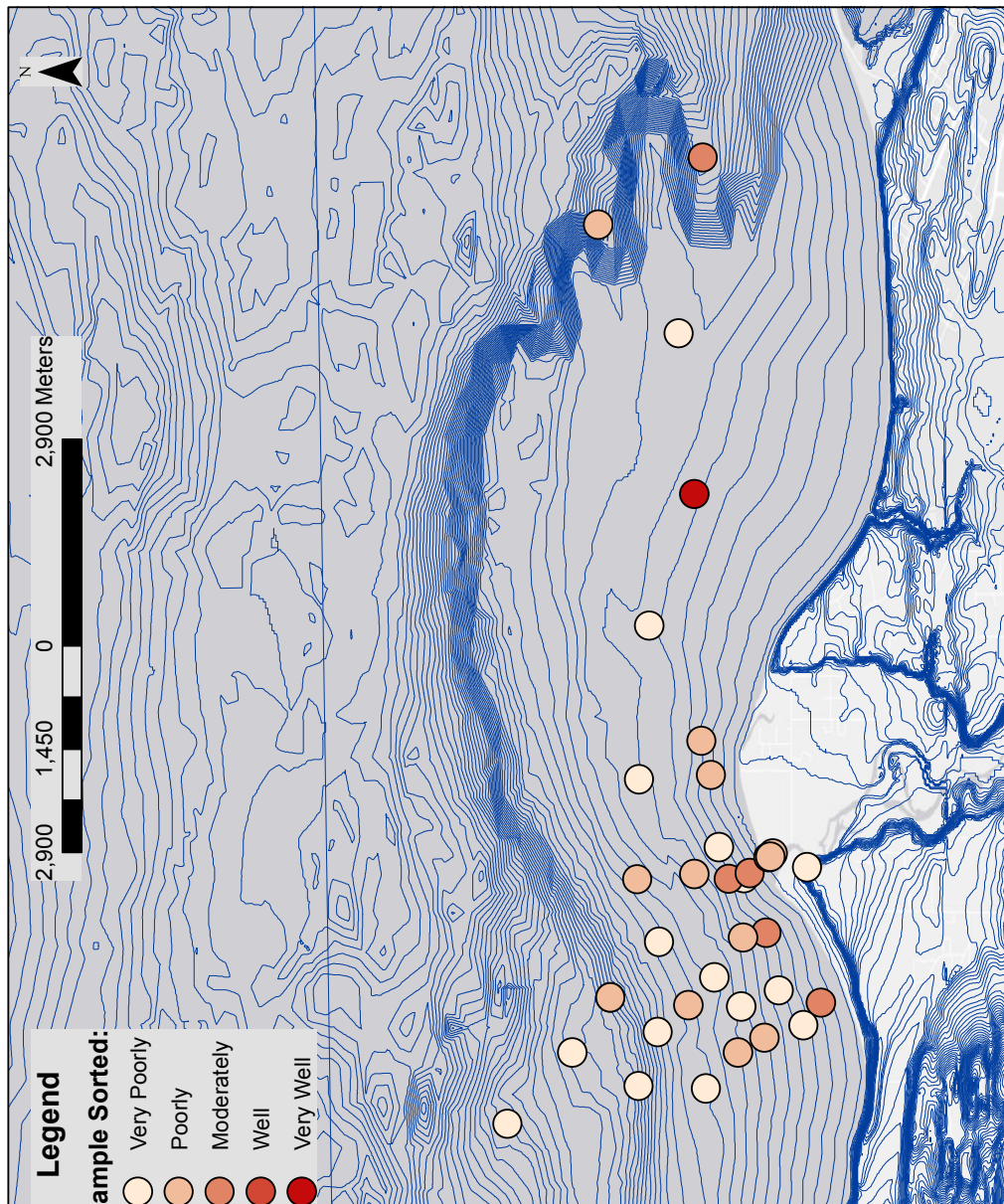


Figure 4. Sorting of substrate samples taken along the Elwha delta. Darker symbols reflect higher levels of sorting, lighter symbols indicate lower levels of sorting. Bathymetry basemap created by USGS (walrus.wr.usgs.gov).

the shore (Fig. 4). Due to the smaller number of samples, it is hard to determine a pattern on the east side of the delta.

4.2 Macrobenthos Inventory

Macrobenthic organisms were collected from Shipek grab samples, and counted from video taken of the delta floor. The total numbers of families at each station from both grab samples and video varied from 1 to 10. Few species were seen to the east of the delta, although sampling was concentrated in the west. Greater diversity (in terms of the number of families) occurred northwest of the river mouth, and decreased with increasing distance from the river (Fig. 5). Counter to this pattern, stations just off the river mouth had low taxa richness (Fig. 5).

Sightings of species are also shown according to sampling method (Figs. 6 and 7). Among grab samples, *Neoloricata* (chitons) and *Ophiuroidea* (brittle stars) were the most commonly seen taxa (Fig. 6). The video showed *Asteroidea* (sea stars) to be the most common fauna (Fig. 7).

A map of phylum locations shows that while certain phyla were located across the delta, such as echinoderms, mollusks and arthropods (Fig. 8). The least common phyla, including nemerteans and brachiopods, were seen in the northwest area of the delta (Fig. 8). This fits with the pattern of diversity observed in Figure 5.

5. Discussion

5.1 Sediment characteristics and macrobenthic diversity

Our results showed patterns within both benthic diversity and sediment characteristics. The question then becomes, what, if any, are the relationships between

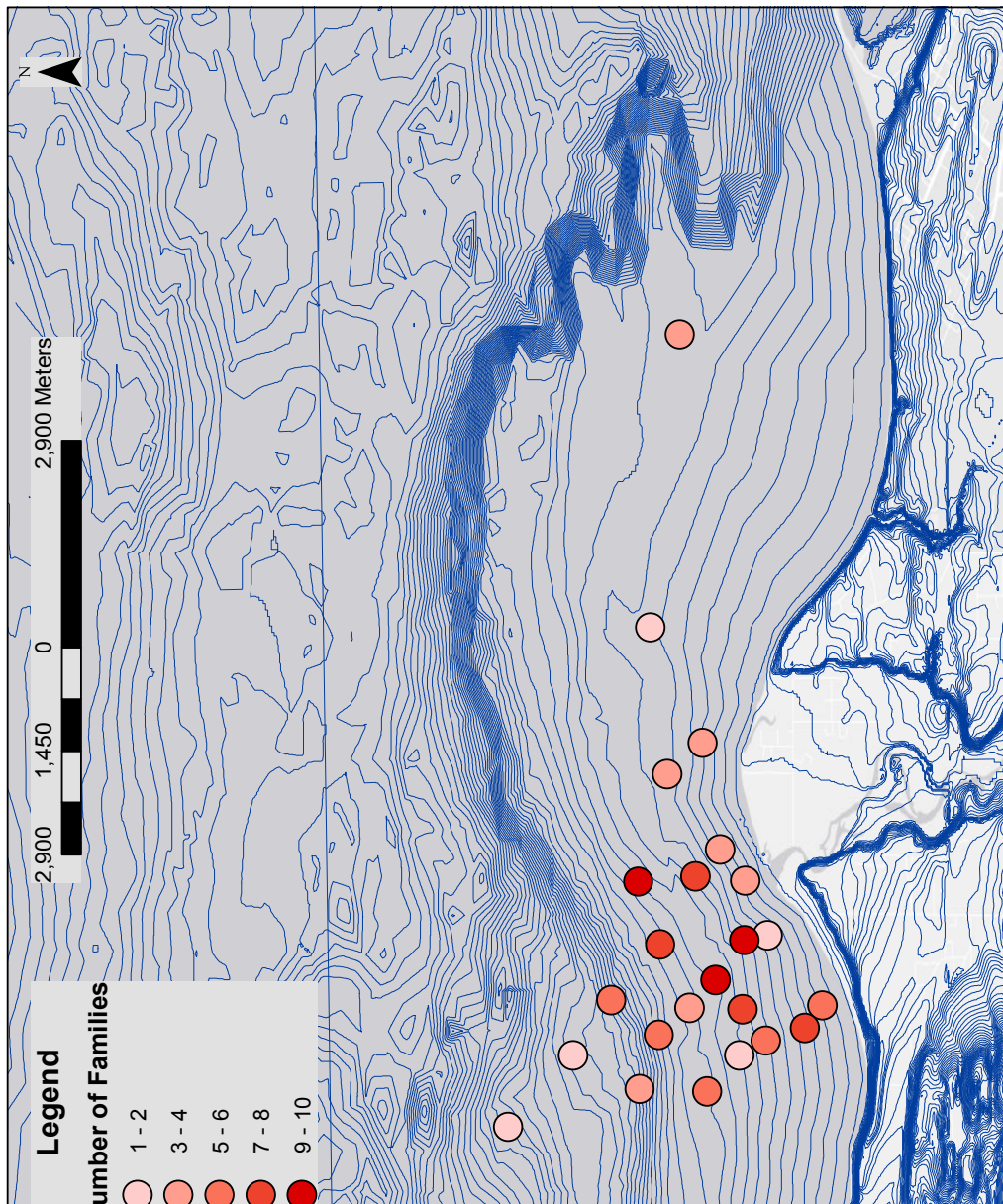


Figure 5. Macrobenthic diversity along the Elwha delta, reflected in numbers of families. The varying shades of symbols represent a range of values of the number of families found at each station, using data from both grab samples and video. Bathymetry basemap created by USGS (walrus.wr.usgs.gov).

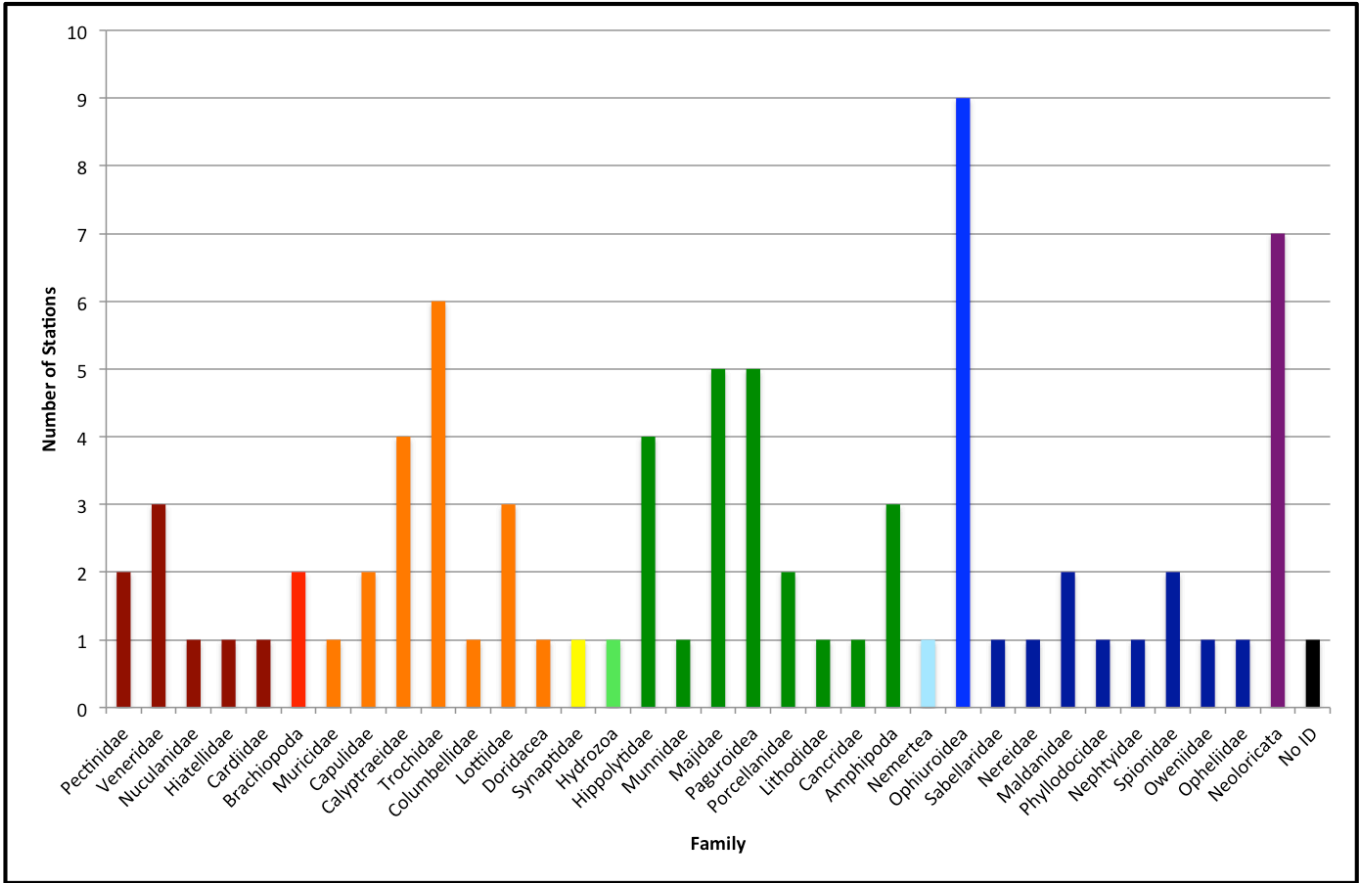


Figure 6. Number of stations at which each family (or other taxonomic level) was found, for grab samples only. Each family is color-coded by class (see legend below).

Classes:

- Bivalvia ■
- Brachiopoda ■
- Gastropoda ■
- Holothuroidea ■
- Hydrozoa ■
- Malacostraca ■
- Nemertea ■
- Ophiuroidea ■
- Polychaeta ■
- Polyplacophora ■
- No ID ■

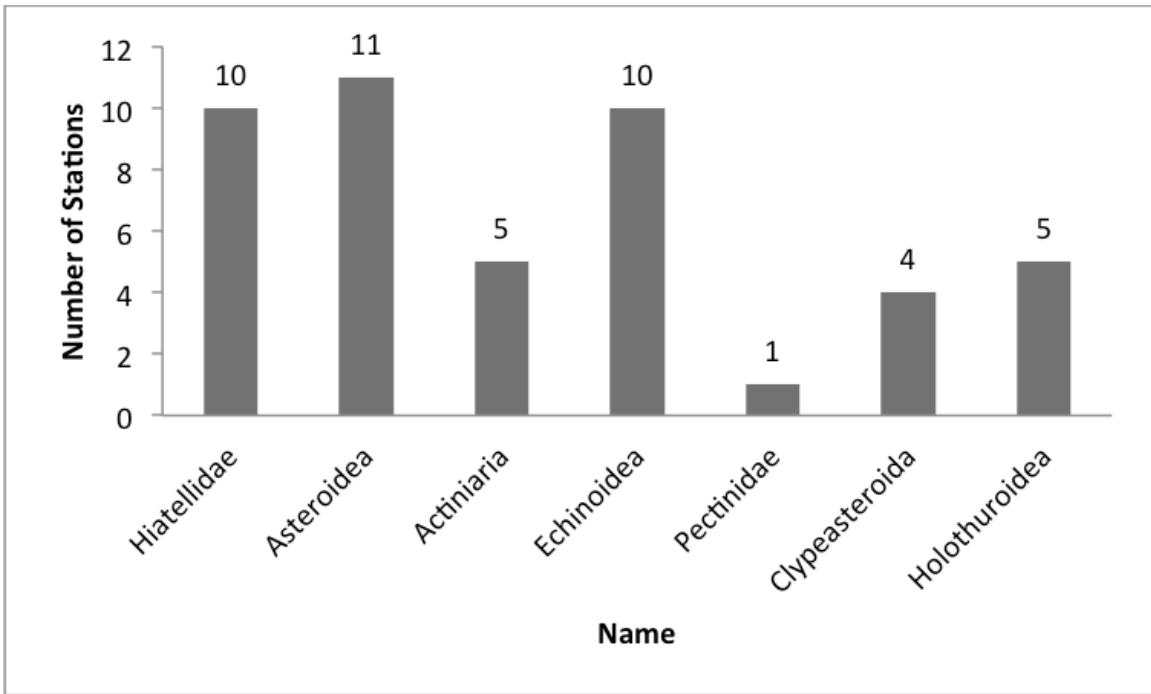


Figure 7. Number of stations at which each taxa was present, from video observations only.

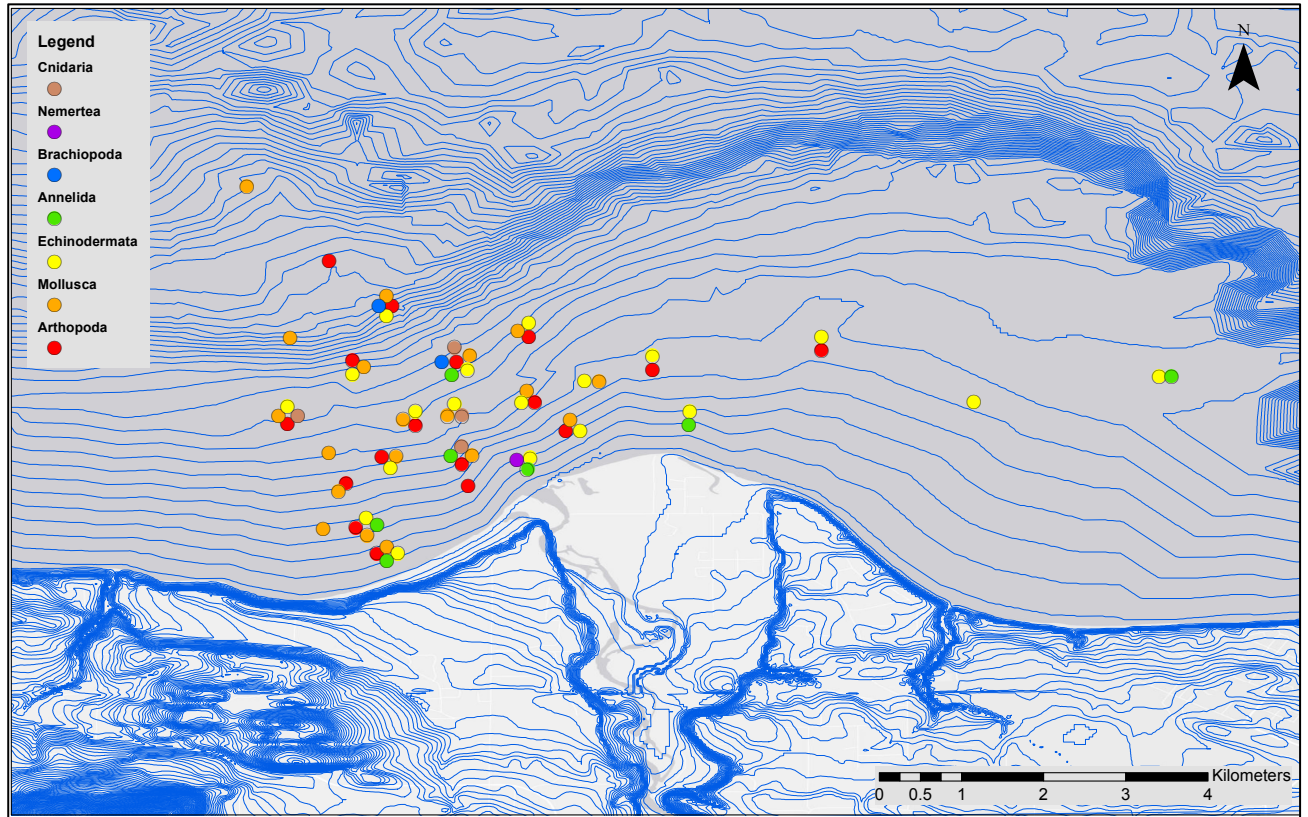


Figure 8. Map of phylums by location on the Elwha delta. Each color represents a given phylum (see legend). Bathymetry basemap created by USGS (walrus.wr.usgs.gov).

diversity and sediment? The number of families was greatest just northwest of the Elwha, and seemed to decrease with distance from the river. The exception to this was just off the river mouth, where the number of families was relatively low (Fig. 5). Substrate also varied spatially. Samples composed mainly of mud were located just off the river mouth and on the eastern side of the delta, which is where the Elwha River plume is directed the majority of the time (Warrick et al., 2011) (Fig. 3). Though samples containing gravel were also found in the middle and east side of the delta, the coarsest samples were located northwest of the river mouth, with sandy samples located farther out to both the west and north (Fig. 3). When these patterns are considered together, a trend emerges. The highest numbers of families (this experiment's measure of diversity) occur in areas where the substrate is composed mostly of gravel (Fig. 9). Sandy areas have intermediate numbers of families, and muddy areas tend to have the lowest numbers of families (Fig. 9).

This correlation between number of families and sediment type is to be expected, given that organisms are typically adapted for certain kinds of substrate (Airoldi, 2003). Knowing also that the Elwha delta substrate has been coarsening since the dams were constructed also helps explain why more families are found in gravelly and sandy areas than muddy ones; since the dams were built, organisms adapted to coarse substrate have probably had greater success as their habitat became the dominant substrate type on the delta (Rubin et al., 2011). The fact that fewer families are found at sites with a higher mud fraction supports studies that have found that sedimentation to rocky coasts decreases diversity (Airoldi, 2003).

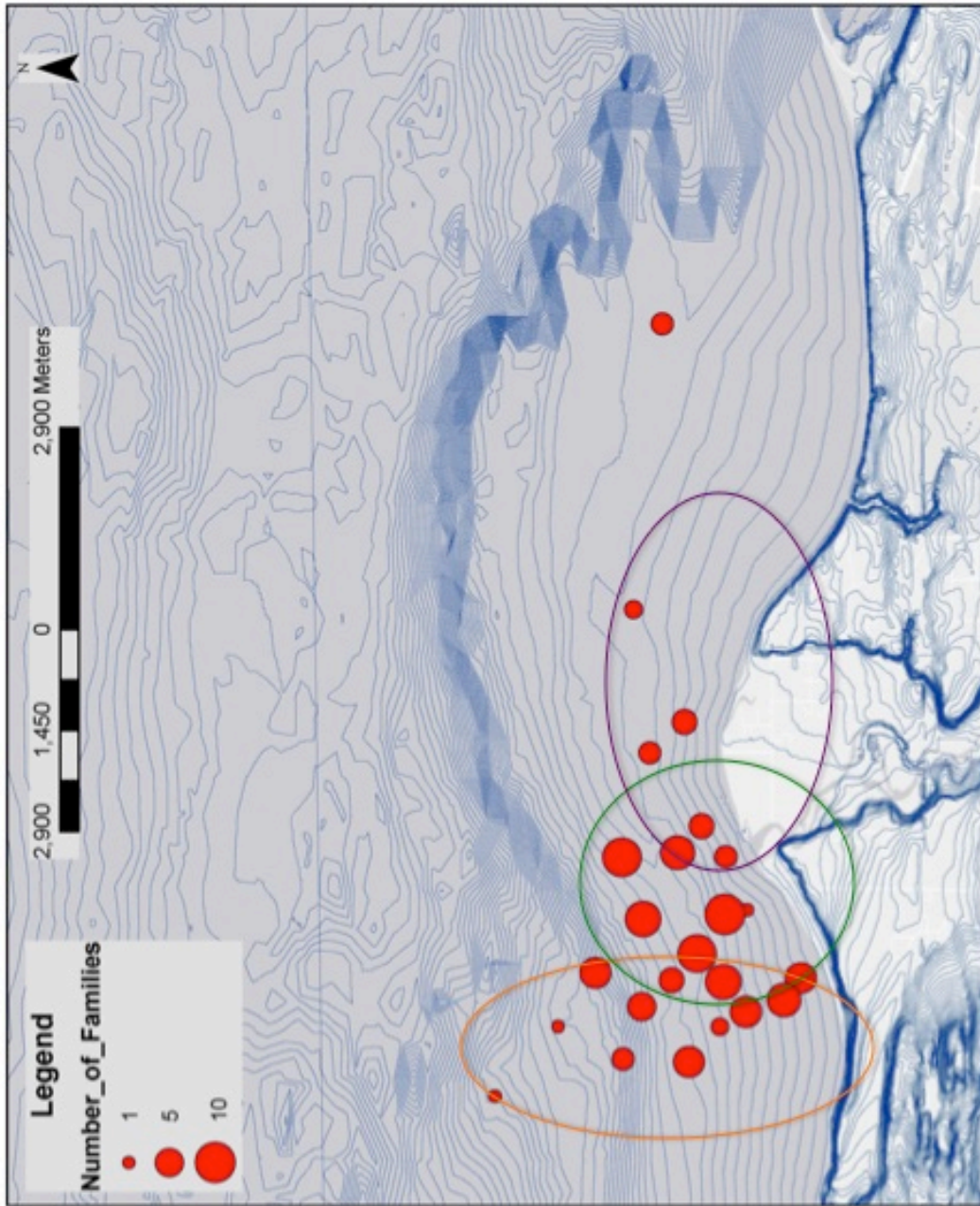


Figure 9. Number of families and general grain type. Larger symbols correspond to greater numbers of families, and each oval represents a grain type. The orange oval represents sand, the green oval represents mud, and the purple oval represents mud. Bathymetry basemap created by USGS (walrus.wr.usgs.gov).

5.2 Future impacts of dam removal on macrobenthic diversity

As dam removal continues, fine sediment formally trapped in the reservoirs will be transported downstream to the Strait of Juan de Fuca (Czuba et al., 2011). Grain-size analysis of the delta substrate has shown that mud is predominately deposited at the river mouth and along the eastern side of the delta, as can be expected from observations of the Elwha plume. If this pattern continues, it is reasonable to expect that the trends discussed above will be exacerbated. This means that macrobenthic diversity will be affected differently to the east and west of the river mouth. To the east, where sedimentation is expected to be significantly higher, diversity will probably be negatively affected. On the western side of the delta, substrate mapping prior to dam removal showed the dominant substrate to be mixed, with varying abundances of boulders. The potential “shelter” from sedimentation that these boulders could offer, combined with the fact that the river plume is directed west only a small amount of the time, probably means that sedimentation in this area will be patchy, and deposited at lower rates than to the east. Spatially irregular deposition of sediment could actually increase benthic diversity by increasing habitat heterogeneity (Airoldi, 2003). Additionally, a lower sedimentation rate (meaning the amount of sediment deposited in a given time period) could be the difference between stressful conditions and lethal conditions for an organism (Airoldi and Hawkins, 2007). So while organisms living on the west side of the delta may experience negative effects from sedimentation due to dam removal, these effects may not be as severe as on the east side of the delta.

Though the patterns found in this study allow us to make predictions about the impact of dam removal on the macrobenthos of the Elwha delta, more observation is

necessary to fully understand these processes. As this is the largest dam removal attempted in the United States, and because it is a restoration project, it is the responsibility of the scientific community to continue to monitor all impacts of the removal. Additionally, because so few field studies on the impacts of sedimentation have been performed, this is a unique opportunity to study the consequences of sedimentation on a large scale. In this study, most observations on benthic diversity were qualitative rather than quantitative, due to the nature of sampling methods. In the future, using more precise measuring techniques and more reliable gauges of diversity would be helpful in furthering our understanding of the impacts of dam removal.

6. Conclusion

The Elwha dam removal project is a milestone among restoration projects. As the largest dam removal ever done, it is important to study all repercussions on the ecosystem so we can understand how these projects affect surrounding habitats and how to improve them in the future. This study looked at the effects of sedimentation due to dam removal on the macrobenthos of the Elwha River delta, and concluded that sedimentation will most likely alter the levels of diversity of those communities; however, consequences will be different on either side of the delta due to sedimentation patterns. The west side of the delta was shown to have higher levels of diversity than the east side, and this pattern will probably be exacerbated by different sedimentation patterns. On the east side of the delta, where the Elwha plume is directed most of the time, diversity will continue to decrease as higher rates of sedimentation continue with dam removal. On the western part of the delta, levels of diversity will probably be preserved or increased due to lower

sedimentation rates and shelter from fine sediment offered by high frequencies of boulders. This should be considered as dam removal progresses, and additional studies performed for the benefit of future restoration projects.

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