Elwha River Dam Removals: A Nearshore Synthesis a Decade After the World's Largest Dam Removal Project

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Summary

The largest intentional dam removal project in the world conducted to date was undertaken by the U.S. National Park Service to fully restore the Elwha River watershed, Washington, USA, per the Elwha River Ecosystem and Fisheries Restoration Act (Public Law 102-495). Removal of two dams (Elwha and Glines Canyon) released a century of stored sediment from two former reservoirs and transformed the watershed and associated nearshore zone via sediment transport processes of the newly undammed wild river. Coastal response was dramatic and continued to evolve over the ten years following dam removal. At the end of the decade post dam removal, sediment has largely been delivered to the coastline and coastal habitat form and ecological function appears to be stabilizing.

Despite almost a decade of work prior to the dam removals, a number of impediments to nearshore restoration remained for years during and after dam removal. A series of projects have occurred to remedy these remaining impediments. This paper provides 1) an overview of work defining the ecological and biophysical changes to the Elwha nearshore since dam removals, and; 2) a synthesis of future nearshore research and management actions, including conservation, restoration, and fishery management, needed to achieve full ecosystem restoration intended thru dam removal,

Introduction

The Elwha nearshore is a large, complex and dynamic drift cell located on the north central Olympic Peninsula of Washington state. Just over a century ago, two large-scale dams were installed in the Elwha River (Figure 1). The lower river was lined with large flood-control dikes, and the majority of the Elwha drift cell east of the river mouth was armored with large diameter rock in front of the industrial waterline that conveyed water from the Elwha River to the city of Port Angeles. As a result, a century of sediment and wood starvation drastically altered the composition and habitat quality of the Elwha River nearshore (Shaffer et al 2008, 2009, 2017b). Dam removals began in 2011 and concluded in 2014. The Coastal Watershed Institute (CWI), along with State, Federal and Tribal partners monitored elements of

the Elwha nearshore prior to, during, and following dam removals and conducted ecosystem scale restoration projects to complete ecosystem recovery of the Elwha. This paper provides an overview of nearshore changes, and remaining priorities to achieve full nearshore ecosystem restoration.

Dam Impacts to Nearshore

A comprehensive overview of dam impacts to the nearshore is provided by Shaffer et al 2008. In overview, the Elwha dams, shoreline armoring, and lower river alterations resulted in the ~100-year elimination of the natural hydrodynamics to the majority of the Elwha drift cell. Dams stored over 20 million cubic meters (mcm) of sediment that otherwise would have been delivered to the entire river and nearshore system. While the sediment supply to the Elwha nearshore adjacent to the river mouth is primarily provided by the river, east of the river delta ~30-meter-tall feeder bluffs contribute the majority of the sediment to the remainder of the drift cell (Parks 2015). Shoreline armoring installed along the Elwha east delta and feeder bluff-backed nearshore from the 1920s combined with in-river dams resulted in almost complete sediment starvation across the drift cell (Parks et al., 2013, Parks 2015). Levees installed along the lower river disrupted river hydrodynamics and blocked fish access to important delta habitats. Collectively these features resulted in chronic sediment and wood starvation and associated erosion along much of the drift cell (Parks et al 2013, 2015, Rich et al 2014).

Nearshore Ecosystems Prior to Dam Removal

Ecologically, the Elwha drift cell prior to dam removals was severely impaired (Shaffer et al 2008, 2017b). Nearshore Impediments, by landform included:

Elwha delta. Prior to dam removals the Elwha delta area was much reduced. At dam removal it was at its' minimus (Shaffer et al 2017b). Estuary habitat available to nearshore migrating salmon and forage fish was small and degraded. Fish use of the Elwha east and west delta habitats was therefore disrupted due to sediment starvation from in river dams and levees. While the estuary on the east side of the river mouth supported fish, surprisingly, the small fragment of un-impounded west estuary along the west delta between the Place Road levee and the Elwha River channel was documented to have the highest and most diverse salmon composition of the Elwha delta (Shaffer et al 2009). The impounded west estuary, west of the Place Rd levee (hereafter called the Place pond), had the highest abundance of fish of any site in the Elwha estuary (primarily three spine sticklebacks). However, this zone of the delta was blocked from the un-impounded west delta and river channel by the Place Rd levee, and experienced severe macro-algae blooms annually in summer (Nelson and Lucas 2011).

Anticipating the Elwha dam removals, the Lower Elwha Klallam Tribe (LEKT) worked with federal agencies to pull back levees along the east delta to expand estuary area available for dam removal restoration (ESA and NSD 2022). Clallam County and WDFW, habitat programs CWI and the LEKT worked to provide fish passage to the impounded Place pond prior to dam removals but were unsuccessful.

Shorelines of Freshwater Bay, East Delta, and Feeder Bluffs. The Freshwater Bay embayed shoreline of the Elwha was one of the few unarmored shorelines of the Elwha drift cell. Surf smelt (*Hypomesus pretiosus*) spawning was documented only along Freshwater Bay and nowhere else in the

drift cell. A small zone of sand lance (*Ammodytes hexapterus*) spawning was documented along the south side of Ediz Hook in Port Angeles harbor-technically outside of the Elwha drift cell. The remaining shorelines of the Elwha nearshore were severely sediment starved foremost from extensive and heavy shoreline armoring necessitated by coastal erosion from interrupted sediment supply from feeder bluffs and Elwha dams (Shaffer et al 2008, Parks et al 2013, 2015).

Kelp habitats of the Elwha drift cell were also impacted by in-river dams and associated shoreline armoring. Overstory kelp distribution (*Nereocystis leutkeana*) was much larger in area along the Elwha drift cell after dams were installed than prior to the dams as sediment starvation resulted in larger diameter substrate that supported kelp holdfasts (Barry 2011). Eelgrass distribution was not significantly different than comparative areas and an extensive eelgrass bed persisted along much of Freshwater Bay and a portion of Ediz Hook (Norris et al 2007).

Vegetated and unvegetated zones of these shorelines were documented to be important juvenile forage fish and salmon migration and feeding corridors, and a critical intersection at which the lifelong associations between these groups of fish are formed (Shaffer et al 2020, Frick et al 2022).

Large Woody Debris (LWD) distribution was much lower along the Elwha drift cell before and during dam removal than comparative drift cells (Rich et al 2014).

Physical and Biological Responses to Dam Removal

Dam removals occurred from 2011-2014 and delivered a large volume of sediment and wood to the nearshore in a very rapid fashion (Parks et al 2013, Parks 2015, Rich et al 2014, Warrick, 2019). Highlights of the nearshore response follows.

Sediment

Of the 30 million tonnes of sediment stored in the watershed, 20 million tonnes were transported downriver and 5.4 million tonnes (6 million cubic meters) were deposited in the nearshore by 2016 (Warrick, 2019, Pess et al., 2022). Once in the marine environment, the sediment initially raised and lengthened the lower river channel by tens and hundreds of meters respectively, and expanded the Elwha delta. At the period of peak conveyance of former reservoir sediment, the delta grew to as much as 150 hectares (Shaffer, et al 2017b). As a result, salinity in the Elwha west delta habitats decreased dramatically and turbidity increased log scale within the first couple years of dam removal (Foley et al 2015, 2017).

The intertidal shoreline and subtidal seabed of the offshore delta transitioned from coarse cobble to a sandy/gravelly surface (Warrick et al 2019). Beginning with dam removal in 2011, the river delta and unarmored beaches in the drift cell once again began to receive Large Woody Debris (LWD) that had formerly been held back by the dams (Rich et al 2014).

By 2017 over 2/3 of the sediment stored in the reservoirs was mobilized with 90% of that volume discharged to the coast (Anderson and Hoffman 2017) . Since approximately 2019 (five years after dam removal ended) the Elwha system, including the nearshore, has been transitioning to a post-dam removal restoration phase. The east delta shoreline spit and lagoon complex are similar to that mapped on the 1908 GLO T-sheets (PNPTC, 2006, Figure 2).

A decade after dam removals, the west delta continues to recede. A large lateral bar along the west side of the Elwha lower river that formed well before dam removals began, has persisted. The west side channel, documented to have the highest salmon diversity and abundance of the Elwha delta (Shaffer et al 2009), appears to be filling in with sediment, and shrinking due continued diminished connection to the main river channel due to the Place Road levee (Shaffer et al in review, ESA and NSD 2022).

Biological Responses

During dam removals, the habitats of the Elwha nearshore underwent dramatic and rapid changes. By landform:

Elwha delta. The Elwha delta grew rapidly during dam removal expanding to over 150 hectares (Shaffer et al 2017b). With the formation of new delta area from dramatic sediment delivery, the water quality of the lower river, responded quickly with high turbidity and sharp decrease in salinity (Foley et al 2015).

West delta: Fish use of the Elwha unimpounded west delta quickly responded to dam removal changes to the lower river. Changes in fish use were observed within weeks of the beginning of dam removal. With the abrupt change in water quality, the former west estuary transitioned to freshwater lower river side channel habitat and became important for juvenile Coho (*Oncorhynchus kisutch*) overwintering. Red-sided shiner (*Richardsonius balteatus*)and Bull trout (*Salvelinus confluentus*) were observed in the west delta side channel, and adult Chum (*Onchoryncus keta*)were thought to spawn there at least one year. Eulachon (*Thaleichthys pacificus*) were also in abundance in 2013 (Shaffer et al 2017a, b). Simultaneously, new estuary habitats formed north of the original delta area. Comparing the newly formed estuary habitat to original Elwha delta habitat and comparative sites, researchers documented that intact, mature habitat had a higher functional resiliency and diversity than newly formed habitats (Shaffer et al 2018).

Since 2019, salmon use of the unimpounded Elwha west estuary has transitioned primarily to Chinook (*Onchoryncus tshawyscha*) and Coho. Juvenile Coho continue to use the site heavily for overwintering (Figure 3). Juvenile Chum salmon numbers have continued to decline over the last decade. When dam removals began hundreds of juvenile Chum were observed annually from January to June in the Elwha west side channel. In 2021, only single digit migrating Chum were observed (Figure 3, Shaffer et al., in review). This is troublesome as Pink (*Onchorynchus gorbuscha*) and Chum salmon were the two most abundant salmon in the Elwha system prior to construction of the in river dams.

In proper numbers these two species, Pink and Chum, are critical for providing marine derived nutrients to watershed systems. Chum salmon seasonally are prey for Federally listed Southern Resident Killer Whales (SRKW) (Dunagan 2016, Ford et al., 2016). The decline of Pink and Chum in the Elwha is theorized to be due to habitat loss as the west side channel fills in (see discussion below) as well as due to continued Washington Department of Fish and Wildlife (WDFW) hatchery practices in the Elwha (Shaffer et al 2017a, b). Additional sampling of the entire estuary would confirm these observations. Seining of the impounded west estuary in 2018 showed that fish abundance in the impounded Place pond continues to be high, and composed primarily three spine stickleback (*Gasterosteus aculeatus*) (Michel, unpublished data).

Beginning in the middle of 2014, the persistent macroalgae bloom of the impounded west side channel/Place pond largely disappeared and has not recurred (Shaffer et al., in review).

Beaver (*Castor Canadensis*) use of the west Elwha delta appears to be responding to dam removals. Prior to dam removal there was limited utilization of the river by beaver and the majority of beaver sign was documented along the east lower river and delta (Knapp, 2009). No beaver use was documented along the west delta. In the years following dam removal, beaver have been observed to expand their range of denning and activity in the river, including the west lower river and west estuary ecosystem. A large lodge is now located in the impounded Place Pond. This west delta expansion corresponds exactly with, and is attributed to, habitat improvement resulting from water quality changes and associated loss of macroalgae, expansion of side channel habitat, and associated riparian food resources. Beaver use of this area is however complex, and appears to be challenged by the complexity of the area and human use (Shaffer et al., In Review).

The lateral bar that has formed along the lower river west delta, parallel to the Place Road levee, is theorized to be in large part a result of the Place Road levee disrupting west lower river hydrodynamics, not dam removals (Shaffer et al., in review, ESA and NSD 2022).

As repeated efforts to reconnect the impounded Place pond with the west side channel have failed due County and landowner opposition, the hydrodynamics of the west side channel between the Place Road levee and river channel continue to be disrupted.

The west side channel documented to be consistently important for juvenile Chinook and Coho (and in earlier years, Chum) salmon, continues to shrink in size and become disconnected from the river.

Beaver use of these side channels to transit to feeding areas and the river channel should help maintain connection (Shaffer et al., In Review).

Along the Freshwater Bay and Elwha drift cell feeder bluff shorelines. Surf smelt spawning area extended west along the Freshwater Bay shoreline but did not extend past the Elwha delta prior to additional restoration (e.g., shoreline armor removal) along the east delta shoreline (Shaffer et al 2017c).

Overstory kelp bed distributions also changed due to changes in shoreline turbidity and substrate and decreased during dam removals. (Rubin et al 2018).

Forage fish continue to be the dominant guild of fish using the Elwha shorelines (Frick et al 2022). Juvenile and adult forage fish abundance have increased significantly in the last five years, which we attribute in part to shoreline ecosystem restoration (see below) (Figure 4, Shaffer et al 2019)

Post Dam Removal Shoreline Restoration

East Elwha delta. At the 2015 Elwha Nearshore Consortium (ENC) workshop, it was discovered that ~1,200 m of derelict intertidal armor ~1,600 m east of the river's mouth was inhibiting the natural rebuild of the beach as a result of the armor interrupting natural sediment and large woody debris transport and deposition processes (ENC 2015). A restoration project was developed and implemented by CWI and partners to remove the 8,400 m^3 of 2-3 meter diameter rip rap and 11 m^2 concrete panels (from the beach at tidal elevations between -1 and +3 meters MLLW). Removal of the shoreline armoring resulted in an immediate natural process rebuild of intertidal beach in the project footprint (Figure 5). Along the east delta and feeder bluff reaches of the Elwha nearshore, the buildout of a sandy/gravely upper intertidal beach increased beach wrack and invertebrates density and expanded

the range of surf smelt spawning (Figure 6), and the ecological community quickly 'caught up' to those of non-armored Elwha shorelines (Shaffer et al., In Review). Ecological and physical benefits of the removal of sediment transport impediments have been observed not only at the restoration site, but also extend throughout the remaining ~10 km of the east drift cell in broader, sandier beaches (Figure 7).

The softening of the subtidal bed shifted kelp dominance and improved the Dungeness crab fishery (Elofson, personal observation). Eelgrass beds of Freshwater Bay continue to be large and robust.

West delta/Place Road levee. Given the importance of the west delta for juvenile fish use, and repeated documentation that removing fish barriers in tidally influenced areas is one of the most successful restoration tools for salmon ecosystem recovery (Bilby et al., 2022), the west delta Place Road levee is a continued restoration priority.

In 2021 a post-dam removal hydrodynamic assessment of the lower river was commissioned by CWI (ESA and NSD, 2022). The intent of this assessment was to 1) understand the role of the levee in influencing river and estuary processes, and; 2) to conduct a feasibility analysis of restoration options that could reconnect historic west estuary habitat without adversely affecting flood risk for adjacent property owners.

In addition to completely blocking fish passage (Shaffer et al 2008, 2009, 2017b) the study revealed that the levee has altered lower river processes and in concert with the west lateral side bar (formed in part due to the levee) is resulting in the sedimentation of the remaining river-connected west estuary habitat.

Next Steps

Given the critical role the Elwha nearshore, including the Elwha delta, plays in the ecosystem functioning of the Elwha ecosystem, we have a number of recommendations for the Elwha nearshore for the future.

Our long term monitoring has revealed a number of functional elements of the nearshore that are critical for understanding dam removal and additional restoration priorities. Based on this work we recommend the following for continued research, management, and restoration:

Research

Future research priorities follow.

Long term monitoring of fish use of both sides of the Elwha delta and shorelines, including seining of east, west, and impounded delta areas is important to define delta wide function for fish, and to define if declines in juvenile Chum abundances are occurring across the entire delta. Monitoring of ecological parameters of forage fish spawning, as well as fish use of embayed and bluff shorelines, and kelp forest and eelgrass beds, should continue. Ongoing long term mapping efforts of the extent of delta, beach and bluff zones, and kelp and eelgrass beds of the Elwha nearshore are important to understand how these nearshore elements continue to evolve over the second decade after dam removals, and test the hypothesis that ecosystem recovery will begin to occur at a more rapid pace as habitats stabilize now that dam removal impacts are over.

Research defining the relationship of beaver to the larger river system and connectivity of the west side channel, and the role beaver may play in mitigating the impact of the Place Road levee is a priority.

Management

Given the complex matrix of ownerships and uses of the Elwha nearshore, there are a number of important and unique management considerations to complete the ecosystem restoration of the Elwha. Science has repeatedly documented the high benefit of restoring connectivity to ecosystem recovery for fish communities, and the importance of restoration at an ecosystem (not site) scale (Shaffer et al., 2013, Bilby et al., 2022). We therefore continue to recommend that the Elwha drift cell be managed at a drift cell scale, with a top priority of ecosystem conservation. The intact, unarmored shoreline of Freshwater Bay, and newly restored east Elwha delta and unarmored shorelines along Elwha feeder bluffs are a top priority for ecosystem conservation. The riparian zones of the lower Elwha regions of the nearshore should be conserved and restored to promote beaver communities, that in turn will promote fish and wildlife habitats.

Additional priority ecosystem restoration actions follow.

In 2019 the Lower Elwha Klallam Tribe enacted the Elwha River Beach and Estuary Access and Management Ordinance (LEKT Resolution 14-19) for Tribally owned areas of the Elwha delta. CWI has developed a draft Elwha Nearshore Management Plan that builds upon the LEKT Management Ordinance to encompass ecosystem-scale management of the Elwha delta and nearshore.

Human Use

The cultural importance of the Elwha nearshore to the Lower Elwha Klallam Tribe, including the Tribe's role in Elwha watershed recovery, cannot be overstated. Recreational use of the Elwha delta and beach and bluff shorelines should be framed by Tribe's conservation-based cultural use of the Elwha nearshore.

The expansion of the Elwha nearshore resulting from dam removals and shoreline restoration has resulted in kilometers of sandy, walkable beaches that have increased human presence in the nearshore significantly. The sites have received some of the highest recreation use of any restored shoreline in the state (RCO pers. Comm.). The majority of recreation occurs along the west delta with access along the Place levee. Along the west delta numerous driftwood shelters and illegal recreational beach fires, made using the newly delivered LWD, disrupt LWD ecosystem function and are a nuisance. In addition to hampering ecosystem function, these shelters are used heavily by squatters, with driftwood fires endangering local homeowners and requiring expensive and challenging fire department response.

Along the delta and adjoining shorelines, wildlife use of the nearshore (including beaver, and migrating and nesting shorebirds) is disrupted by high human (and in particular associated domestic dog) use and associated negative dog/wildlife interactions. As the region experiences burgeoning development, it is imperative that a conservation, ecosystem based management plan for the Elwha nearshore be developed and implemented. We recommend the draft plan developed by CWI in 2021 provide the base for this planning. Dog use should be top management priority as they are the top challenge to ecosystem engineering benefit of beaver.

Fisheries Management

We recommend fisheries management plans and actions, including hatchery management, incorporate nearshore ecosystem habitat function, species composition and release times, that better reflect the pre-dam salmon composition and so the Elwha River ecosystem recovery goals. This includes incorporating pre-dam species composition and in particular, wild Pink and Chum salmon, the two dominant species prior to dam installation that are not recovering after dam removal, in hatchery management planning and practices.

Remaining restoration priorities

Elwha west delta. Long term monitoring before, during, and after dam removals, has documented persistent, high salmonid utilization, as well as the highest ecological function, of the un-impounded lower river west side channel habitat adjacent to the Place Road levee. Since dam removals the un-impounded section with connection to the main river channel has become important over wintering side channel habitat for juvenile Coho. The impounded section continues to support high numbers of fish (though not salmon due to the Place Road levee blockage). Together these findings suggest immediate benefit to salmon if access to the historic estuary was restored. While establishment of beaver along the impounded Place pond area, and increased use of the connected west side channel to travel to food and the main river channel may help maintain this connection it appears their presence is not enough. The continued shrinking of, and potential loss of this west side channel due to filling in, as a result of continued disrupted lower river hydrodynamics, is therefore a strong concern. Hydrodynamic modeling indicates that any modification of the levee to reconnect habitat would also increase flood risk for adjacent properties, and a number of homes have been built along this shoreline since dam removal legislation was ratified. Subsequently, Place pond landowners are in strong opposition to restoration actions that modify the levee. We therefore continue to recommend that parcels in the historic west estuary be conserved with willing landowners as opportunities become available such that at some point in the future the historic west estuary can once again support watershed restoration and salmon recovery goals.

We also recommend measures that will support and protect beaver establishment and use of the west side channel, which may help maintain the side channel connection.

Industrial Waterline. The industrial waterline and City of Port Angeles Landfill shoreline armoring that extends east from Dry Creek ~3.2 km to the mill on Ediz Hook has been documented to be a significant and ongoing ecological degradation (Shaffer et al., 2008). The waterline is armored with large rip rap and sheet pile, most of which is no longer structurally intact. Fine sediments have been delivered through the armor onto the upper beach, suggesting that the armor is no longer a functional structure. This non-functioning shoreline armoring feature should be a priority for removal.

Conclusion

Ten plus years following the removal of the Elwha River dams, the Elwha nearshore ecosystem is benefitting from re-engaged natural sediment and wood transport processes and has begun to recover from the impacts of the dam and dam removal era. Many nearshore species have positively responded to the newly available habitat, and additional shoreline restoration has resulted in dramatic and swift ecosystem recovery at a drift cell scale. Long term monitoring and lower river modeling have revealed a

number of important functional responses to dam removal, as well as conservation priorities and additional restoration needs. Conservation of intact nearshore habitats of Freshwater Bay and unarmored delta and bluff shorelines are a top priority. Restoration of historic nearshore habitats, and in particular reconnecting the impounded and un-impounded west delta will provide the best opportunity to achieve the watershed restoration goals of the Elwha River Ecosystem and Fisheries Restoration Act and should continue to be a top restoration priority.

Hatcheries continue to confound nearshore ecosystem function and species assemblage and should be re-configured to reflect and promote the watershed ecosystem prior to dams.

Human use of the Elwha nearshore should be managed for ecosystem conservation and guided by Tribal cultural ecological conservation.

In the years ahead, continued research, adaptive management, public use management, public education, conservation and restoration planning will be important undertakings to help ensure appreciation for and full recovery of the Elwha Delta/nearshore ecosystem and the species dependent upon it.

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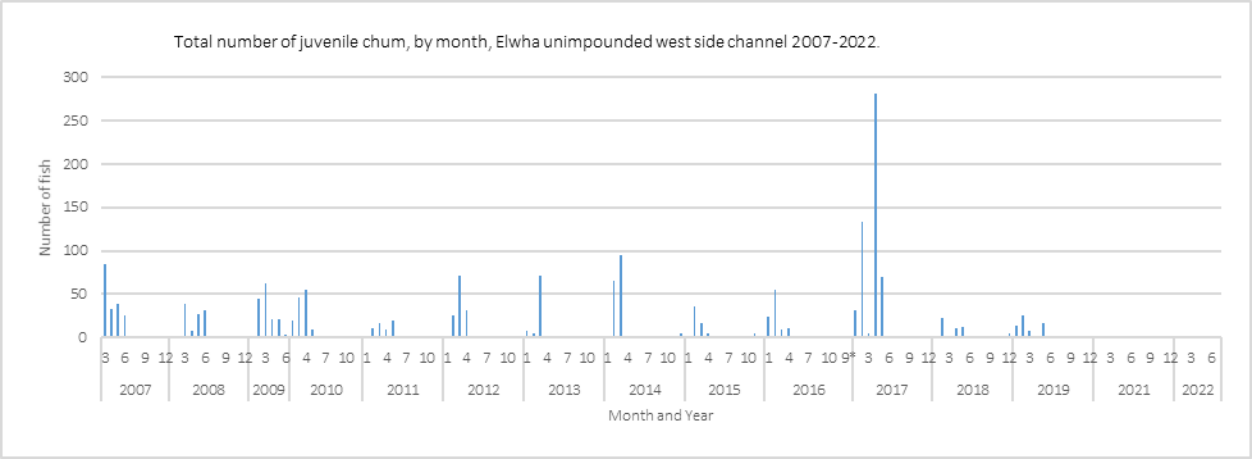
Figures

Figure 1. Location of Elwha River Watershed in Washington State

Figure 2. Elwha River Delta in the pre-dam era (1908), the dammed sediment starved era in which the estuary was almost entirely lost (2011) and the post-dam era where the east estuary (left side in 2011 photo) has naturally rebuilt with sediments made available by dam removal, while the lower river and west estuary remain altered by the Place Rd levee.

Figure 3. Juvenile Coho and Chum use of the Elwha unimpounded west side channel 2007-2022. Note no sampling occurred from 3/2020-01/2021 due to Covid.



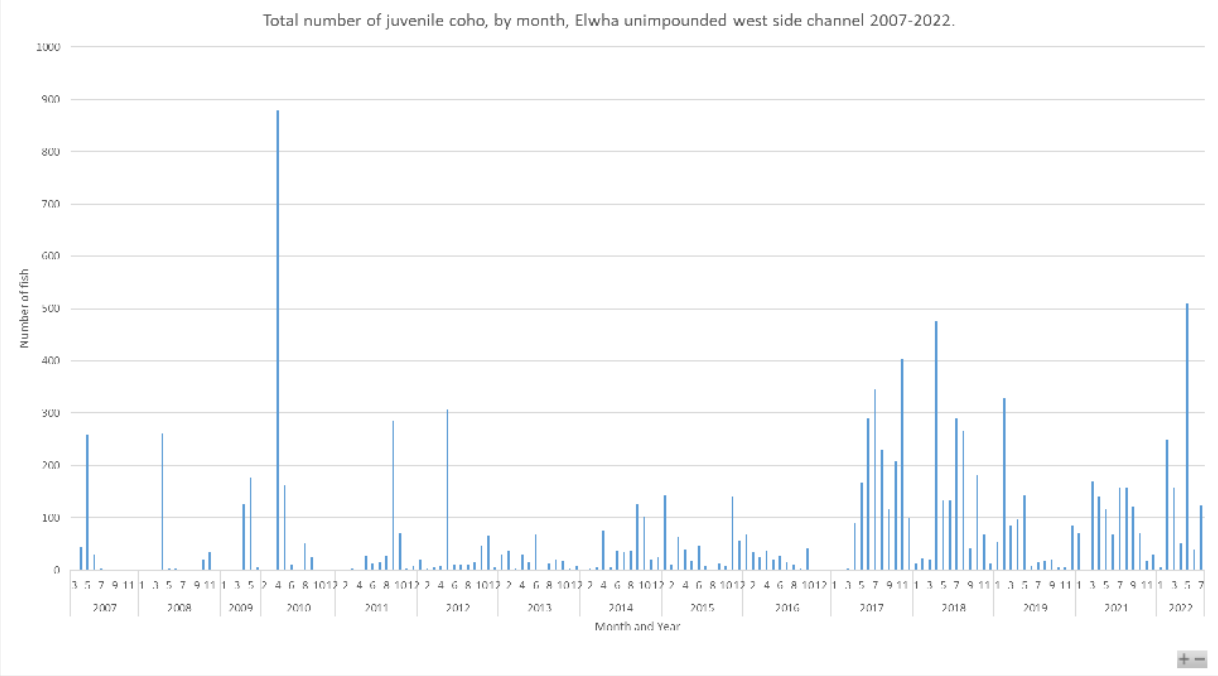


Figure 4. Typical images of juvenile and adult surf smelt, sand lance, and herring, Elwha nearshore 2019. (Shaffer 2019).Photos provided with permission of author.

Figure 5. Elwha east delta before and after shoreline armor removal

Figure 6. Results of long term monitoring of forage fish spawning of the Elwha drift cell. Surf smelt spawn range extension post dam removal and shoreline armor removal. Symbols indicate egg location by dam removal stage. Data from Shaffer and CWI.

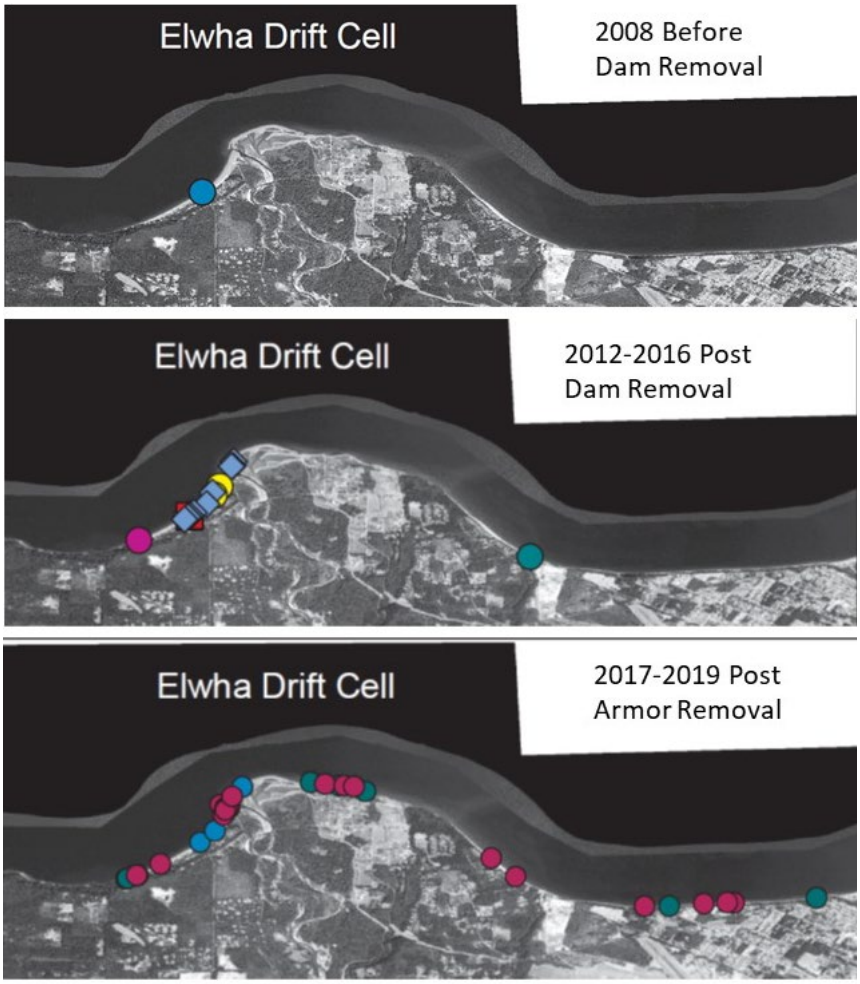
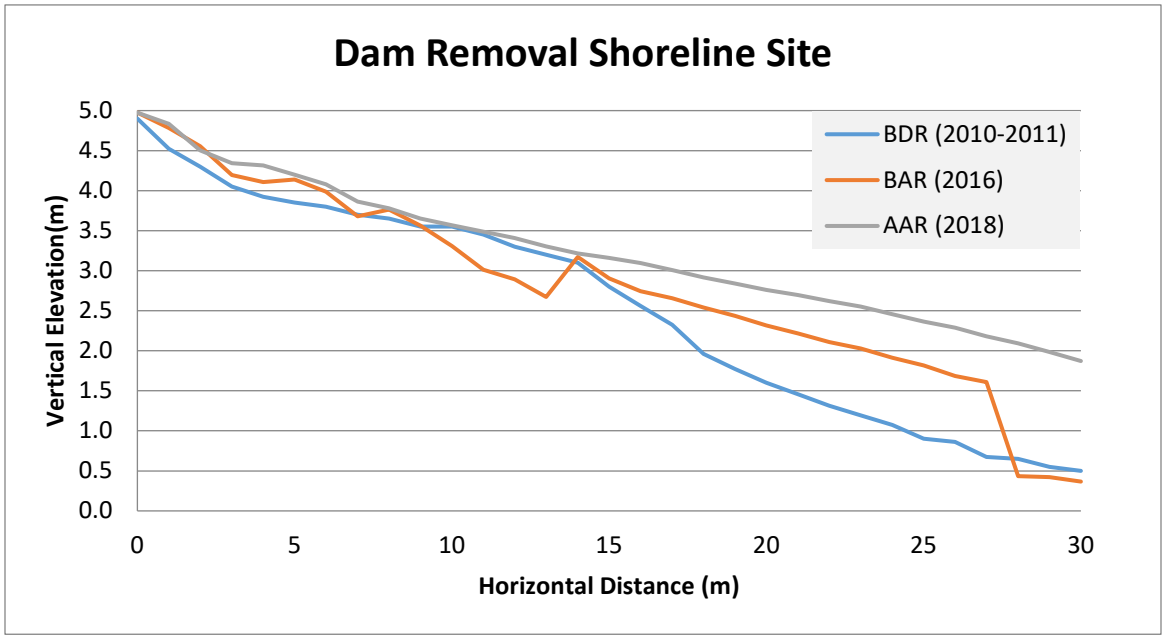
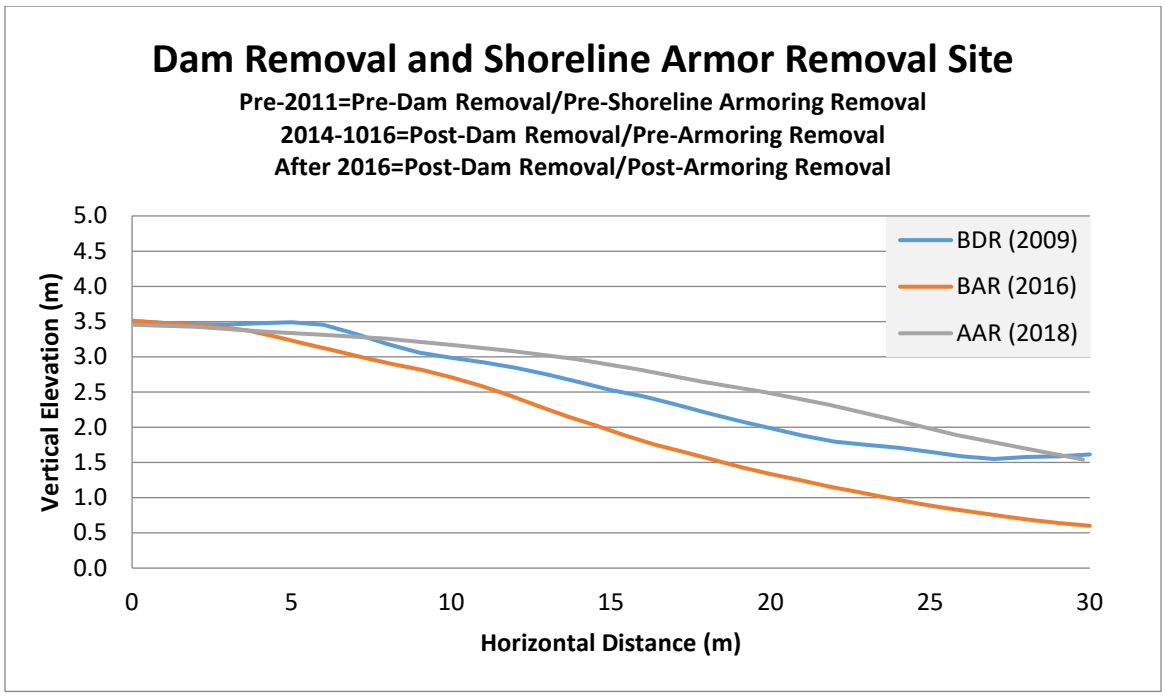
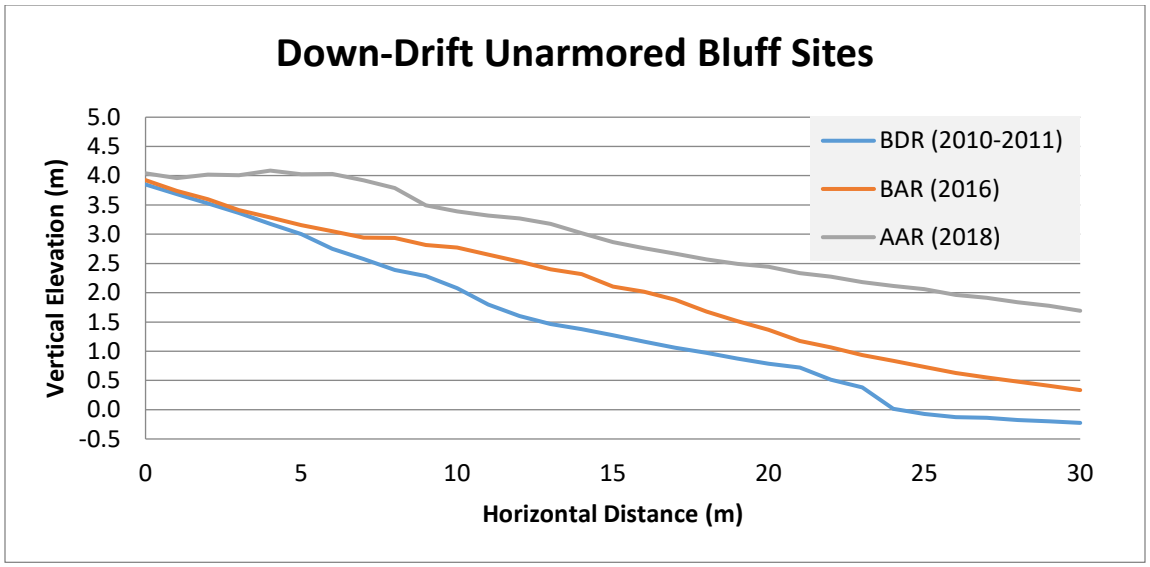

Elwha Drift Cell
2008 Before
Dam Removal
Elwha Drift Cell
2012-2016 Post
Dam Removal
Elwha Drift Cell
2017-2019 Post
Armor Removal

Figure 7. Beach profiles Elwha west, east, and down-drift unarmored bluff shorelines. BDR= pre 2011=pre-dam removal/pre-shoreline armoring removal; BAR=2016=post-dam removal/ pre-armoring removal; AAR=2018 =post-dam removal/post armoring removal.






Down-Drift Unarmored Bluff Sites
Vertical Elevation (m)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
0
5
10
15
20
25
30
Horizontal Distance (m)
BDR (2010-2011)
BAR (2016)
AAR (2018)