<u>A Dam Good Group</u>

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The Lower Elwha Klallam Tribe

The Elwha River holds the creation story of the Lower Elwha Klallam Tribe, and it is sacred to them. They were once the Klallam people, also known as "Clallam," a Coast Salish Indigenous group native to the northern Olympic Peninsula[5]. They are citizens of four recognized bands. Three are federally recognized tribes in the United States and one in Canada. Two Klallam tribes, the Jamestown S'Klallam, and the Lower Elwha Klallam live on the Olympic Peninsula, and one, the Port Scia'new First Nation is based at Becher Bay on the southern Vancouver Island in British Columbia[5].

Prior to European settlers, the Klallam people occupied most of the north coast of the Olympic Peninsula from the mouth of the Hoko River on the west to Port Discovery Bay[5]. Based on interviews with tribal elders there was estimated to be over thirty villages who inhabited this region and along the coast. The Klallam tribe held potlatches, which were gift giving feasts that played a large role in determining social status[5]. The separation into the different regions was influenced by historical events: European settlers and the establishment of different settlements. The first contact between the Europeans and the Klallam people was made in 1788, when an Englishman named Robert Duffin arrived on a longboat[7]. The Europeans carried smallpox, measles, influenza, and tuberculosis, which the indigenous people had no immunity to[7]. Entire villages withered in a massive social dislocation as waves of epidemics swept through. The passage of the Oregon Donation Land Act in 1850 further changed the lives of the Klallam tribe and many others for the worse[7]. The act authorized the distribution of free land to settlers in the regions that eventually became Oregon and Washington[7]. The federal government offered acreage to homesteaders without first acquiring ownership from the first occupants. The Lower Elwha Tribe historic territory was in the northeast of the Olympic Peninsula, approximately from the Hoko River to the Strait of Juan de Fuca. From ancient times, the Lower Elwha Klallam Tribe occupied several villages along the Elwha River, including on the bay sheltered by Ediz Hook, as of present-day Port Angeles[7]. In the 20th century, the federal government bought land outside Port Angeles and persuaded the tribe to relocate there 1935-1936 from their property in the city, to allow for industrial development along the waterfront[7]. Lumber and paper mills were built over tribal land. In 1968, the land at the mouth of the Elwha River was designated as the Lower Elwha Reservation[7]. As of today, the Lower Elwha Klallam tribe includes about a thousand acres of land on and near the Elwha River. Despite all the atrocities made, of losing thousands of acres of homeland, uprooting their people, and displacing them and the death of hundreds of their people due to disease brought by foreign settlers, the Lower Elwha Klallam Tribe history is marked by resilience, bravery, and determination.

In ancient times, the Klallam tribe had many villages along the Elwha River, and has lived in the lower Elwha River Valley and its neighboring buff since time immemorial. They were the first inhabitants of this land and a recent discovery from the local parks service has reported finding a location within the former reservoir of the Elwha Dam that documents human activity as far back as eight thousand years ago[10]. This establishes the Klallam Tribe presence as one of the oldest known archaeological sites on the Olympic Peninsula.

For the last few generations, the people of the Lower Klallam Elwha Tribe only knew of their creation site through stories told by their elders. Only in memory could they keep this knowledge alive and continue to pass this remarkable part of their culture onto their children. In historic times, the Lower Elwha Klallam tribe had claimed a rock along the Elwha River as their creation site, calling it a word in Klallam that means coiled basket, for its shape[10]. This was known as the place where the creator "bathed and blessed the Klallam people and other tribes," according to Jaimie Valadez, a Klallam language instructor. It was known as a place for vision quests. This site was submerged under a lake created by the construction of the Elwha Dam in 1913[11]. The creation site is a rock with two deep depressions that was covered by water behind the Elwha Dam. When the dismantling of the dams began the creation site slowly emerged. Archeologist, Tribal Chairwoman Frances Charles, informed the tribe in July 2012, that the sacred site had been uncovered[11]. Within days of the news of the legendary creation site, about a dozen, including children, walked to it. “A group of us walked to the site and actually stood on the rock known to us as the creation site,” said Charles. “It was eerie in some ways. We were walking on the soil that had been underwater for 100 years and witnessing the old cedars. It was emotional, with joy and happiness. We sang a prayer song and an honor song and had the opportunity to stand there and really praise our ancestors and the elders for telling the stories.”[11] For the tribe, the recovery of its cultural sites is a deeper dimension of the Elwha restoration, affirming the truth of the tribe’s presence here for so long.

Towards the early 19th century, the United States was growing in size and power. It was land hungry and ambitious, the United States was drastically changing its policies towards the Indian nations and nowhere is it more evident than in the treaties. The United States primary interest in treaty making was to acquire Indian land and dictated the terms of the treaty. Every means of fraud and trickery was employed against the Native Nations. Treaties are not “special rights,” for Indian Nations, they are native nations giving rights to the United States. Eventually, all these treaty making processes ended up with the acquisition of all Indian ancestral homeland. On January 26, 1855, at Hahdskus, or Point No Point, on the northern tip of the Kitsap Peninsula the Treaty of Point No Point was signed[8]. The treaty was signed by the Governor of Washington Territory Isaac Stevens and the S’Klallam, the Chimakum, and the Skokomish tribes. Under the terms of the treaty, the original inhabitants of northern Kitsap Peninsula and Olympic Peninsula were to cede ownership of vast amounts of land, approximately three quarters of a million acres, and resources in exchange for the right to hunt and fish in their historic lands and grounds[8]. In addition, the treaty terms promised a payment of $60,000 to the tribes payable over 20 years, however it was dispersed in small various amounts throughout the years[8]. The treaty ceded their access to the land in favor of the ownership of white settlers as the S'Klallam tribe were assigned to the Skokomish Reservation, over 100 miles away from their ancestral home in and around Hood Canal[9]. Many of the Lower Elwha Klallam people refused to relocate and struggled to remain at the mouth of the Elwha River and the shores of Port Angeles. The displacement of the tribe affected their ability to adapt and thrive as they had managed their own land, had traditional hunting and fishing practices, and had known the area well for maintaining their subsistence and cultural life.

The treaty of Point No Point was ultimately the most effective tool in removing the dams. When the ancestors of the Lower Elwha Klallam Tribe signed the treaty in 1855, ceding their homelands to incoming settlers in return for "the right to taking fish at usual and accustomed grounds," had ensured that their descendants would have harvestable fish[9]. The dams prevent this and the Lower Elwha Klallam Tribe had legal standing to bring down the dams. Finally, in 1992, Congress passed the Elwha River Ecosystem and Fisheries Restoration Act, authorizing dam removal to restore the altered ecosystem and the native anadromous fisheries therein[12]. After two decades, the largest dam removal in U.S. history began on September 17, 2011[12]. Six months later the Elwha Dam was gone and then in 2014, the Glines Canyon Dam was removed[12]. As of today, the Elwha River flows freely and the overall health of the river is returning to its former self.

Environmental Injustice

The Elwha River Dam removal, a complex and nuanced process, involves a wide range of stakeholders, including Tribal governments, environmental organizations, communities, farmers, and various governmental entities. It represents a pivotal chapter in addressing historical injustices and disruptions experienced by Native populations, specifically the Klallam Tribe. Political ecology, rooted in studies on the impacts of capitalism, provides a comprehensive framework for analyzing dam removal conflicts globally, with a focus on marginalized rural populations, particularly Indigenous and minority communities.

The Treaty of Point No Point in 1855 initially guaranteed fishing rights to tribes, including the Klallam, but the construction of the Elwha and Glines Canyon Dams in 1910 led to forced relocation and the loss of salmon. Despite a landmark court ruling in 1974 reaffirming their fishing rights, dam construction disrupted these rights, causing significant cultural and environmental impacts. The Tribe's longstanding opposition to the Elwha Dam and subsequent advocacy for its removal showcased their enduring struggle for environmental justice and tribal sovereignty. They played a pivotal role in challenging dam licensing processes, intervening in the Federal Energy Regulatory Commission (FERC) process in 1986, and advocating for dam removal during relicensing. Collaborations in the 1980s and a 1992 settlement agreement paved the way for the Elwha River Ecosystem and Fisheries Restoration Act, granting powers for full ecosystem restoration. The Final Programmatic EIS in 1995 identified dam removal as the preferred alternative, emphasizing salmon restoration and associated benefits. The 2011 dam removal process, executed with care to avoid stream damage, marked a historic event crucial for the Tribe's cultural practices and held potential implications for large-scale watershed and ecosystem restoration projects. The collaborative Elwha River Fish Restoration Plan outlined a scientific framework, achieving the restoration of the river's natural flow by 2012, commemorated by a salmon ceremony performed by the Tribe [14].

Dam removal operates at the intersection of restorative environmental justice and decolonizing practices, exploring the spiritual and cultural significance of rivers for Tribal communities while acknowledging the differences between Indigenous and Western ontologies. Beyond issues of resource control, environmental considerations for Tribes address vital aspects of Tribal health and well-being. It serves as a unique space, allowing Tribal leadership to spark new political discussions, shaping debates on the value, protection, and cohabitation with nature. This collaborative effort unites diverse actors and communities well beyond Tribal boundaries, underscoring how such joint endeavors can elevate Indigenous epistemologies, ultimately influencing broader societal understandings and coexistence with rivers [16].

Transitioning to Indigenous environmental justice, the research frames dam removal as a form of restorative environmental justice. The approach proposed is an "Indigenizing environmental justice," explicitly highlighting the restorative aspects of environmental justice in the context of dam removal as a decolonizing practice. In dam removals with Tribal participation, restoration efforts extend beyond environmental aspects to embrace a "political ontology" recognizing diverse worlds and ways of being in nature. This perspective encourages more relational and non-dualistic interactions with rivers, allowing Tribes to fulfill inherent stewardship responsibilities for their watersheds. The educational dimension of Tribal stewardship presents opportunities to inform non-Native citizens about historical continuities within Tribal relationships with rivers.

Fundamentally, dam removal is positioned as an act of restorative environmental justice, particularly evident when Tribes are involved, embodying a "geography of hope." Collaboration with Tribes in dam removal projects contributes to a deeper understanding of and respect for Indigenous water ontologies within non-Native communities. The sacred responsibility that Tribes feel for their rivers is a source of valuable lessons for repairing and restoring relationships with river ecosystems, challenging historical views of water as a resource for human exploitation in the United States. The political ecology approach emphasizes that dam removal projects, framed as environmental restoration, are inherently political and shaped by the dynamics of Tribal involvement. Studied cases indicate a shift in political situations with the increasing influence of Tribes, showcasing their growing political power and advanced influence in dam removal initiatives, portraying the Tribe's involvement as a form of Tribal restoration aiming to restore cultural tradition, sovereignty, and self-reliance. Political power in these cases is intertwined with legal rights associated with federal recognition, treaties, and the FERC's obligation to consult during relicensing processes, providing leverage points for Tribal mobilization [16].

Fig 1: Lower Elwha Klallam Tribe fishes river for the first time after dam removal [15]

The highlighted collaboration among diverse stakeholders, including tribal entities, researchers, and governmental bodies, is crucial for successful restoration actions, emphasizing the interconnectedness of past and present within Tribal environmental practices. This comprehensive effort not only demonstrates the effectiveness of collaborative initiatives but also underscores the advocacy and sovereignty of the Lower Elwha Klallam Tribe. Their unwavering commitment to their traditional understanding of and dependence on the land is evident throughout the dam removal process. The Tribe's robust coalition-building, strategic political strategy, and emphasis on natural resource management significantly contributed to the success of dam removal, providing an example of tribal empowerment. As restoration efforts persist, they highlight the Tribe's ongoing and vital role in shaping the Elwha River's course, ensuring the revival of both the ecosystem and the rich cultural heritage intertwined with the river.

Predicted Effects

The Elwha dam removal was the largest dam removal project at that time and there were many unknowns in regards to the impacts, both positive and negative, from such an undertaking. With the initial goal of full salmon restoration in mind it was clear that total removal of both the Elwha and Glines Canyon dams was the best possible chance to fulfill this commitment. However, the removal had the potential to cause numerous other benefits as the surrounding habitat is restored, sediments are allowed to return to the estuary, and an increase in economic gains from fishing and tourism. These proposed gains would come at the cost of the hydroelectric power generated by the dams and potential water quality issues.

Anadromous Restoration

Many fish species including all five Pacific salmon species return to the Elwha river from the ocean to spawn [17][14]. The introduction of the dams not only reduce the salmon's range but also prevent nutrients, sediments, and woody debris which is crucial to juvenile fish development from flowing downstream [17][14][18]. Moreover, the changes in river morphology had caused an increase in river temperature between 2 and 4 degrees celsius [17]. While this may not seem like a large difference, young salmon are particularly sensitive to temperature changes and are susceptible to disease with the Chinook salmon in particular seeing increased levels of incidence [17]. These factors led to the rapid decline of salmon and steelhead populations from an estimated 400,000 annually to fewer than 3,000 after the dams were constructed [18]. It had become evident that the anadromous fish populations in the Elwha river could not coexist with the dams and both the Chum and Pink salmon populations were at risk of extinction from the river without immediate action [17]. With restoring salmon populations in accordance with Lower Klallam tribe fishing rights being a driving factor for dam removal the National Park Service worked to predict population increase based on the Ricker curve-based recovery models.

	No Action**	Dam Retention	Glines Canyon Dam Removal	Elwha Dam Removal	Proposed Action
Chinook	1,500-2,000 fish+	16,060 fish 29 – 33 years	25,670 fish 29 – 33 years	20,020 fish 29 – 33 years	31,360 fish 21 – 25 years
Coho	<500 fish +	24,960 fish 29 – 33 years	31,190 fish 22 – 25 years	27,680 fish 26 – 29 years	34,570 fish 15 – 18 years
Chum	200 – 500 fish	0	0	Negligible	36,000 fish 18 – 21 years
Pink	0 – 50 fish	0	0	Negligible	274,286 fish 16 – 20 years
Steelhead	<500 fish	7,297 fish 29 – 32 years	9,017 fish 30 – 35 years	8,272 fish 30 – 35 years	10,100 fish 15 – 18 years
Sockeye	0	0	0	6,500 fish 12 – 20 years	6,500 fish 12 – 20 years

Fig. 2. Ricker curve modeling predictions of salmon recovery and response time [17].

Fig (2) summarizes the predicted population increase to peak production as well as recovery time. The paper looked into alternative solutions including the removal of one dam with the "Proposed Action" being total dam removal. It is important to note that the figure above did not take into account aid from fisheries and such action would likely increase the recovery rate [17]. The only option that was seen to have potential in recovery of all salmon species was total removal with most species reaching peak populations between 15 and 20 years after removal. All species except Sockeye salmon were determined to have an "excellent" chance of recovery. This is due to the fact that they require a freshwater lake to complete their life cycle and the only suitable one along the Elwha river was Lake

Sutherland which had been degraded due to development in the area [17]. Even with restoration of their river habitat, Sockeye salmon was determined to only have a "fair" chance of recovery [17].

In restoring salmon populations the greater ecosystem of the Elwha river will also likely see benefits. It was estimated that more than 22 species of wildlife fed on the fish and the seasonal patterns of the different salmon spawn would allow them to be an important year round food source [17] . Additionally, salmon carcusses are an important source of nitrogen, phosphorus, and organic matter into the river [17]. It was predicted that "800,000 pounds of fish biomass would return to the middle and upper Elwha River and, with it, 13,000 pounds of recycled nitrogen and phosphorus in the form of decaying carcasses," [17]. This influx of nutrient loading would enter the river increasing the biological productivity [17].

Habitat Restoration

Removal of the dams was thought to quickly restore river morphology to its natural meandering state and temperature [17]. Revegetation of the reservoirs had the potential to restore 715 acres of riparian and upland terrestrial habitat with predictions that natural succession would have an impact within three years [17]. Early successional forests would be able to take hold almost immediately but it will likely take hundreds of years for full restoration of mature foressets [17]. This could be particularly important to native elk populations greatly increasing their migratory range [17]. The increased habitat and food availability could also aid threatened and endangered species that live along the Elwha river such as bald eagle, marbled murrelet, and spotted owl [17].

The health of the natural estuary at the mouth of the Elwha river was thought to also see improvement from removing the dams. It was thought that before the dams were implemented 50,000 to 80,000 cubic yards of sediments were brought into the estuary yearly [17]. With the dams in place the sediment loading dropped to a mere 5,900 cubic yards annually [17]. This is thought to be a main contributor to the erosion of beaches and cliff sides with estimates attributing the loss of sediment deposition leading to a 55% decrease in stabilization of the surrounding marine cliffs [17]. By removing the dams it was theorized that the river delta would increase in length somewhere between 100 to 500 feet [17]. This would create shallower sandy areas known as barrier bars that are crucial to maintaining the salt water fresh water interface [17]. This could greatly impact the ecosystem transitioning from rocky species to ones that prefer brackish conditions and sand such as mussels and Dungeness crab [17].

Cost

Deconstructing both the Elwha and Glines canyon dam was always going to be an expensive project but it was predicted that the economic gains could outweigh the initial costs. In order to acquire the dams the federal government would have to pay $29.5 million with the estimated final cost of the project being between $75 and $101 million [17]. Many factors can impact the final price tag including mitigation strategies regarding release of the sediment buildup behind the dams. However, the increase in recreation and tourism was thought to create a benefit of $133 million over a 100 year period [17]. $3.5 million would come annually from fishing both in the river and due to increased shellfish in the estuary [17]. It was also thought that $1 million would be saved through less need for erosion control [17]. Additionally, the project would cause the loss of the hydroelectric potential of the dams an average of 18.7 MW annually [17]. At the time of the removal the Daishowa mill was the sole user of the power produced by the dams [17]. While this loss could be costly it was believed that the Bonneville Power Administration grid could easily accommodate the increased load [17].

Water Quality

During the lifetime of the dam's sediments including clay, silt, sand, gravel, and larger cobbles had accumulated behind the dams with predicted 21 million yards to be present by 2012 [19]. By removing the dams this sediment loading could be quickly flushed out, greatly increasing turbidity. It was thought that a majority of sediments would have washed out within 6 months of the dam removal but could have impacts for up to five years [17][19]. With initial turbidity levels expected to rise to over 10,000 ppm residents of the nearby city of Port Angeles had concerns regarding water quality [19].

Port Angeles holds 200 cubic feet per second of water rights on the Elwha with and 50 cubic feet per second coming from the Ranney well and 150 cubic feet from surface flow [17]. Many were worried that the existing infrastructure would not be able to accommodate the sediment influx and the capacity would decrease. It was determined in the Elwha River and Ecosystem Restoration Act that the water rights and quality of the city of Port Angeles had to be protected [17][20]. Initially, construction of the new Elwha Water treatment plant was deemed necessary and cost $24 million [20]. The treatment plant was designed to handle sediment loading of up to 40,000 ppm and would treat 10.6 million gallons of water daily for the city's use [17][20].

Fluvial Processes

The Elwha and Upper Glines Canyon Dams held back an estimated 30 million tons of sediment combined [21] with a majority of it being stored in Lake Mills behind the glines canyon dam [27]. Dams trap sediment by raising the local base level and slowing down flow. The river's velocity slows down when it reaches this new base level and suspended sediments start to settle out. Deltas often form when sediment settles out of suspension that contain large amounts of fine sediment like silts and clay. Normally silt and clay would be carried out of the fluvial system and deposited in the puget sound in the case of the Elwha, but the two dams put in place changed this dynamic. Things like woody debris which create pools and spawning habitat are also blocked behind these dams.

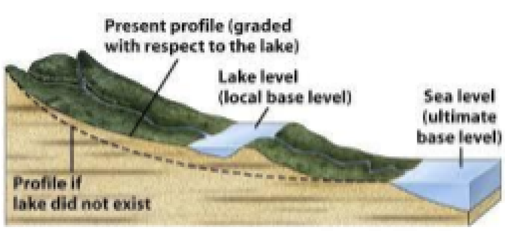

Figure 3. Lakes and dams can raise local base level and affect fluvial processes [34]

When dams are removed there is a sudden drastic lowering in the local base level. Erosion and sedimentation respond accordingly by eroding down to the new base level and building up at the point where the system reaches its new base level. A sudden drop in base level also often leads to increased water velocities and the formation of rapids. This increase in erosion can lead to many morphological changes in the river. Without the dams present to control the amount of flow, it was also predicted that high flows would increase in intensity.

Dam removals can have a wide range of outcomes. Morphological changes like increased meandering, increased scour, increased channel width, as well as deposition of sediment at the fluvial systems output, and as previously mentioned the formation of rapids [25]. As the river system goes through changes such as increased meandering and channel width, human infrastructure can be affected. Buildings or roads built along the river can be taken out by lateral erosion. Fish habitat like pools can also be filled in [25].

There was also worry about the ultimate fate of the sediment at the river delta. With the city of Port Angeles only around 5 miles away from the outlet of the Elwha, there was worry the local ecosystem would be heavily affected. Kelp and other autotrophs which rely on sunlight might be clouded out by the increased turbidity, and other effects were anticipated.

To avoid catastrophic results from removing the dam, physical and quantitative modeling was done. Physical models run in a lab showed how removal of the glines canyon dam would likely result in a large amount of uneroded unstable sediment if the flow of the channel was not carefully managed [28]. This large amount of unstable sediment could result in landslides and would be very dangerous. Quantitative modeling also showed that a third to half the sediment trapped behind the dams would be transported in the years following their removal.

Figure 4. Physical lab models showed potentially dangerous effects of lowering dams [28]

It was important that the removal of the dams was done incrementally and carefully. The water level of the dams was lowered before removal began and the dams were lowered and removed in increments of 15 feet [28]. After each 15 feet lowering, there was a break to let the river adjust to the new lowered base level. This system allowed for a gradual release of sediment. The flow was also carefully controlled to avoid leaving any unstable sediment as mentioned before.

As this was the largest dam removal project ever at the time, many studies were done on the sediment transport and other processes. It was shown that after 5 years almost two thirds of the trapped sediment was released [25]. This was much higher than predicted and in a relatively short period of time. The sediment left beyond where the reservoirs used to be consists of much finer sediment than would normally be found at that part of the river. The amount of clay here is very high and the 15 foot increments that the dam was lowered in can be visibly seen. Most of the sediment was eventually transported out of the system and deposited in the Elwha River Delta or into the sound. Only around 10% was deposited within the river system [25]. As a result of the increased sediment load, turbidity in the river rose by three orders of magnitude in some places [21].

Figure 5. Picture taken from previous site of lake Aldwell. The red lines show layers of sediment. Jeron for scale.

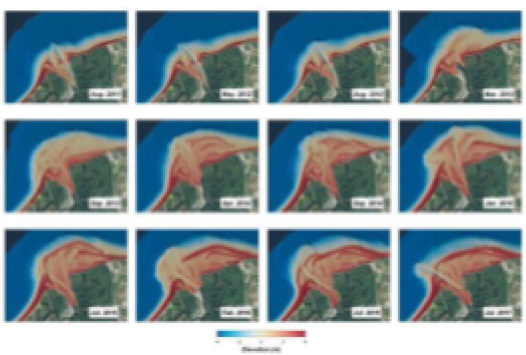

Figure 6. Increase in delta area over time from sediment deposition [24]

The vast majority of the sediment was deposited at the delta though. The delta grew by 60 hectares [25]. As discussed there was worry about the effects this increase in sediment would have on the ecosystem. With a sudden increase in turbidity there was a brief reduction in kelp and other algae, but these populations recovered very quickly once the system returned to its new equilibrium [21]. Many different locations were monitored during the sediment deposition at the delta. In some areas the communities and species present at certain sites changed and never returned to their original state [21]. This was largely due to sediment deposition which changed the characteristics of the environment.

Another change that occurred after the dam removal was the amount of woody debris in the system. Log jams caused by woody debris play an important role in sediment transport. They can stop sediment and cause it to be deposited and create large pools which serve as important fish habitat [35]. Many engineered log jams have been put in along the Elwha and other river systems to help create habitat. Root wad revetments are also an important and popular tool to prevent lateral channel erosion from

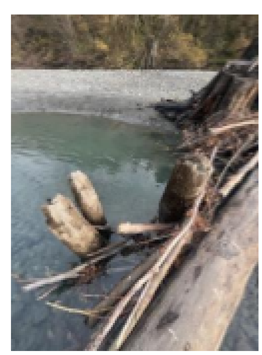

Figure 7. Picture showing log jam (potentially an engineered log jam) in previous site of lake Aldwell

washing away roads and houses while also creating more habitat. In one study, 208 pieces of woody debris trapped behind the dams were tagged and monitored. 68 of these pieces were seen to have been transported down the system. A large amount of the debris ended up being deposited in the previous lake aldwell which was held back by the lower Elwha dam. Log jams developed unexpectedly rapidly here. Overall log jam area also increased in the main channel as well [35].

Human infrastructure was also affected by the dam removal. The Olympic Hot Spring road has been washed out multiple times since the dams were removed [30][31]. One historic back channel that the river used to flow through also had flow return after the dams were removed [25]. Some of the road repairs on the Olympic Hot Spring road utilized rootwad revetments to stop the river from continuing to erode it away [30].

Figure 8. Aerial view of previous and new Elwha River Bridge [29]

The Elwha River Bridge has also had to be replaced and the project is currently under construction. The foundation for the bridge were originally thought to have gone down to bedrock. When the dams were removed and erosion increased, this was shown not to be the case. The river eroded down and showed the foundation was actually placed in a bed of gravel. Rip rap was placed as a temporary measure to prevent further erosion, but a full bridge replacement project is currently in the works [29].

Comparison of the Hoh & the Elwha: Undammed versus Dammed Ecological Systems

Comparing the Functions of the Two River Systems

Comparison of the Hoh and Elwha Rivers presents an opportunity for comprehensive ecological analysis and conservation insights into *one*, the dynamics of Pacific Northwest rivers and *two*, the health, progress, and functions of the Elwha River as seen today. Both river ecosystems share geographic proximity in the Olympic National Park, contributing to their parallel climatic, ecological, hydrological, and geomorphic features and characteristics. In addition, the Hoh and the Elwha serve as diverse aquatic and riparian habitats, supporting various vital cultural and ecological species– namely the Chinook, Coho, and Steelhead salmon populations.

Conducting an analysis between the progress of an interrupted system (the Elwha) with that of an uninterrupted one (the Hoh), provides an opportunity for a broader understanding of river ecosystems and watershed dynamics as a whole. The comparison factors investigated in this section will include annual peak streamflow as a lens for influences on successful ecological transitions, temperature, and climate change resiliency.

Annual Peak Streamflow

Streamflow is one of the largest barometers and contributors when examining the overall health of a river– particularly flow factors like peak magnitude, duration, frequency, and timing. These are fundamental indicators of the functions (and the levels of functioning) that a river performs. Instead of simply seeing the typical dampened levels of *average* streamflow as a result of dams, this study examines purely the *annual* peaks and highlights the manipulation of that annual peak streamflow in order to generate hydropower. With the Elwha lying adjacent to the Hurricane Ridge fault line, an important consideration to its annual peak flow and timing is the peak snowmelt & precipitation received from the mountain range. These environmental factors drive the *natural* annual peak streamflow and thus, the production of the river's support of fisheries and riparian habitats, maintenance of dissolved oxygen levels in the river, and ability to flush accumulated sediment and algae from the ecological system. Furthermore, the annual peak flow maintains the shape of river channels, facilitates forest reproduction, and sustains groundwater connections that moderate stream temperatures.

Figure 9 depicts the Annual Peak Streamflow of the Elwha from 1898-2022 , highlighting the construction and demolition of the Elwha Dam in the respective timeline. The graphed data was sourced from the USGS water data inventory (noting the missing data period from 1902-1920), at the

McDonald Bridge Gauging Station [48.05481143, -123.58324625], and demonstrates the manipulated annual peak streamflow patterns as a result of the Hydroelectric dam.

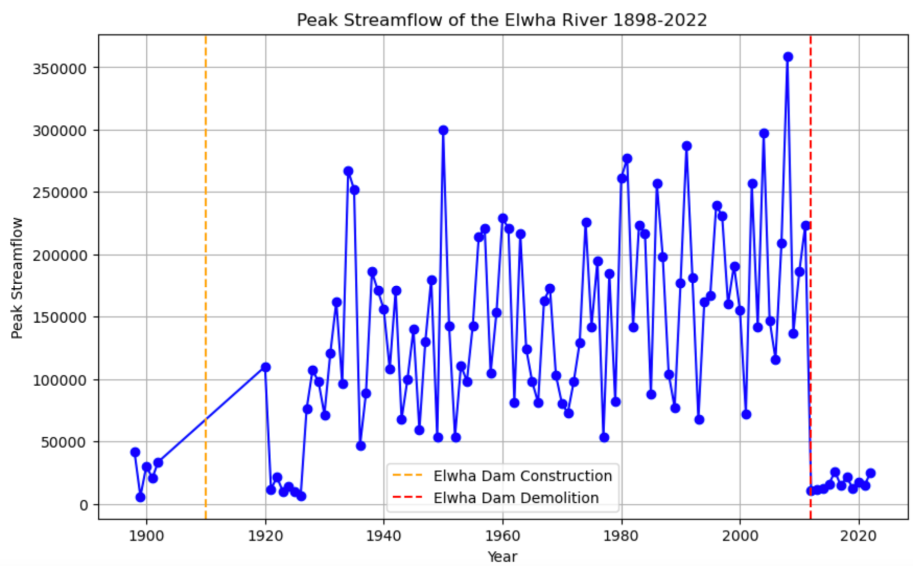

Figure 9: Data source: USGS Annual Peak Streamflow of Elwha River (1898-2022)

In 1914, the Aldwell Olympic Power company facilitated the Elwha power plant as the first hydroelectric facility on the Olympic Peninsula in order to supply the region's residential, commercial and industrial users. As the paper and pulp industry rapidly expanded in the area post-World War I, the region built the Glines Canyon Dam in 1927 [38]. This infrastructure development is responsible for the dramatic, *unnatural* annual peak streamflow increase around the 1930s, as such, the spikes which occurred during the dam years are a direct result of manipulated annual peak flow to generate hydropower.

The Elwha Hydroelectric impoundment dams, dams that require large amounts of stored water, regulated the flow of the river via controlled release of– what ends up being thermally modulated– water for power generation [40]. The altered velocity and stream flow impacted temperatures, decreased vital dissolved oxygen levels, accelerated erosion and geomorphic river changes (as mentioned in the sediment analysis), allowed for toxic algal blooms in reservoirs, destroyed habitat, flooded historic homelands and cultural sites of the Lower Elwha Klallam Tribe, and severely affected salmonid growth and presence in the Elwha [47] .

Examining the transition period of removing the dams, the return to pre-dam annual peak flow patterns, and the climate implications surrounding increases in annual peak flows between the Hoh River and the Elwha uncovers the ecological implications of anthropologically interrupted or uninterrupted river ecosystems.

Ecological Transitions and Temperature

Figures 10 and 11 below include a close up on the USGS hydrological data surrounding annual peak flow measurements between the Hoh and the Elwha. It's important to note that with the complete demolition of the dams by 2014, as seen in Figure 10 and 11, the resulting patterns demonstrate the orderly return and then slow recovery to pre-dam peak annual streamflow levels as seen today.

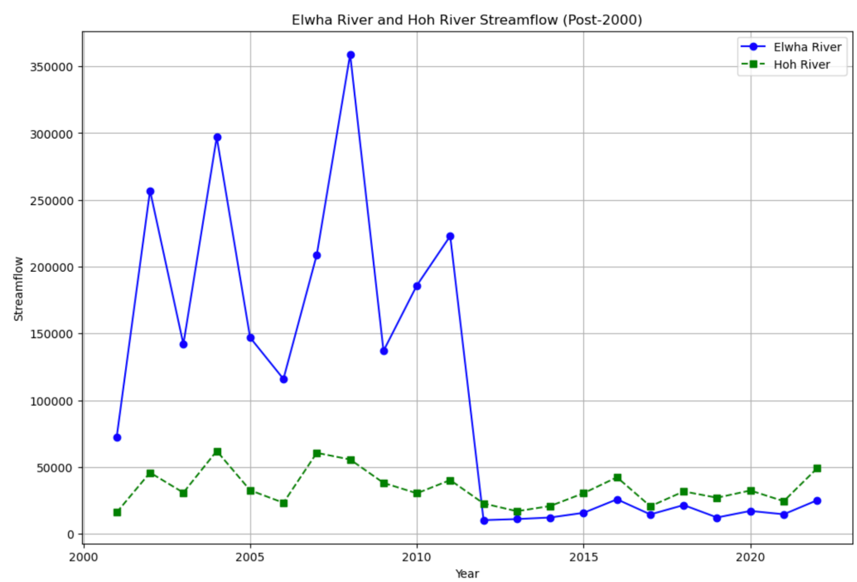

Figure 10: Data source: USGS Annual Peak Streamflow of Elwha River (Transitioning Years).

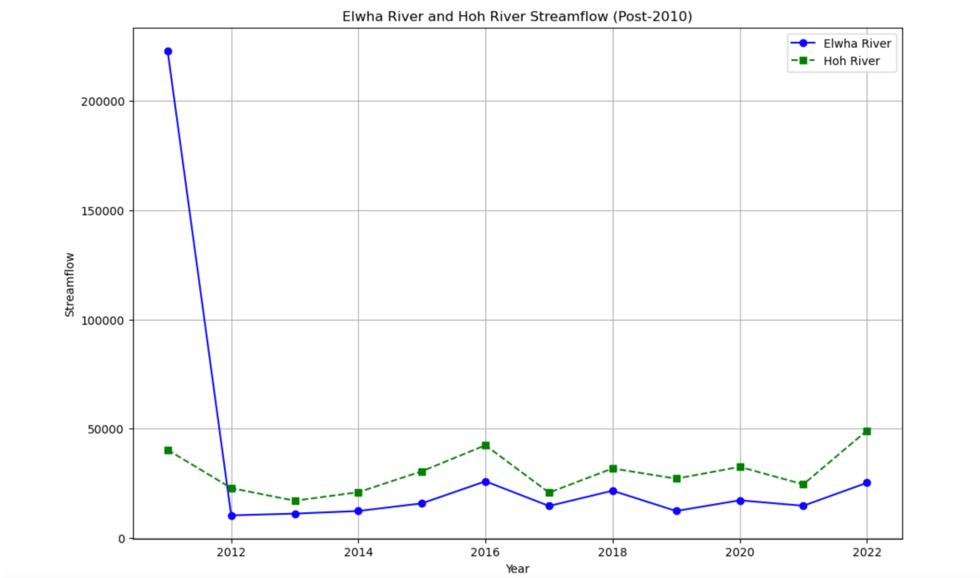

Figure 11: Data source: USGS Annual Peak Streamflow of Elwha River (Post-Dam Removal Years).

The above figures illustrate the return to natural seasonal streamflow patterns as a result of *natural* precipitation, snowpack & snowmelt, and other climatic factors– which are shared between the Hoh and the Elwha. Seeing such similarities validates the successful execution of ecological intervention in removing the dams. Similar returns were seen in the river temperature.

It is imperative to understand the full impact the Elwha dams had on the temperature and therefore, salmonid growth, presence, and resilience, in order to comprehend the significance of the temperature returns.. Hydroelectric dams control water temperatures downriver via fluctuating discharge for hydropower generation , resulting in uniform temperatures for the 5 miles of river that were accessible to spawning salmon at the time [45]. Stream temperature variations affect the incubation period and, consequently, the emergence time of Salmon. So, river temperatures play a pivotal role in the development of Elwha salmon populations. In the case of the Elwha, uniform stream temperatures previously constricted the emergence time and growth trajectories of salmon, limiting the distribution and variation of juvenile salmonids. However, the removal of the two dams increased the diversity of stream temperatures available to salmon, resulting in increased variability in predicted emergence timing and growth trajectories [Figure 12].

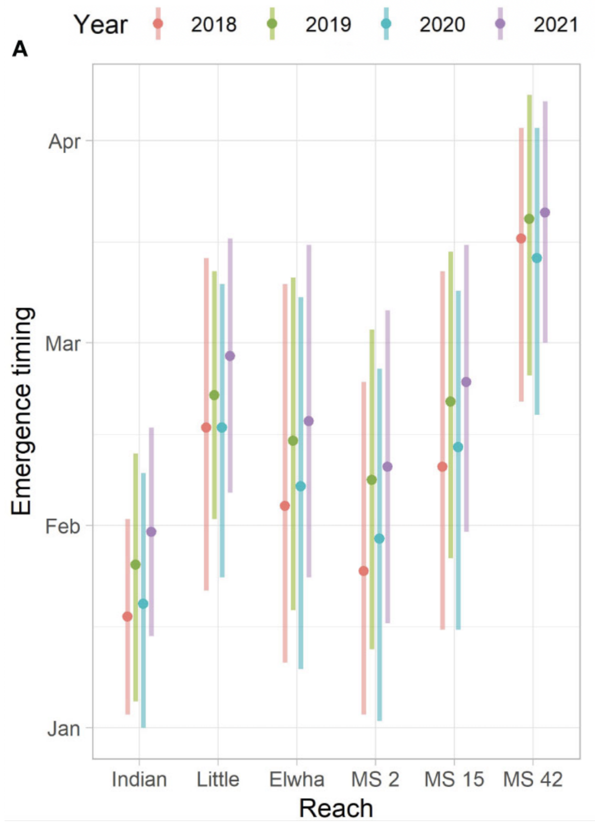

Figure 12: Predicted Emergence times for Elwha tributaries, Indian Creek (Indian) and Little River (Little), and mainstream. MS 2, MS 15, and MS 42 indicate mainstem reaches at rkm 2, rkm 15, and rkm 42 respectively [43].

This diversity of emergence times and growth trajectories increases the chances of suitability to year-specific conditions in juveniles, resulting in higher population resiliency when compared to the pre-dam conditions [46], [47]. Noting the return in these aspects of ecological health and river functioning is important because it raises the question: “did everything in the interrupted system return to pre-dam levels?”

Climate Change Resiliency and Seasonal Annual Peak Flow

The Elwha hydroelectric dams also altered the *timing* of natural annual peak flows. The dams withheld and released water to generate power for demand periods– the more electricity required, the more peak flow manipulation. The irregular releases destroyed *natural* seasonal annual peak flow variations that are imperative for triggering natural growth and reproduction cycles in many species, especially salmon [48].

The Hoh and Elwha Rivers in the Pacific Northwest face multiple climate impacts that could compromise their climate resilience. Rising temperatures (both for rivers and overall), shifts in precipitation patterns, snowmelt & snowpack, and glacier retreat are altering the rivers' hydrological cycles and impacting aquatic ecosystems [51]. In fact, the Lower Elwha Reservation is facing an average annual precipitation that is projected to increase by 2.3 inches or about 9% by the end of this century [41]. Meanwhile, rising stream temperatures lower the metabolic rates of aquatic organisms and contribute to dead zones. Sea level rise also poses an additional threat, particularly as these rivers are located close to the Pacific and the Straits of Juan de Fuca. Relative sea level in Port Angeles occurs at a rate of about 0.016 inches, an equivalency of 4 centimeters if extrapolated over the past century [42]. Finally, extreme weather events, including storms and floods, can lead to infrastructure damage and disrupt river habitats. Climate-induced changes in vegetation and habitats, as well as alterations in water quality, further challenge the rivers' biodiversity.

Each of these climate considerations contribute to increasing seasonal extremes. In the context of streamflow, these discrepancies are happening exactly when streamflow is needed most and when water temperatures are at their highest [52]. An investigation by the Northwest Treaty Tribes demonstrated the lower annual low streamflows and higher annual peak streamflows as a result of climate impacts on the Hoh river [figure 13], showing the increasing seasonal extremes; however, this timeline is unsuitable for a juxtaposition with the Elwha, as it would include the manipulated annual peak streamflow.

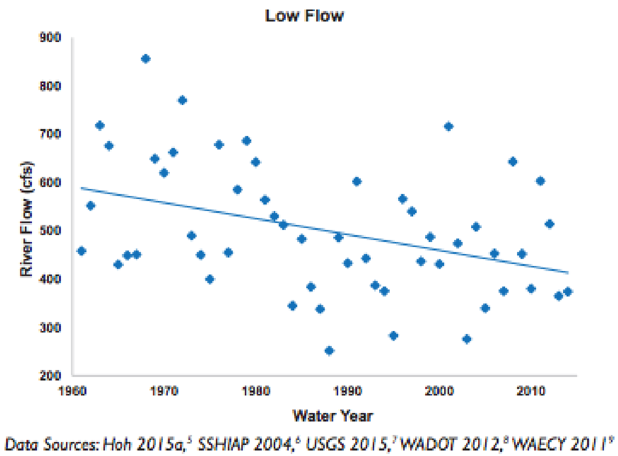

Figure 13: Annual Low Streamflow of Hoh River (left) & Annual Peak Streamflow of Hoh River (right)[1961-2016] [50] .

Regardless, the Elwha demonstrated similar trends in annual extremes. From 1950-2006, summer streamflow declined by 25%, spring streamflow by 17%, and winter streamflow increased by 6% [44]. In an effort to determine the rates of impact that the anthropomorphic interruption (both with the addition and removal of the dams) had on the Elwha's river functioning, health, and climate resiliency, the graphs below [Figure 14] contextualize the transition of comparing the annual peak flows for the Elwha and the Hoh.

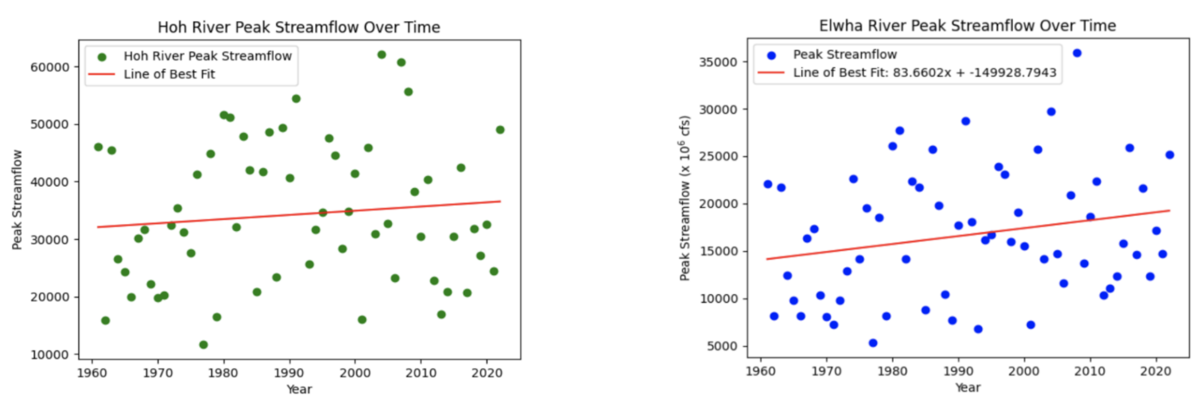

Figure 14: Data source: USGS Annual Peak Streamflow of Hoh River (left) & Elwha River (right)[1961-2022].

In both cases, the annual increase corresponds to the slope of the line of best fit. These values provide an indication of how much the annual peak streamflow would be increasing annually for each river (if we were to ignore the dramatic variations caused by the dam years) based on the lines of best fit. Using this timeline, as mentioned before, includes the manipulated annual peak streamflow and falsely suggests the yearly increase of the Elwha's annual peak streamflow occurs approximately 34.05 times faster than the Hoh.

$$Ratio = \frac{Slope\ of\ Elwha\ Peak\ Flow\ Line\ of\ Best\ Fit}{Slope\ of\ Hoh\ Peak\ Flow\ Line\ of\ Best\ Fit} = \frac{203.61\ cfs}{5.98\ cfs} = 34.048$$

While this is not an accurate indication of current river functioning in response to climate change, it is revealing of the river's climate response as a result of the damming years. Instead, for the purposes of this study, running an analysis on the two rivers' annual peak streamflow in the years following the dam removal (2012-2022) [figure 15] would focus on the *naturally* occurring annual peak flows and answer the question: "did the dam years accelerate climate change in the Elwha or has it maintained the same resiliency as the Hoh?"

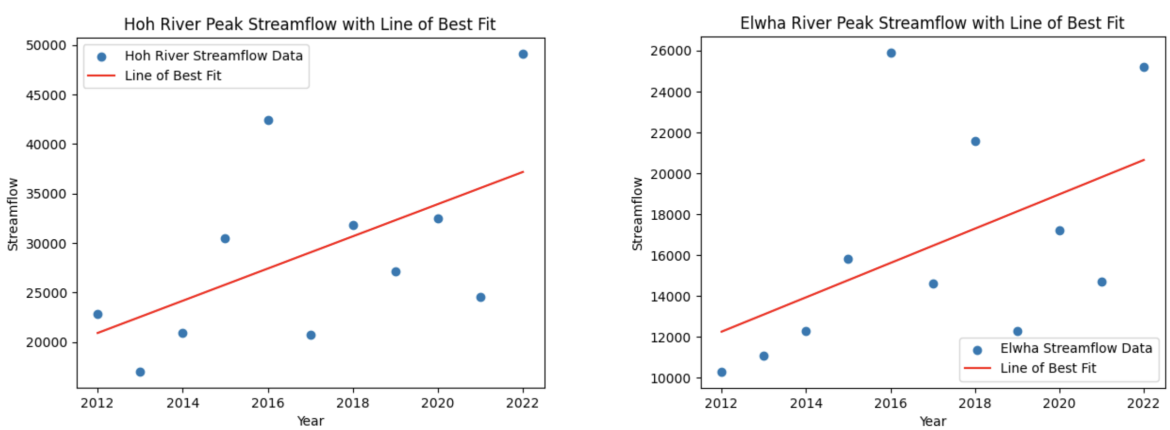

Figure 15: Data source: USGS Annual Peak Streamflow of Hoh River (left) & Elwha River (right)[2012-2022].

Normalizing the streamflow data allowed for an easier visual comparison and statistical analysis of the rates of increase between the Hoh and the Elwha [Figure 16].

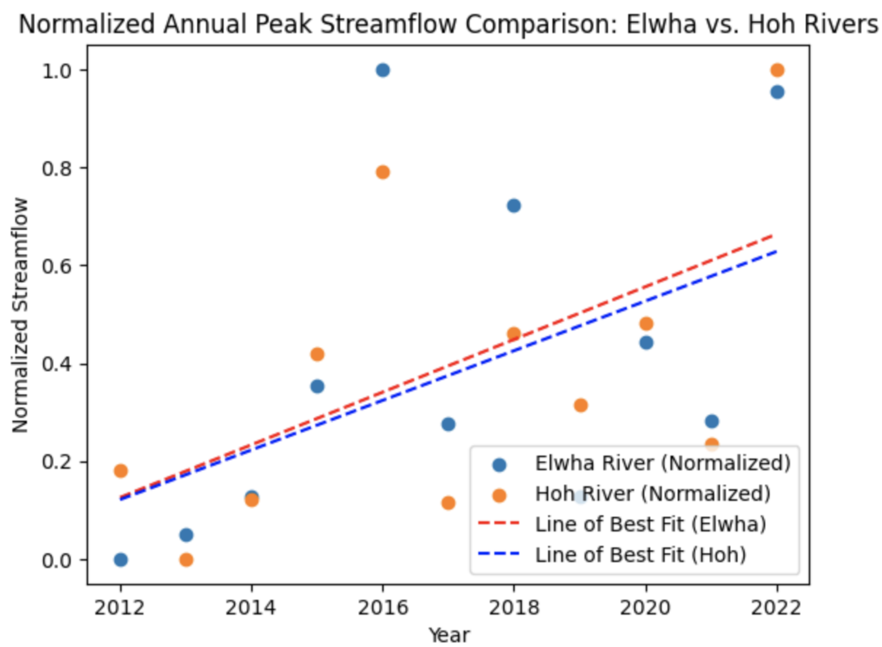

Figure 16: Data source: USGS Normalized Annual Peak Streamflow of Hoh & Elwha River [2012-2022].

Considering the data is not normally distributed, non-parametric tests like the Mann-Whitney U statistical analysis would be a better determinant for telling if the slope differences were statistically significant. Streamflow measurements may exhibit skewness, heavy tails, or other non-normal characteristics [39]. As a result, when analyzing this streamflow data, it's important to use non-parametric statistical methods, which do not rely on assumptions of a specific distribution.

The results of the Mann-Whitney U statistic were 1.0, and a P-value of 1.0, revealing the difference in slopes were not statistically significant. Meaning: while the dam years may have resulted in 'accelerated climate change' in the Elwha, the removal of the dams have allowed the river ecosystem to maintain the same climate resiliency as the Hoh.

What does this mean for future dam removal projects?

Further investigation into the streamflow data revealed that this ecological intervention successfully restored the functioning, health, and climate resiliency of an anthropologically interrupted river ecosystem to that of an uninterrupted one. These findings underscore the importance and impact of the Elwha Dam removal project's incorporation of environmental considerations into dam planning and implementation, emphasizing the need for ecosystem restoration measures alongside traditional project goals. As a result, the removal of the Elwha and Glines Canyon Dams has influenced the evolution of regulatory frameworks, with an emphasis on stricter environmental standards for responsible dam development– spurring technological innovations in dam design and construction to minimize ecological impact, fostering a global awareness of the environmental implications of dam projects, and encouraging collaboration for more sustainable practices worldwide.

Results Summary

Water Quality

While the city of Port Angeles was able to maintain clean water intake through supplementing with the Raney well there were many issues with the newly built Elwha Water treatment plant [53] [54][55]. The sediment loading caused clogging leading to a delay in the project in October of 2012 [53] [54]. The original design was built around filtering out mostly fine sediment but gravel and sand was able to get through the intake system and into the plant [53]. After the dam removal project was completed the government planned to turn over the treatment plant to the city of Port Angeles in 2018 [56] [57] [58]. The city feared the cost of maintaining and running the treatment plants would increase water costs from $60,000 to $600,000 [56] [57]. The city sued the government stating "The city will be financially crippled if it has to assume ownership and operation of the water treatment facilities in their current condition... Those costs are more than 10 times what the city currently pays and would necessarily be passed onto the city's citizens in the form of rate increases," [56]. The city was able to come to a settlement in which they took ownership of the water systems with a $6.5 million stipend from the government for maintenance as well as an additional $2.5 million in 2023 [57][58].

Cost

The removal process for the Elwha Dam ended up costing $325 million some of which was due to the water treatment facility issues and delays [58]. Of the $325 million, $32.9 million went to construction costs and roughly $150.2 million, or 46.2% of the final cost, went to mitigating water quality effects and building the treatment facilities [59]. As predicted the loss of the hydroelectric facilities had little impact as the 18.7 MW produced is much smaller than the 12,000 MW used in the Bonneville Administrative Grid and the Disawoa mill was able to connect into it [17][60].

Environmental Impact

Revegetation efforts along the previous reservoirs have proven highly successful [61]. Locations with finer sediments have seen increase in many native plants including Douglas fir, red alder, black cottonwood, western red cedar and Sitka willow while coarser sediment areas have seen growth of Oregon sunshine and riverbank lupine [61]. This has greatly increased the natural habitat and is working to prevent erosion and increase soil quality in the reservoirs [61]. The release of sediment has led to a 400 meter increase in the river mouth delta [61]. As seen in Figure 17.

Fig. 17. Changes in Elwha Mouth from 2011 to 2014 [60].

Anadromous fish populations have also seen an increase in both population and range since the dam removal. Thus far the Chinook salmon are showing the most success with steelhead trout also recovering well with population increase between 2 to 4 times initial level [18]. However, Pink and Chum salmon populations are still quite low [61]. Many species are now seen above the Gline canyon dam, some increasing their previous range by 60 km [18]. Fig. 18. Provides a timeline of fish sightings relative to the dam removal showcasing this increase in range [18]. While there is still a long way to go before full restoration is achieved it is evident that the removal quickly allowed for the migratory fish populations to begin recovery.

Fig. 18. Timeline of migratory fish range expansion [18].

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