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Research Article

Coastal beaver, Chinook, coho, chum salmon and trout response to nearshore changes resulting from diking and large-scale dam removals: synergistic ecosystem engineering and restoration in the coastal zone

J. Anne Shaffer[1,2], Dave Parks[1], Katrina Campbell[1], Anna Moragne[1], Bligh Hueske[1,2], Pamela Adams[1], Jenise M. Bauman[2]

1 *Coastal Watershed Institute (CWI) PO Box 266, Washington 98362, Port Angeles, USA*
2 *Western Washington University, College of the Environment, 516 High St, WA 98225, Bellingham, USA*
Corresponding author: J. Anne Shaffer (anne.shaffer@coastalwatershedinstitute.org)

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Abstract

In this paper we assess long-term trends and habitat changes to understand the relationships between coastal beaver (*Castor canadensis*), salmon, shoreline alterations, large-scale dam removals and nearshore ecological restoration. From this work we conclude that the removal of two large scale dams in the Elwha River has benefited beaver use of the coastal zone through water quality changes that allow beaver to re-establish high-quality zones and the expansion of riparian zones that provide extensive new food resources to beaver. However, the lower river hydrodynamic processes continue to be disrupted by a 200-meter earthen dike installed by local government and landowners for flood protection in the Elwha coastal zone in the 1960's. The dike acts as a driver of lower river geomorphology and has resulted in the formation of a large and persistent lateral bar along the lower river channel. Associated disrupted hydrodynamics are causing a critical coastal zone of the unimpounded lower river side channels to fill in. This channel habitat has decreased by 23%, with an annual average shrinkage rate of 13%, from pre-dam removal size, resulting in a decrease in both quality and quantity of nursery function for juvenile wild fish in a coastal zone that was historically documented to be the highest functioning for endangered juvenile salmon and trout. Inversely, physical changes including improved water quality in the adjacent impounded west side channel and continued expansion of riparian vegetation along the west delta lateral bar benefitted coastal beaver that recolonized the west delta after dam removals. The newly colonized coastal beaver may provide ecological engineering services to offset side channel loss as well as promote continued fish access. However recreational use was found to negatively impact beaver use of the area. We therefore recommend a series of additional ecosystem restoration actions that incorporate beaver as an ecosystem restoration component of the coastal zone. These actions include a public outreach program to encourage passive recreation measures to prevent negative impacts to beaver, and legacy, ecosystem scale restoration projects that reconnect the hydrodynamics of the west delta to complete Elwha ecosystem restoration. Together, these steps, if implemented, will result in a synergistic ecosystem restoration throughout the watershed to the benefit of the coastal ecosystem, including both beaver and salmon, as intended by the large-scale dam removal project.

Key words: hydrodynamics, marine ecology, shoreline impediments

Introduction

Beavers are documented to be ecosystem engineers that are important for the restoration of watershed functions and provide invaluable ecosystem services including fish and wildlife habitat, flood mediation, water quality improvements, and fire management (Brazier et al. 2021). The role of beaver (*Castor canadensis*) in nearshore ecosystem conservation and restoration is an emerging topic. Hood (2012) and Hood and Larson (2014) documented that estuaries with beaver dams produced significantly more juvenile Chinook (*Oncorhynchus tshawytscha*) and coho (*Oncorhynchus kisutch*) salmon than coastal regions without beaver dams. Concomitantly, the removal of human-built large-scale in river dams is emerging as an important restoration action to restore watershed ecosystem functions, and juvenile fish use as an important and useful metric for understanding these ecosystem functions (Shaffer et al. 2009, 2017a). However, the relationships between coastal ecosystem restoration responses to large-scale dam removals and beaver, including in the nearshore, have not been defined.

Located in Washington State, USA, the Elwha River is the site of the largest dam removal restoration to date (Magirl et al. 2015). The Elwha River is 72 km long and falls 1372 m in elevation as it flows from the glaciated Olympic Mountains north to discharge into the Strait of Juan de Fuca. The majority of the river and watershed is located within the federally protected Olympic National Park, however the lower linear 12 km of river and coastal shoreline are not protected federally and instead have a myriad of private, Tribal, and public ownership (Fig. 1). The use of the delta coastline is primarily residential and recreational. The Elwha ecosystem, including beaver and salmon, was catastrophically impacted by the installation of two large-scale dams at the turn of the century (Winter and Crain 2008). Removal of the two large scale dams began in 2011 and ended in 2014. Dam removal resulted in extensive riverbed changes including evolution of braiding and bars in the lower river (Draut and Ritchie 2015). These include lateral bars, defined by Riverstyle (2022) as "a bank-attached unit bar that develops along low-sinuosity reaches of gravel- and mixed-bed channels with a bar surface that is generally inclined gently towards the channel". The riverbed along the delta raised by over a meter and the river mouth extended upwards of 300 meters offshore (Ritchie et al. 2018).

Post-dam removal restoration goals were framed around restoring wildlife populations which included understanding baseline distribution and abundance of terrestrial fauna and describing the role of anadromous salmon on trophic riverine structures. Knapp (2009) surveyed beaver of the entire Elwha watershed and found numerous cuttings, but only one beaver dam and two bank lodges that were located along the lower reach of the eastern shore of the entire 72 km long watershed. After the two dams were removed McCaffery et al. (2018) documented beaver activity on both reservoir beds and developed a framework predicting wildlife response, including beaver, and their functional roles within large-scale restoration. However, a decade after dam removal, beaver response in the Elwha nearshore is largely undefined.

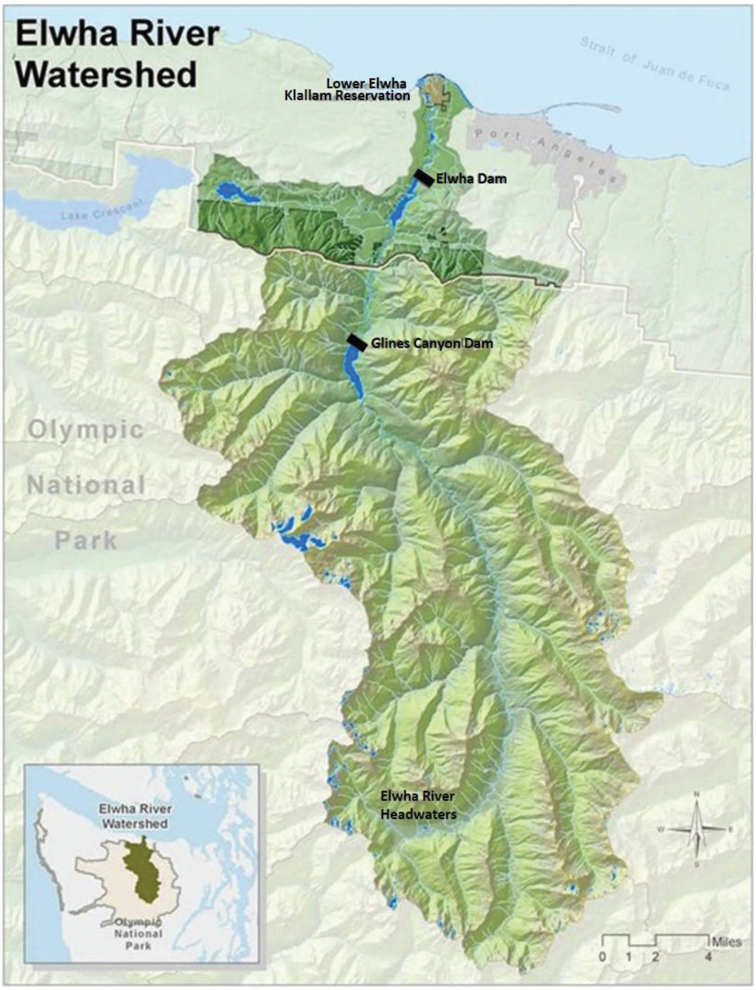

Figure 1. Elwha watershed in Washington State. The headwaters of the Elwha River reside 72 km within the Olympic Mountains where it flows south to north into the Strait of Juan de Fuca. Image maps the placement of two former dams, the formerly 32 m high Elwha dam located 8 km and the formerly 64 m high Glines Canyon dam located 22 km from the river mouth. Base map provided by Olympic National Park.

The nearshore of the Elwha is a critical component of the Elwha watershed. The Elwha delta consists of three zones: the east and west delta (which are separated by the Elwha River), and within the west delta, two zones, termed the impounded zone (also termed 'impounded Place Pond'), due to a 200-meter-long earthen dike, and the un-impounded west delta zone (Fig. 2). Shaffer et al. (2009) documented that proportionally, the Elwha west delta and side channels supported the majority of juvenile fish, more than 90% of all juvenile salmon across the entire Elwha delta. The west delta was therefore identified as one of the most important fish habitats in the Elwha delta nearshore, and thus is one of the highest priorities for additional monitoring and restoration actions in the Elwha watershed (Shaffer et al. 2017a). The adjacent impounded zone of the west Elwha delta was found to also be highly functioning for fish, but inaccessible to salmonids due to the dike. The impounded west delta was also defined by persistent green algae (*Ulva* spp.), from here forward called 'macroalgae blooms', that were a product of a combination of saline conditions, lack of circulation and nutrient loading from residential lawn treatment and septic systems (Nelson and Lucas 2011).

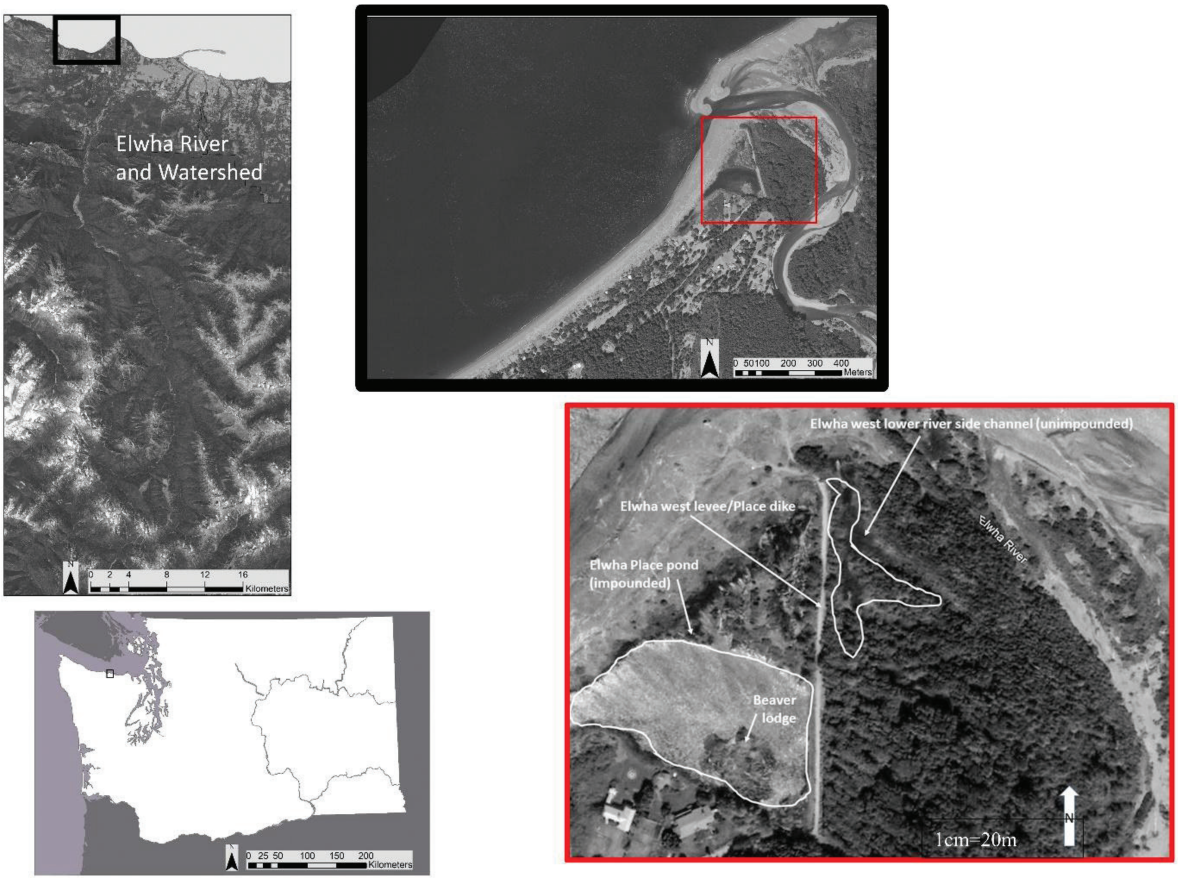

Figure 2. Figure of Elwha watershed, delta, and west delta including un-impounded west side channel and impounded west delta (Place Pond) study area.

The dramatic changes in the riverbed, delta extent, and water quality also resulted in changes in Elwha riparian corridors including the lower river and west delta (Fuentes et al. 2011; Foley et al. 2015; Warrick et al. 2015; Shaffer et al. 2017a, b; Prach et al. 2019). It is unclear how removing large dams will restore pre-dam communities important for beaver habitat when faced with the potential of nonnative plant species invading the newly deposited sediments (Shafroth et al. 2011). Brown et al. (2022) reported lower native plant species richness downstream from the two dams along the Elwha River; however, while dam removal caused species richness to increase in the middle reach, it did not increase within the lower river reaches within five years after dam removal. The authors speculate that the reconnection of the river channel through sediment transport and increased hydrochory may increase species richness over time in the lower river segments. Nonnative species richness or cover did not appear to be affected by the dams or dam removal but they increased 32% and 36% respectively from 2005 to 2017 (Brown et al. 2022). This suggests that nonnative species invasion could become a problem for the large, persistent lateral bar along the public, west lower river channel and delta that is the focus of our study. Early detection and rapid removal of exotic species will be required to ensure the recovery of habitat most conducive for beaver activity.

To date, no detailed study has been undertaken to understand the coastal beaver response to large-scale dam removals or the relationship between coastal beaver, shoreline impediments, dam removals, and salmon recovery.

In this study we provide an overview of the key post-dam removal physical and ecological changes to the Elwha west delta, including the delta extent and associated riparian vegetation; changes in water quality and macroalgae blooms in the impounded area of the west Elwha delta, changes in water quality, topography, and fish use of the un-impounded west side channel of the Elwha delta, recreational use of the Elwha west delta site, and how these are related to beaver use of the Elwha west delta coastal zone. We use a series of field studies and mapping to test our hypothesis that dam removals alone were not driving physical and ecosystem changes along the lower west delta of the Elwha.

We conclude that a series of factors, not just dam removals, are synergistically contributing to the Elwha west delta ecosystem. Specifically: 1. The west Place dike is playing a role in defining changes in lower river physical attributes including profiles, area, and water quality; 2. These changes are in turn affecting the ecological function of the west lower Elwha lateral bar and unimpounded west side channel extent, including riparian plant composition and cover, juvenile salmon and trout, and beaver use; 3. Riparian vegetation extent and composition changes post-dam removal are related to lateral bar extent, and may be contributing to beaver recolonization; 4. Beaver recolonization of the west delta is positively related to habitat changes driven by water quality changes documented to be associated with dam removals, but may be offset/ challenged by human use and; 5. Using juvenile fish abundance over time as an indicator of ecological function of the unimpounded west side channel, there has been a decline in habitat function of the un-impounded west delta due to the site shrinking and the concomitant decrease in the habitat quality for fish due to an increase in temperature and a decrease in dissolved oxygen. Finally, we discuss the future relationship the beaver may play in sustained ecosystem function of this important and evolving nearshore region given the persistent impaired nature of hydrodynamic function of the Elwha delta nearshore, and steps to support beaver in this role.

Methods

Physical changes to the Elwha delta

A. Elwha-west side channel topography: The topography and areal extent of the Elwha west side-channel between 2002 and 2018 was mapped using LiDAR bare earth digital elevation models (DEMs) in ArcGIS 10.6.1. A topographic cross-section from east to west across the side-channel was evaluated using the 3-D Analyst extension in ArcGIS 10.6.1 to map the extent of channel in-filling before and after dam removals on the Elwha River (Fig. 2).

B. Elwha-west side channel habitat mapping: The wetted area of un-impounded west side channel area was digitized from LiDAR Digital Terrain Models using Global Mapper Version 22.0. For each year LiDAR imagery was available the un-impounded westside channel areas were digitized three times, and the average used to estimate area.

We used the elevation NAVD88 2.13 meters to establish wetted area (ha) across all years using Crescent Bay Tidal Station 9443826 MHHW = 2.152 meters NAVD88.

C. Elwha-west side water quality: The un-impounded west side channel of the Elwha lower river was sampled once a month during beach seining for basic water quality parameters of temperature, salinity, and dissolved oxygen (DO) from 2008 to present using a handheld YSI model proDSS meter. Prior to beach seining the probe was positioned in 0.6 meters of water and values recorded. These point data were summarized by month and year and dam removal phase. Data were analyzed using single factor ANOVA analysis and a post hoc Tukey test between water quality parameters before, during, and after dam removal.

Ecological changes to the Elwha west delta

A. Elwha west delta riparian extent and riparian vegetation cover: The Elwha delta and the west delta riparian areas were mapped using ortho-rectified aerial photographs with ARC GIS 10.6.1 software (ESRI 2021). Historical aerial photographs were georeferenced to 1-meter digital ortho-photographs and the area (hectares) of habitats were digitized and recorded for the years 1939–2021 (Table 1).

B. Elwha west delta riparian composition: Vegetation plots were located along the un-impounded zone along the west side of the mouth of the Elwha River within the riparian and shrub-emergent marsh habitats. On May 21, 2020,

Table 1. Annual (from previous year) percent change of west delta and riparian vegetation extent. Single asterisk (*) indicates west Elwha delta/Place levee installation, double asterisks (**) designate when the Elwha dam removals began, and triple asterisks (***) denote when the Elwha dam removals were completed.

Year	Change in west Elwha delta area (m²)	Change in Elwha west delta riparian vegetation area (m²)
1939	–	–
1965*	5%	–
1974	180%	–
1976	10%	109%
1977	-1%	356%
1981	-22%	36%
1985	-9%	41%
1990	15%	25%
2005	63%	76%
2006	18%	-8%
2009	3%	23%
2011**	4%	12%
2012	-2%	1%
2013	-1%	2%
2014***	40%	-9%
2015	-29%	14%
2016	30%	15%
2017	-18%	-2%
2021	-5%	13%

transects were placed parallel to the river along the lower bank edge where the first vegetation patch was located, as described in the PacFish InFish Biological Opinion Monitoring Program (Archer et al. 2016). Eight, 50-meter transects were placed, starting at the river's mouth where riparian vegetation began, and continued south (total of 400 m of transect). Line-point intercept data was recorded along each meter of each transect wherein the species with the nearest stem, leaf, or plant base intercepted was recorded. Along each 50 m transect, three 1 m × 1 m quadrats were randomly placed (8 transects × 3 quadrats = 24 total 1 m^2 quadrats). Within each quadrat, vegetation cover was estimated using the following cover classes: 1 = 0–1%, 2 = >1–10%, 3 = 11–25%, 4 = 26–50%, 5 = 51–75%, 6 = 76–90% and 7 = >90%. Both transect and line intercept data were standardized to reflect relative abundances. All plants were identified to species using Hitchcock and Cronquist (1973) and Pojar and MacKinnon (1994). Brome species were difficult to identify to species; therefore, they were categorized as *Bromus* spp. This documentation provides a species list for adaptive management as well as a baseline for long-term comparisons.

C. Impounded Elwha west delta area and macroalgae cover: This was mapped from ortho-rectified aerial images using Google Earth Pro. All images were analyzed with north facing orientation at 475-meter altitude. Images were gathered from all years that had distinguishable images of the west delta Place Pond and macroalgae. The area of the main impounded Place Pond and the area of floating macroalgae were mapped from 2004 to 2021 for the main growing season (July-October) using Google Earth Pro built-in mapping tool. The area, in square meters, of the pond and visible macroalgae were calculated to determine the relative percent cover of macroalgae.

D. Fish use: The Elwha un-impounded west side channel was sampled monthly from 2008-current for juvenile salmon abundance using a standardized sampling technique known as beach seining (Miller et al. 1980; PSWQA 1996), as described in Shaffer et al. 2009; 2017b; 2018). Seining involves deploying and retrieving a standard 11.2 × 1.8 m net with 0.32 cm mesh size using a small rowboat, and then idling, counting, and measuring fish intercepted. The beach seine net mesh is designed specifically to entrain small, young fish. This site has been studied since 2007 and subsets of these data have been included in a number of earlier studies (Shaffer et al. 2009; 2017b; 2018). Shaffer et al. (2009) documented that the west delta had the highest abundance of fish and proportion of salmon of the entire delta. As a result, the un-impounded west side channel of this study was designated a long-term study site and continuously sampled before, during, and after dam removal. The impounded area was not expected to have changes in fish use due to the fish barrier of the dike and so was not sampled regularly. We analyzed water quality parameters of temperature, DO, salinity, and juvenile salmon and trout abundance to illustrate changes in water quality over the course of dam removals and the relationships between juvenile salmon and habitat associated water quality changes. Fish abundances' distributions were not normally distributed, therefore a Spearman's Rank correlation was used to model correlative relationships.

E. Beaver presence: We determined beaver behavior using three main indicators: 1) Cataloging the evidence of the beaver lodge, beaver channel, vegetation harvesting, and food caches of the west delta in May, September, and December of 2020, and again March, June, September, and October of

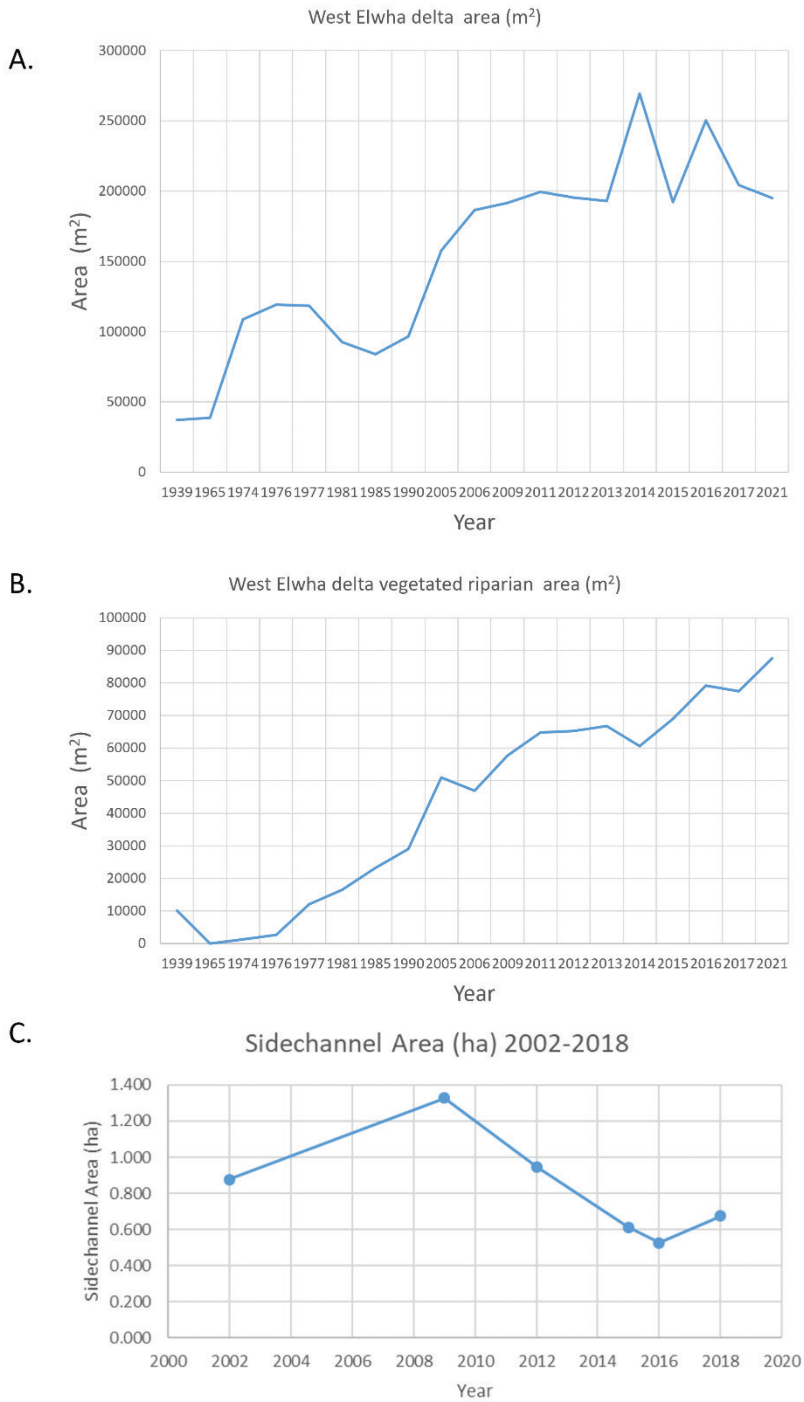

Figure 3. A–C West Elwha delta mapping graphs.

2021 using aerial imagery (Figs 2, 3), 2) an inventory of beaver observations reported by the community, and; 3) a two-year field survey of the west Elwha delta for beaver sign from 2020–2021 (Fig. 3). The west Elwha delta dike, side channel and river were split into three zones, and then walked quarterly for beaver sign which was recorded. Beaver sign included fresh drag marks, fresh chew marks, fresh scent mounts, and actual beaver sightings. For each survey, every definitive new beaver sign observed was recorded by GPS location and photographed.

Results

Physical changes to the Elwha delta

Elwha west delta extent, topography, and side channel area

The area of the west delta increased from 1965 to 1977, decreased until 1990, and then began a trend of growing again steeply over the next 15 years to and through 2005, with temporary dramatic increases in 2014, and 2016 that corresponded to delivery of large volumes of dam removal sediment, followed by decreases in 2015 to 2017. The lateral bar that borders the east of the un-impounded west delta increased by an average of 26% prior to dam removals but only 2% on average for the years during and after dam removals. In 2021, the Elwha west delta appeared to decrease to the 2011 extent of 200,000 square meters (Table 1, Fig. 4). The side channel area decreased from an average of 1.104 hectares before dam removal to an average of 0.641 hectare after dam removal, which is a decrease of 42% overall after dam removals at an average rate of -12.5% per year (Table 2, Fig. 3C).

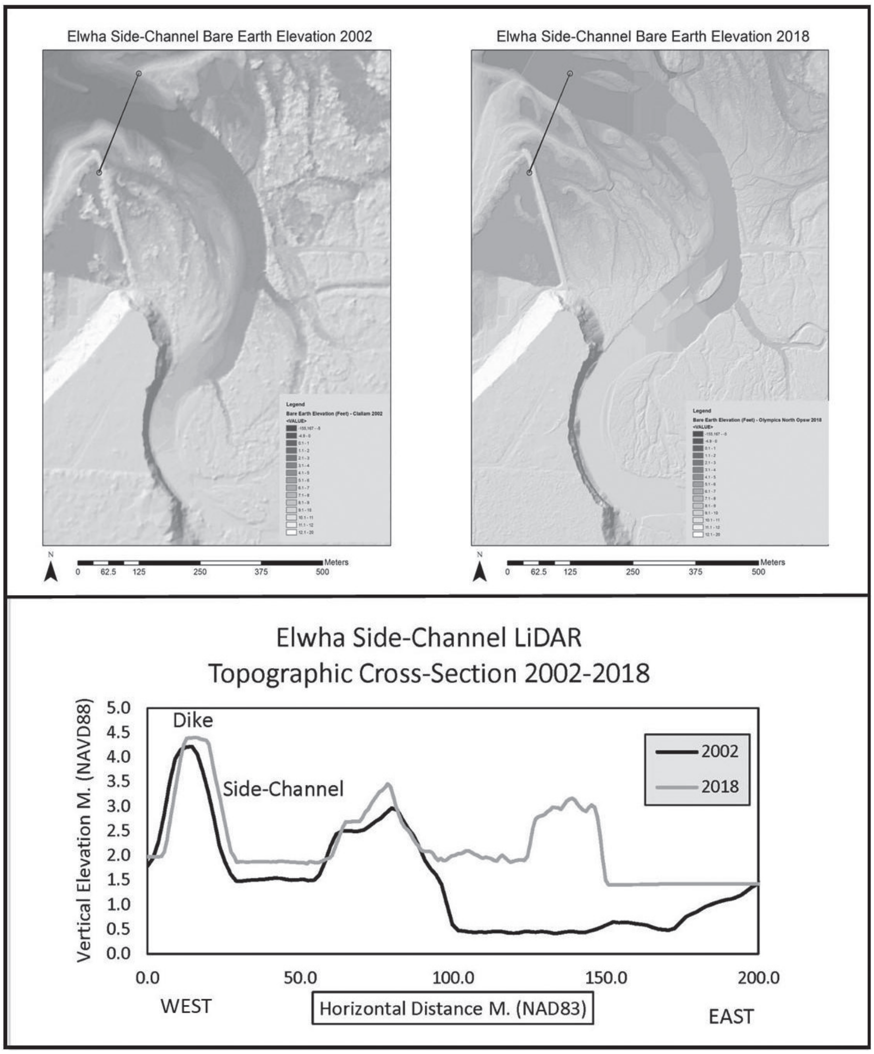

Figure 4. Elwha side-channel topography between 2002 and 2018 from bare earth LiDAR. LB = lateral bar.

Table 2. Summary of the side channel area after dam removal and percent change from previous year.

Year	West Elwha Delta Area (m2)	West delta Veg Area (m2)	West side channel habitat
2011	4%	12%	–
2012	-2%	1%	-29%
2013	-1%	2%	–
2014	40%	-9%	–
2015	-29%	14%	-35%
2016	30%	15%	-14%
2017	-18%	-2%	28%
Average % change since dam removals	3%	5%	-13%

The side channel between the Place dike and Elwha River lost approximately a half meter of depth between 2002 and 2018. The main river channel moved east and lost almost three meters of depth over the same time period (Fig. 4).

Water quality

Water quality parameters of the west Elwha delta have changed over the last fourteen years. Salinity decreased significantly following dam removal, and temperature changed seasonally, consistent with findings of Foley et al. (2015). Dissolved oxygen (DO) values of the un-impounded west side channel have significantly declined since dam removal to some of the seasonally lowest recorded observations since monitoring began (Table 3, Fig. 5 A–C).

Ecological changes to the Elwha west delta

Riparian vegetation extent

The riparian vegetation extent along this west delta steadily increased by an average of 82% from 1965 to 2011, and was positively correlated to delta extent (R^2=0.86; $P_{(2,18)}$,<0.001. However, the riparian vegetation cover does not correspond to west delta extent changes during and after dam removal, ($R^2_{(2,6)}$=-0.166; P>0.05) but instead continued to steadily increase by an average of 6% from 2011–2021 with a continued increase in vegetation cover in 2014 and 2016.

Riparian zone vegetation composition

Spring vegetation surveys documented a total of 52 plant species (Suppl. material 1, Table 4). Forbs had the greatest species richness (28) and were comprised of 21% native, 9% naturalized non-native, and 6% noxious weeds (Table 4). The most notable forbs by plant origin included coastal mugwort (*Artemisia suksdorfii*), nonnative common plantain (*Plantago major*), and nonnative herb-Robert (*Geranium robertianum*), respectively. Grasses comprised 25% of the vegetation and consisted mostly of native dunegrass (*Elymus mollis*) and naturalized,

Table 3. Water quality trends un-impounded west side channel 2008–2021. DR = During dam removal; Pre = pre dam removal, Post = post dam removal. NS = Not significant. DO = dissolved oxygen). Salinity values were natural log.

WQ Metric	DR Phases	Significant Change	p-value
DO (%)	Pre:DR	NS	0.43
DO (%)	DR:Post	decrease	<0.001
DO (%)	Pre:Post	decrease	0.001
Temperature (C)	Pre:DR	NS	0.49
Temperature (C)	DR:Post	NS	0.86
Temperature (C)	Pre:Post	NS	0.15
Salinity (g/kg)	Pre:DR	decrease	<0.001
Salinity (g/kg)	DR:Post	NS	0.5558
Salinity (g/kg)	Pre:Post	decrease	<0.001

non-native orchard grass (*Dactylis glomerata*), with one noxious invasive species present, reed canary (*Phalaris arundinacea*). Woody trees (29%) and shrubs (9%) collectively made up 38% of all plant species sampled. Most were native species with one exception, evergreen blackberry (*Rubus laciniatus*).

The native woody species that were reported to have been used by beaver included Sitka willow (*Salix sitchensis*), red alder (*Alnus rubra;* 8.3%), Hooker's willow (*Salix hookeriana;* 6.2%), big-leaf maple (*Acer macrophyllum;* 2%), and black cottonwood (*Populus trichocarpa;* <1%) (Suppl. material 1).

Impounded Elwha west delta area and macroalgae cover

Percent macroalgae cover in west delta (location of original beaver lodge) was approximately 25% of the total impounded Place Pond area until 2013, when the proportion of the pond covered with macroalgae dropped to ~7%. Macroalgae percent cover decreased to 0% by 2015, where it has remained since (Fig. 6, Table 5).

Beaver observations

Aerial imagery indicates the west delta lodge area was well vegetated with no sign of channels or beaver caches until 2015. By 2021 all the vegetation in the area of the west delta lodge had been harvested by beaver and a large cache area with a lodge had been created (Fig. 7).

Interviewing long-time landowners revealed that beavers were first observed and recorded along the west delta, and specifically the impounded Place Pond in October 2014-but not before. After 2014, observations of beaver were consistently and regularly reported along both sides of the dike, in the impounded Place Pond, and west side channel from 2014 until May 2018, when a beaver was killed on the dike via predation. No beavers were observed again until 2019 when they were spotted intermittently.

Standard surveys for signs of beaver including tree chewing, scent mounds, tail drag trails, and actual beaver sitings were conducted along the west delta quarterly from 2020 and 2021 and are summarized in Table 6. No fresh signs of beaver were seen in summer surveys. Fresh beaver sign was observed during all other seasons.

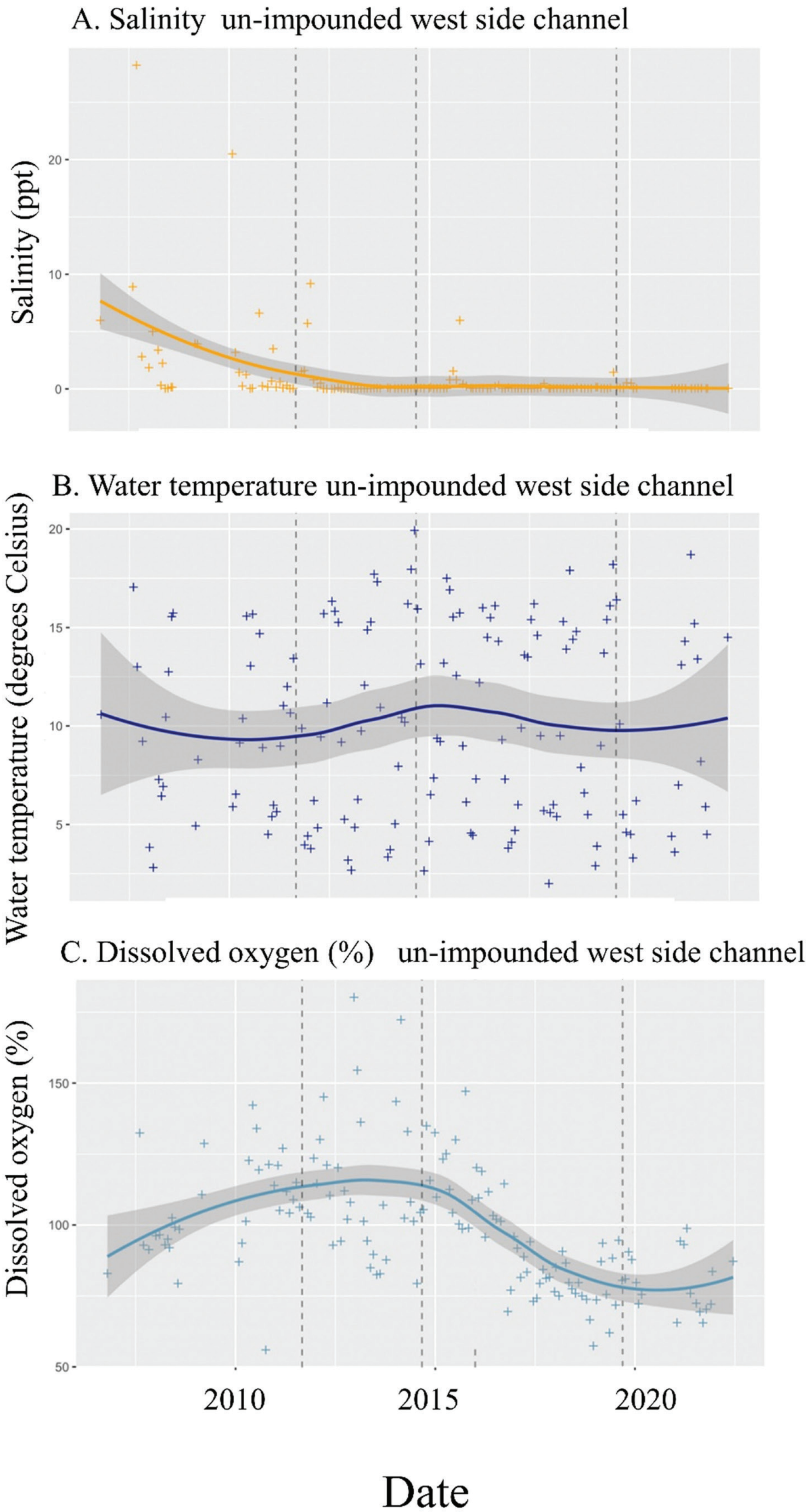

Figure 5. Water quality Elwha west un-impounded side channel 2008–2021. Hatched lines indicate dam removal phases left to right: dam removal beginning, dam removal ending, and five years after dam removals ended.

Table 4. Summary of mean plant abundance by life form and origin surveyed from the riparian and shrub-emergent marsh vegetation present along the west side of the mouth of the Elwha River in 2021. SR = Species Richness. A complete species list is reported in Suppl. material 1.

Life Form	SR	Origin	Abundance	Most Abundant per life form and origin
Forbs	28	Native	21%	Coastal Mugwort (*Artemisia suksdorfii*)
		Naturalized	9%	Common plantain (*Plantago major*)
		Noxious	6%	Herb Robert (*Geranium robertianum*)
Grass	9	Native	16%	Dune grass (*Elymus mollis*)
		Naturalized	8%	Orchard grass (*Dactylis glomerata*)
		Noxious	1%	Reed Canary (*Phalaris arundinacea*)
Shrubs	6	Native	9%	Twin-berry (*Lonicera involucrate*)
		Naturalized	0	NA
		Noxious	1%	Evergreen Blackberry (*Rubus laciniatus*)
Trees	9	Native	29%	Sitka Willow (*Salix sitchensis*)
		Naturalized	0	NA
		Noxious	0	NA

Table 5. Place pond area (m^2), macroalgae area (m^2) and percent cover, and change in percent macroalgae cover recorded between 2004–2021.

Year	Month	Pond Area (m^2)	Algae Area (m^2)	Percent of pond covered with macro algae	Change in Pond area macro algae area	
2004	8	16,539	5,355	32%	–	–
2006	10	15,922	6,432	40%	-4%	20%
2009	9	17,341	7,273	42%	9%	13%
2011	11	17,124	5,912	35%	-1%	-19%
2012	8	16,394	5,594	34%	-4%	-5%
2013	7	17,549	1,818	10%	7%	-68%
2015	9	16,768	0	0%	-4%	-100%
2016	7	17,888	0	0%	7%	0%
2017	7	18,701	0	0%	5%	0%
2021	7	18,568	0	0%	-1%	0%

Table 6. Summary of quarterly beaver surveys Elwha west delta 2020–2021.

Season	Month	Year	Beaver sign observed	West of dike	East of dike
Spring	5	2020	y	y	y
Summer	9	2020	n	n	n
Winter	12	2020	y	n	y
Spring	6	2021	y	y	n
Summer	9	2021	n	n	n
Fall	10	2021	y	y	y
Winter	12	2021	y	y	y

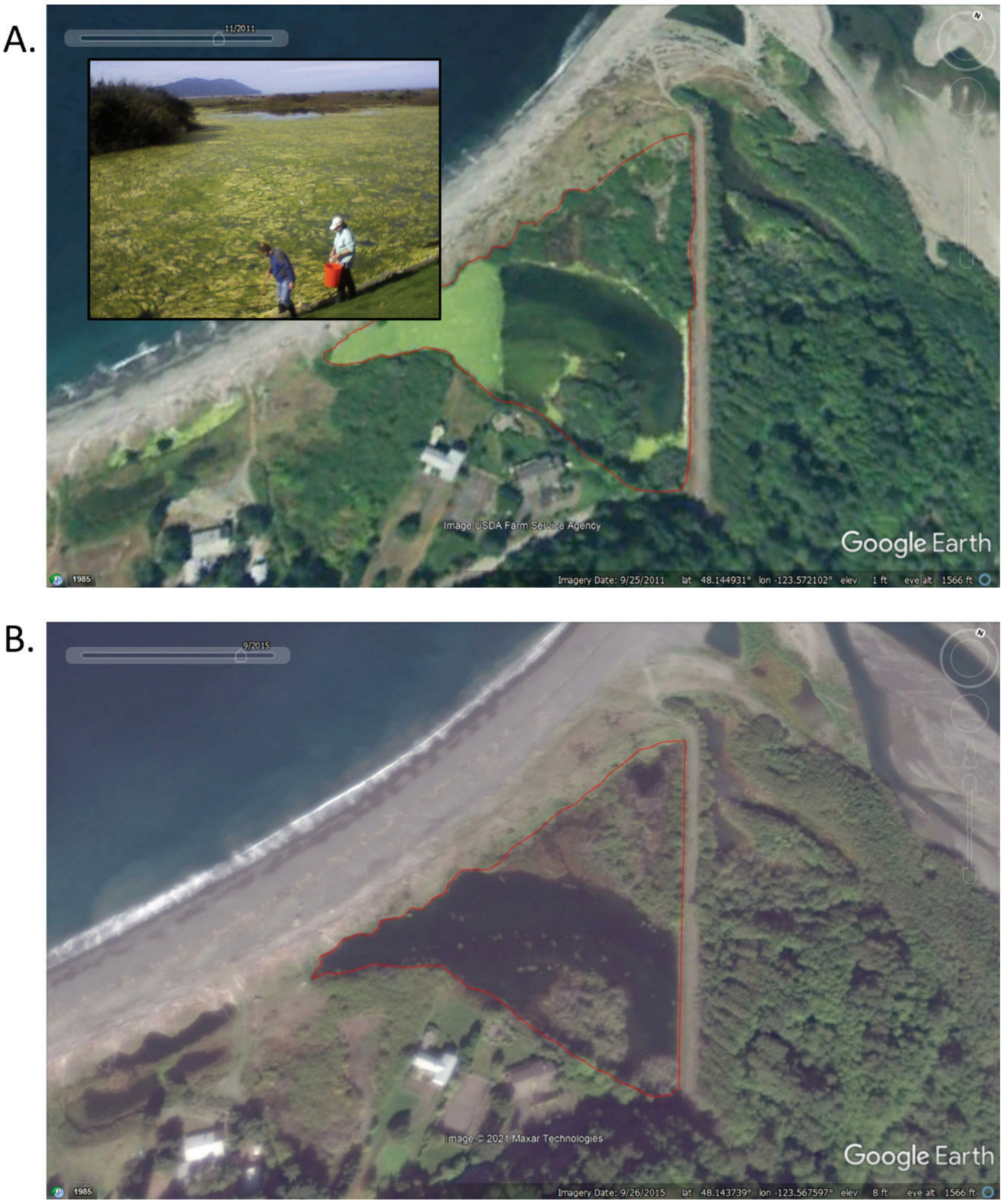

Figure 6. A, B Impounded west delta (Place Pond) illustrating-high macroalgae cover prior to dam removals (2011) and B post dam removal with no macroalgae cover (2014).

Table 7. Summary of beaver (this study), and humans, and dog numbers by month 2020–2021 for the Elwha west delta. Recreation data reprinted with permission from CWI 2022.

Month	Humans	Dogs	Beaver
1	45	9	2
3	24	3	2
5	11	2	4
6	41	5	1
9	46	9	0
10	16	0	4

Figure 7. Photograph of Elwha west delta impounded area beaver lodge in 2021.

We correlated beaver observations to dog and human use data collected for a different study but from the same area and over the same time period (CWI 2022, Table 7). Beaver observations were negatively correlated with dogs (R^2 = -0.79, $P_{1,4}$<0.02), and humans (R^2 = -0.88, $P_{1,4}$<0.01).

Fish use

Fish abundance and composition of the impounded Place pond have remained unchanged over the last 15 years and is comprised solely of high numbers of three spine stickleback (*Gasterosteus aculeatus*; Shaffer et al 2009; Michel 2021 unpublished data).

In the un-impounded Elwha River west side channel, the abundance of individual species of juvenile salmon and trout changed before and after dam removal. Overall, juvenile Chinook (*Oncorhynchus tshawytscha*) and coho salmon (*Oncorhynchus kisutch*) numbers increased, while juvenile chum salmon (*Oncorhynchus keta*), steelhead (*Oncorhynchus mykiss*), and cutthroat trout (*Oncorhynchus clarkia*) decreased (Fig. 8).

Spearman rank correlations between individual species abundance and water quality parameters revealed that coho and chum abundance were related to water quality parameters of dissolved oxygen, temperature, and salinity (Table 8). Specifically regarding coho, fish abundance was negatively correlated to DO (r = -0.33, P < 0.001) and salinity (r = -0.32, < 0.001), yet positively correlated to temperature (r = 0.19, P = 0.05). The opposite pattern

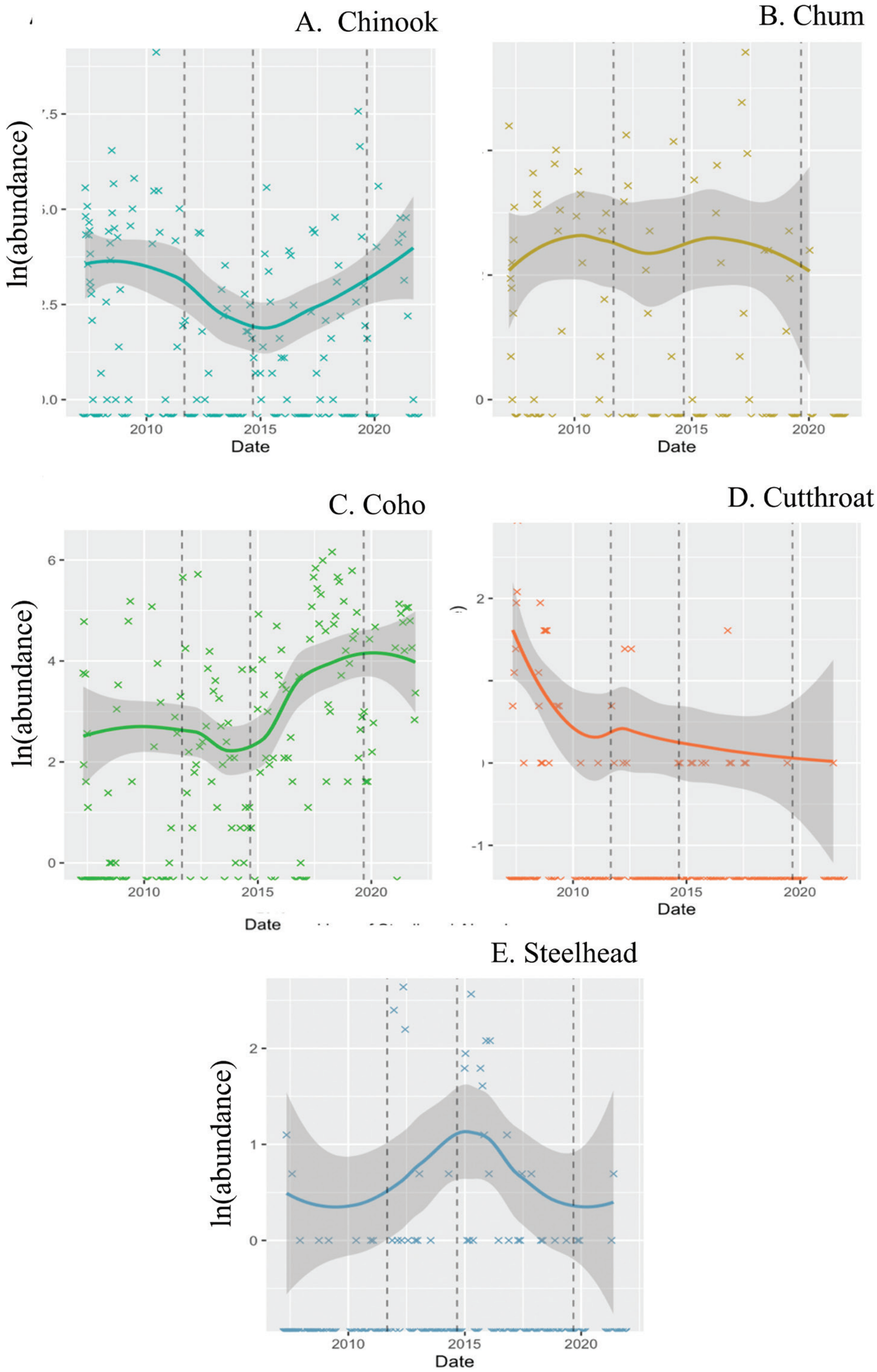

Figure 8. Monthly fish abundance Elwha un-impounded west side channel 2007–2021 (data are natural log; some data reprinted with permission from authors). Hatched lines indicate dam removal phases left to right: dam removal beginning, dam removal ending, and five years after dam removals ended.

for chum revealed a positive relationship between DO ($r = 0.20$, $P = 0.04$) and salinity ($r = 0.20$, $P = 0.04$) and a negative correlation with temperature ($r = -0.51$, $P < 0.001$). Chinook had a positive correlation to water temperature ($r = 0.19$, $P = 0.05$).

Table 8. Spearman correlation tests using an alpha level of 0.05. of natural log of species abundances (+1) and their monotonic correlation to different water quality metrics. Table indicates fish species, water quality variable, and the correlation coefficient (r) with sign indicating either positive or negative correlation. Significant p-values are emphasized in bold font.

Species	Water Quality Metric	r	P-value
Chinook	DO (%)	-0.08	0.43
Chinook	Temperature (C)	0.19	**0.05**
Chinook	Salinity (g/kg)	-0.14	0.17
Coho	DO (%)	-0.33	**<0.00**1
Coho	Temperature (C)	0.19	**0.05**
Coho	Salinity (g/kg)	-0.32	**<0.001**
Chum	DO (%)	0.20	**0.04**
Chum	Temperature (C)	-0.51	**<0.001**
Chum	Salinity (g/kg)	0.20	**0.04**
Cutthroat	DO (%)	0.11	0.11
Cutthroat	Temperature (C)	0.21	**0.03**
Cutthroat	Salinity (g/kg)	0.02	0.84
Steelhead	DO (%)	0.16	0.10
Steelhead	Temperature (C)	-0.06	0.52
Steelhead	Salinity (g/kg)	-0.15	0.14

Discussion

Both dam removal and beaver are important for river ecosystem function, and in coastal restoration their benefits may be synergistic. In the coastal Elwha nearshore, both dam removals and lower river alterations have contributed to an expanded beaver habitat and colonization through water quality improvements along the impounded west delta, and expansion of riparian vegetation growth along the un-impounded west delta (specifically the lateral bar driven by the dike along the west delta). Interestingly, the lateral bar persistence is the result of the west Place dike and not dam removal.

The vegetation of the lateral bar of the west Elwha has increased significantly since dam removal, likely to the benefit of beaver. Fuentes et al. (2011) showed that prior to dam removal the impounded Elwha west delta vegetation was primarily shrub-marsh transition. The un-impounded west delta, including the lateral bar, was dominantly riparian forest and willow-alder forest with dune grass ringing the northern portion of the delta. These vegetation groups and relative cover have stayed largely the same, expanding a bit (6% on average) after dam removal. Further, the vegetation collected in the newly expanded riparian zone and shrub-marsh transition reflected the developing complexity of the nearshore environment, which has been extended to connect with the expanded river delta and was comprised of abundant Sitka willow (*S. sitchensis*) red alder (*A. rubra*), and Hooker's Willow (*S. hookeriana*). Both genera were previously reported prior to dam removal and their proximity prior to restoration allowed for rapid recruitment along the newly deposited sediment (Shafroth et al.

2011; Prach et al. 2019). Both willow (*Salix spp.*) and alder (*A. rubra*) have been cited as important forage tree species for food, dam, and lodge construction for beaver (Stoffyn-Egli and Willison 2011; Ritter et al. 2020). Black cottonwood (*P. trichocarpa*), another preferred beaver forage source was present, as well as big-leaf maple (*A. macrophyllum*), but both had relatively low abundance when compared to mature riparian forest that previously dominated the nearshore environment prior to dam removal and beach expansion.

Habitat complexity is further represented by sub-canopies of small trees and shrubs that were there prior to restoration and include Indian plum (*O. cerasiformis*), bitter cherry (*P. emarginata*), Pacific dogwood (*Cornus nuttallii*), thimbleberry (*R. parviflorus*), Nootka rose (*R. nutkana*), and salmonberry (*R. spectabilis*). Vegetation followed the nearshore expansion and included species previously sampled within the shrub-marsh and riparian zones such as pacific silverweed and slough sedge (Shafroth et al. 2011). The significant extension of the beach post-dam removal has also expanded the dunegrass habitat (*E. mollis*), which prior to dam removal, were confined to narrow corridors of the sediment depleted beach. Some native species such as Coastal mugwort (*A. suksdorfii*) and riverbank lupine (*L. rivularis*) were new to the nearshore and represented native species that were used in the upstream restoration of riparian forests in the former lake reservoirs (Michel et al. 2011; Chenoweth et al. 2021).

Non-native species sampled post-dam removal included mostly naturalized species with some class B and C noxious weeds, which are widespread and recommended for control. Noxious weeds included species such as herb-Robert (*G. robertianum*), hairy cat's-ear (*H. radicata*), oxeye daisy (*L. vulgare*), wild teasel (*D. fullonum*), and reed canary grass (*P. arundinacea*). These weedy species are facilitated by recent disturbance and will need to be monitored due to the influence these species invasions can have on native species richness (Woodward et al. 2011). The establishment of a larger proportion of riparian vegetation will hopefully stabilize and promote the long-term re-establishment of the west delta beaver habitat (Bruner 1989; Bailey et al. 2019), however, management and monitoring should emphasis control of non-native plant species.

These vegetation changes combined with water quality improvements likely benefit beaver, allowing them to expand into additional areas not used before dam removals. Beaver use of the Elwha west delta appears complex and changing. Regular surveys of beaver presence along the impounded west estuary, dike, and un-impounded west estuary from 2020–2022 indicate that the most use (based on chewing and tail drag marks) was during winter months. Over the course of the study no beaver use of the Place dike area was observed during summer months. This could be a result of the beaver changing their food source during summer months. However, as beaver have to chew on hard wood/substrates regularly to maintain teeth we would expect to see some sign even if food resource use changed seasonally. Given the high volume of food resource on the east side of the dike along the lateral bar, we assume there are other reasons apart from low food availability that explain why the beaver do not transit across the dike to the heavily vegetated areas. There are a number of reasons for beaver seasonal use of this area including lodge access due to increased summer human/dog presence, which would discourage beaver use, and the calmer river conditions which would make larger reaches of the main river channel more suitable during the summer months. Beaver and human observations are significantly negative correlated, indicating that beaver avoid using the area when humans and dogs are present. The negative impact of dogs on wildlife is well documented, including for beaver (Hennings 2016; Schüttler et al. 2018). The Place dike, which sits between the lodge area and the west Elwha River riparian and side channel areas, is the sole recreation access to the west delta and used heavily used for recreation, including heavy domestic dog use.

Alternatively, beaver use of this region may be defined by other factors. For example, beaver may use the impounded Place Pond lodge zone in the winter when river flows are high and challenging for beaver. Beaver use of the area in summer may be more variable when water levels in the impounded pond are low, the pond is shallower, and possibly making accessing the lodge more complicated. A broader more comprehensive study on beaver use of this area would help explain these fluctuations.

Juvenile salmon and trout use of the unimpounded west side channel indicate that the physical changes in area, depth, and water quality are having ecological repercussions. Fish use of the nearshore has been documented to be a very sensitive metric defining ecosystem changes that are foundational components of coastal systems. In this study we used water quality as an indicator of habitat quality attributed to changes in the unimpounded west delta extent. Relative to water quality, we find relationships between fish abundance relative to dissolved oxygen and temperature. As the site shallows and becomes smaller it transitions to lower salinity, warmer off-channel habitat that is suitable for coho. The significant decrease in DO is likely due to both the change to freshwater dominated system, and the site becoming smaller and shallower with poorer connection to the river. This, in turn, results in the site becoming less accessible and/or less hospitable to fish, and significantly so for chum. The relationship between salmon, habitat, and water quality, however, which is extremely complex and varies by species and life history stage, can also be masked by hatchery releases, and which in the Elwha have increased log scale for Chinook and coho salmon since dam removals (RMPC 2022; Shaffer et al. 2017b). While our data indicate both trends and relationships in the physical habitat and fish response of the unimpounded west delta side channel, our data are only point data (monthly). A more detailed study will provide resolution needed to fully define causative relationships between water quality, salmon and trout abundance.

Conclusion

Beaver, as ecosystem engineers that increase channels and ponded water in their habitat zones, may be a positive coastal response to dam removals. As the Elwha system, including the lower river and riparian zones, continue to restore two decades after dam removals, we expect beaver to continue to expand their numbers and range throughout the Elwha coastal zone. We recommend recovery and conservation measures be developed to support the beaver of the Elwha west delta that include public outreach to educate about the impacts of off leash dogs on wildlife (Sterl et al. 2008; Schüttler et al. 2018).

An additional finding illustrated the problems associated with the Place dike that blocks fish passage between the Elwha River and the otherwise high quality historic west side channel zone of the impounded west delta. This is also causing a decrease in the size and quality of one of the most important and persistent areas of the Elwha delta for salmon rearing. Therefore, we also recommend continued pursuit of legacy, ecosystem scale restoration actions to hydrologically reconnect the two sides of the Place pond/west Elwha delta. Implementing education and ecosystem engineering restoration actions will result in a synergistic ecosystem benefit for the entire Elwha recovery, including salmon and coastal beaver.

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Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

No ethical statement was reported.

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Author contributions

Anne Shaffer led all aspects of this project; Dave Parks provided physical habitat mapping science, Katrina Campbell conducted macroalgae mapping, Anna Morgan provided fish and water quality data synthesis, Pamela Adams provided beaver monitoring and expertise, Jenise Bauman provided riparian zone field data and analysis.

Data availability

All of the data that support the findings of this study are available in the main text or Supplementary Information.

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Supplementary material 1

Mean woody plant abundance surveyed from the riparian and shrub-emergent marsh vegetation

Authors: J. Anne Shaffer, Dave Parks, Katrina Campbell, Anna Moragne, Bligh Hueske, Pamela Adams, Jenise M. Bauman

Data type: occurrences

Explanation note: Mean woody plant abundance surveyed from the riparian and shrub-emergent marsh vegetation present along the west side of the mouth of the Elwha River in 2021. Species-level data are relative abundances (percentages of the total counts). Plant species and Family names are divided by life form (tree, shrub, forb, and grass) then sorted by abundance (from high to low). Plant origin: N, native plant and I, introduced plant. If introduced, plant is classified as naturalized (n) or class of noxious weed (B, C).

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