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Age Structure and Hatchery Fraction of Elwha River Chinook Salmon: 2016 Carcass Survey Report

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Executive Summary

Monitoring the recolonization of Pacific salmon and steelhead following the removal of two dams is a critical component of the Elwha Restoration Project. During the fall of 2016, we collected adult Chinook salmon (*Oncorhynchus tshawytscha*) carcasses from the Elwha River in order to evaluate the proportion of hatchery fish, the age distribution of returning adults, and the ratio of fish that exhibited stream vs ocean type life history strategies. Surveys were conducted from the confluence of Idaho Creek at Geyser Valley (river km 31.5) downstream to where the river enters into the Strait of Juan de Fuca, including three tributaries. Of the carcasses sampled from the river and its tributaries (N = 264), the majority (88 %) were located upstream of the former Elwha Dam site. We also sampled fish (N = 290) throughout the season at the WDFW hatchery in the lower Elwha River. Carcasses were sampled for physical measurements, hatchery marks, scales and genetics. We sampled 422 non-jack carcasses during the sampling season, representing 20.1 % of the estimated escapement above the Elwha SONAR site. Over 95% of the fish sampled were marked hatchery fish. Age-4 was the dominant age class (61.6%), and age-2 fish (jacks) accounted for less 6% of our total sample. We sampled two age-3 natural origin fish and ten age-4 natural origin fish whose parents had access to habitat upstream of the former Elwha dam site following its removal in 2012. However, we have not observed a reduction in hatchery mark rate for the age classes that might have been produced by spawners upstream of the Elwha Dam site, and thus have no evidence that recolonization of newly accessible habitat has boosted natural production of Chinook salmon. Natural origin fish returning to the river as age-3 or age-4 adults to date were exposed to extreme environmental conditions associated with dam removal. All of the Chinook that migrated to the ocean as yearlings were hatchery origin, and so we did not observe any stream-type life histories among unmarked fish. We estimated that Chinook that spawned naturally in the Elwha could have deposited over 5.9 million eggs in 2016. Finally, an analysis of spawner to spawner productivity indicated that naturally spawning fish from the four most recent complete cohorts (brood years 2007 – 2011) did not replace themselves (average productivity = 0.33), whereas the combined productivity of natural plus hatchery spawners did exceed replacement (average productivity = 2.5).

Introduction

The Elwha River is the site of the largest dam removal project in Unites States history. The passage of the Elwha River Ecosystem and Fisheries Restoration Act in 1992 authorized the removal of two dams, Elwha and Glines Canyon, from the mainstem Elwha River. The removal of the dams will allow all five species of Pacific salmon plus steelhead trout to recolonize approximately 115 km of habitat, the majority of which is located in the Olympic National Park, that has been blocked since 1913 (Hosey and Associates 1988). Removal will also facilitate the resumption of anadromous life history strategies in resident cutthroat trout and bull trout populations. The long term goal of the restoration project is the recovery of naturally producing, self-sustaining runs without reliance on hatchery production (Ward et al. 2008). Dam deconstruction began in September of 2011; demolition of Elwha Dam was completed in March of 2012 and Glines Canyon Dam in late August of 2014.

Compared to the Chinook salmon native population that historically inhabited the Elwha River prior to dam construction, the current population exhibits truncated life history diversity, notably the absence of the early-timed adult returns (Ruckelhaus et al. 2006). In recent decades, Elwha Chinook salmon have largely been supported by hatchery production in the limited habitat below the Elwha Dam. In an effort to preserve the genetic integrity of the Elwha Chinook stock, fishery managers intentionally limited the release of out of basin hatchery fish over the years (Brannon and Hershberger 1984; WDFW and WWTIT 1994). Contemporary genetic analyses confirm that the Elwha stock is unique with respect to Puget Sound and groups much more closely to Chinook salmon from the neighboring Dungeness River than other watersheds in the region (Ruckelshaus 2006).

Guidelines for monitoring the recovery of ESA-listed Chinook salmon and steelhead were laid out in the Elwha Monitoring and Adaptive Management (EMAM) plan for listed species of Chinook salmon and steelhead (Peters et al. 2014). A series of four recovery stages were described including: 1) Preservation, 2) Recolonization, 3) Local Adaptation and 4) Viable Natural Population. Progression through the phases is measured using the Viable Salmon Population (VSP) metrics abundance, productivity, spatial distribution and diversity (McElhany et al. 2000).

Several of these VSP metrics rely on data describing the hatchery mark rates, age structure, and juvenile life-histories of fish returning to the Elwha River watershed. In order to estimate the abundance of natural-origin salmon, one must subtract the proportion of the total return that was produced in hatcheries. Age structure data are required for the cohort analysis needed to evaluate spawner to spawner productivity and smolt-to-adult return rates.

For Chinook salmon, a key diversity metric is the proportion of naturally spawned salmon that adopt stream-type vs. ocean-type life histories. Stream-type Chinook have a longer freshwater residency time than ocean-type Chinook salmon, spending an entire year in freshwater prior to seaward migration. Ocean-type Chinook migrate within their first year of life, either as small fry soon after emergence or as larger parr that have spent 1-6 months rearing and growing in freshwater. Within Puget Sound, dam construction has selectively restricted access to the majority of snow-melt dominated headwater streams that are typically associated with the stream-type life history (Beechie et al. 2006). Currently, the vast majority of natural-origin Elwha Chinook utilize the ocean type life history strategy (McHenry et al. 2015). It is hypothesized that access to the upper watershed might allow for the stream type life history trait to reemerge (McHenry et al. 2016).

In response to this need for biological information, we conducted Chinook salmon carcass surveys in the fall of 2016. The primary hatchery marking strategy for Elwha River Chinook salmon are thermal otolith marks induced during hatchery rearing, and so samples must be collected from carcasses. Age structure and juvenile life history data are commonly derived from scales also collected during carcass surveys. Our primary objectives for the carcass collections were to:

1) Measure the proportion of hatchery to natural-origin Chinook salmon returning to the Elwha River

2) Describe the age structure of hatchery and natural-origin Chinook salmon returning to the Elwha River

3) Assess the relative frequency of stream-type vs. ocean-type juvenile life histories of naturally produced Chinook salmon returning to the Elwha River

We conducted carcass surveys throughout the Elwha River and tributaries downstream of the former Glines Canyon Dam, allowing us to evaluate two spatially explicit hypotheses. First, we predicted that the proportion of hatchery marked fish would decrease with the distance upstream from the WDFW Hatchery located at river km 5.6. Second, we predicted that adults adopting stream-type juvenile life history would tend to be found at more upstream locations nearer cold-water, snowmelt dominated headwaters. We intend these hypotheses as long term guides for our monitoring efforts and expect that the data needed to evaluate them will accumulate in future years. This is particularly true for evaluating the rate of stream-type life histories, which may depend on colonizing habitats upstream of the former Glines Canyon Dam site.

This report describes the results from the carcass recovery project for the 2016 spawning season, summarizes trends in age structure and hatchery mark information in recent years, and presents an analysis of spawner to spawner population productivity for Elwha River Chinook salmon.

Methods

Sample collection

We surveyed the mainstem Elwha and tributaries from the head of the Elwha Grand Canyon at river km 31.5 to the mouth of the river at the Strait of Juan de Fuca. Surveys were conducted by foot and inflatable raft. The Elwha River was broken up into 8 sections (Table 1, Figure 1). Each reach below Rica Canyon was scheduled to be surveyed every 7 to 10 days. The Grand Canyon to Goblins Gate section was surveyed one time during the peak spawning period. Based on redd survey numbers from previous spawning seasons, we felt this sampling structure would allow us to sample most of the available carcasses in each reach throughout the season.

Table 1. Description of Sampling Reaches for the Elwha Chinook Carcass Recovery from August 29 to October 11, 2016.

Reach	Description	River Km		Survey Crew
		Start	End	
1	Former Elwha Dam Site to mouth of River	7.9	0.2	WDFW
2	Gooseneck to former Elwha Dam Site	10.1	7.9	WDFW
3	Highway 101 Bridge to the Gooseneck	12.4	10.1	WDFW
4	Fisherman’s Corner to Highway 101 Bridge	20.1	12.4	WDFW
5	Altaire Bridge to Fisherman’s Corner including Hughes Creek	20.1	17.2	ONP, WDFW
6	Glines Dam powerhouse site to Rabbit Hole	21.4	18.2	ONP, WDFW
7	Rica Canyon to Glines Dam	25.7	21.7	ONP
8	Grand Canyon to Goblins Gate	31.5	28.2	ONP
Tributary	Indian Creek	1.6	0	LEKT
Tributary	Little Creek	1.6	0	LEKT

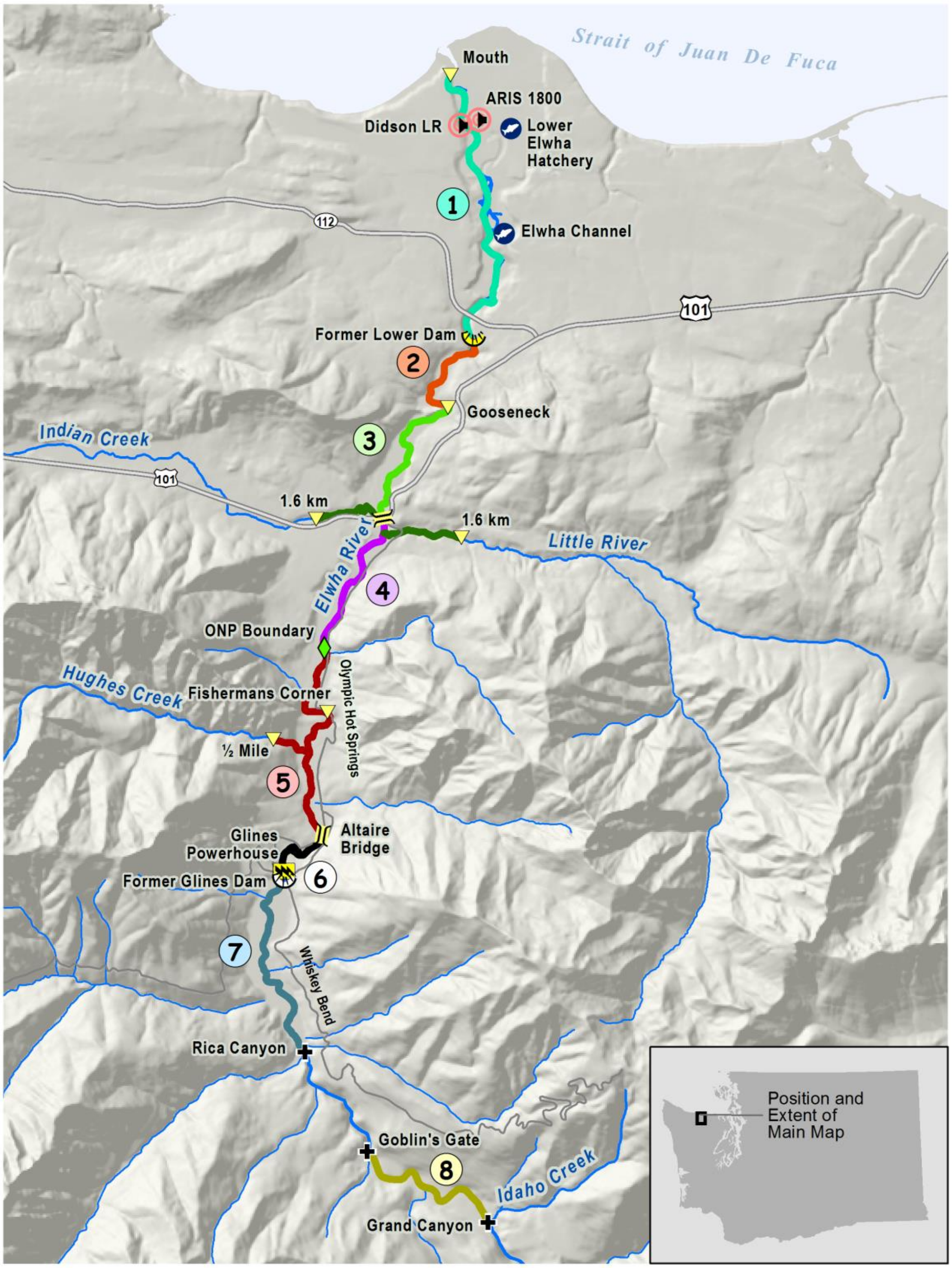

Figure 1. Map of Elwha River with carcass surveys sections for 2016 sampling season.

In addition, two backcountry surveys were conducted. On August 22, the reach from just above hayes River to Elkhorn was surveyed, approximately 9 km. A more extensive backcountry survey was conducted on September 20-21. This survey covered the mainstem Elwha River from the footbridge just downstream from Chicago Camp (approximately river km 61.7) downstream to the Mary's Falls campground (river km 38.8). Within this stretch of the river, approximately 2.3 km of Carlson Canyon was not surveyed due to its inaccessibility. None of the tributaries in this stretch of river were surveyed.

Chinook salmon carcasses were sampled weekly at the WDFW Elwha adult raceways (hereafter WDFW Hatchery) throughout the spawning season. Chinook salmon broodstock spawned at the WDFW hatchery were collected using a variety of methods. The primary collection method was by gill net from the Elwha River. Chinook salmon broodstock also included volunteers to the WDFW hatchery trap and volunteers to the LEKT hatchery trap that were subsequently transported to the WDFW adult holding ponds. New for 2016, WDFW used three individual fish raceways to segregate fish by collection method. In addition, WDFW PIT tagged fish that were captured early in the season to assess survival of early captured fish vs late captured fish. Some broodstock were also collected from the river via gaffing and spawned on-site rather than at the hatchery.

At all locations, carcasses were sampled for fork length, postorbital-hypural (POH) length (length from the posterior margin of the eye orbit to the end of the hypural plate), sex, presence of CWT tag, presence of any adipose marks, otoliths, DNA fin clip and scales. If a CWT was detected, the head was removed and taken to the lower Elwha Hatchery freezer for processing after the season. DNA was only collected from carcasses that showed more than 50% red coloration in the gills in order to maximize sample quality. DNA samples are currently archived at the WDFW Molecular Genetics Laboratory in Olympia, WA but were not analyzed in this study. At the WDFW Hatchery, fish were also scanned for a PIT tag to distinguish early captured fish vs later captured fish.

In addition to the measurements above, we also sampled up to 10 females per spawn day at the hatchery for egg mass and total eggs (fecundity). Females were spawned into individual buckets to measure total egg mass. A small subsample of the eggs was counted and measured for mass so that we could extrapolate for the total number of eggs for each female.

Daily stream discharge and turbidity data were downloaded from the U.S Geological Survey (USGS) Water Data website. Discharge data were reported as cubic feet per second (CFS) and collected at the McDonald Bridge station (site = 12045500). Turbidity was reported in formazin nephelometric units (FNU) from the water diversion immediately upstream from the WDFW Hatchery (site = 12046260).

Average daily discharge ranged between 274 and 4,380 cfs during the sampling season (Figure 2). Peak average flow occurred on October 14 and never fell below 1,090 CFS for the remainder of the season. Turbidity ranged between 0.7 and 325 FNU, and stream visibility was greatly reduced following the increase in flow on October 8, when the river rose from 471 CFS to 1,380 CFS. A turbidity measurement was not available for September 17.

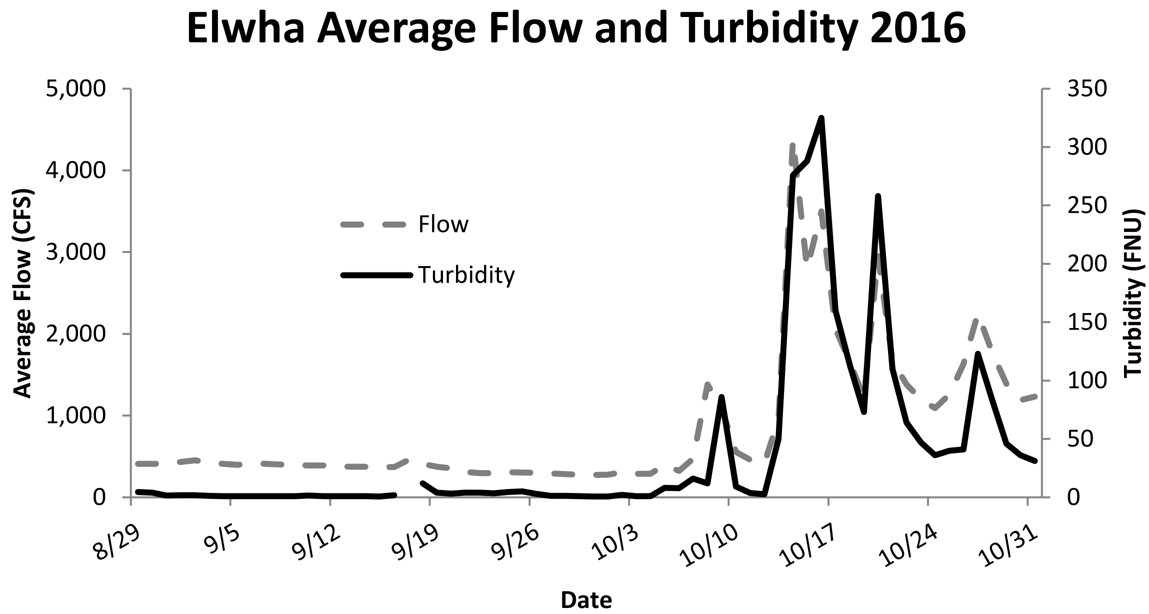

Figure 2. Average daily discharge (cfs) and turbidity (FNU) for the Elwha River, August 29 – October 31, 2016.

Evaluating hatchery mark rates

The primary hatchery marking strategy for brood years of Elwha Chinook salmon expected to return in 2016 was a thermal otolith mark (Table 2). Avoidance of the adipose clip was intended to reduce vulnerability to mark selective fisheries. Most hatchery Chinook salmon are released into the Elwha River as subyearlings, but there is also a smaller yearling release group (Table 2). All of the yearling releases from brood years 2011, 2013 and 2014, and a portion of the subyearling releases in brood years 2012 and 2013 received a CWT mark in addition to the thermal otolith mark (Table 2).

In some years, equipment malfunctions limited the capacity to induce thermal otolith marks. Thermal otolith marks require sequentially altering water temperature during embryonic development in a prescribed protocol over the course of approximately 1-3 weeks, and specialized chillers are required to accomplish this task. Any hatchery juveniles that were not otolith marked due to chiller malfunctions were selectively placed into the yearling program receiving the CWT mark (Table 2, brood year 2012).

Table 2. Releases of hatchery Chinook in the Elwha River Basin, brood years 2011-2014.

Brood Year	Type	Thermal Otolith	Thermal Otolith + CWT	CWT	AD + CWT + Thermal Otolith	Total
2011	Subyearling	1,524,769	0	0	0	1,524,769
	Yearling	0	196,575	0	0	196,575
2012	Subyearling	907,387	0	0	251,892	1,159,279
	Yearling	0	0	201,074	0	201,074
2013	Subyearling	2,388,947	0	0	251,024	2,639,971
	Yearling	0	177,269	0	0	177,269
2014	Subyearling	2,429,097	0	0	250,295	2,679,392
	Yearling	0	158,799	0	0	158,799

Potential Egg Deposition

We attempted to estimate the total potential egg deposition (PED) from fish that spawned naturally in the Elwha River during the fall of 2016. To do this, we first assumed:

1) The proportion of males to females of fish in the hatchery was similar to fish in the river. Methods used to capture fish for the hatchery were random and did not selectively target one sex, were behavioral differences between the sexes may bias carcass surveys from the spawning grounds.
2) The lengths of the females we sampled from all locations, including the hatchery and the river, was representative of the fish that spawned naturally in the river.
3) Females that were gaffed from the spawning grounds but not spawned by hatchery staff were assumed to already have spawned in the river (Troy Tisdale, WDFW, personal communication).

Using the above assumptions, we took the non-jack estimate of returning adults from the sonar sites and applied our ratio of males to females. This gave us the total number of returning females for the entire basin. To get the total number of females that spawned in the river, we subtracted all the females that were spawned in the hatchery or that were gaffed from the river and spawned. We then calculated the average length of all the females we sampled throughout the season. Using a regression relationship between size and fecundity, we estimated for the average fecundity for all females returning in 2016. To calculate the total PED for fish that spawned naturally, we multiplied the average fecundity by the total number of females spawning in the river.

Spawner to spawner productivity

In order to estimate productivity, we divided the total number of Chinook salmon spawning in each cohort 2004 – 2014 by the number of adults they produced that returned to the Elwha River in subsequent years. Our analysis began with the 2004 cohort because this was the first brood year with a mass marking goal at the hatchery of 100%. Following Peters' et al. (2014) guidelines, we calculated the productivity of Chinook salmon spawning naturally in the Elwha River, and the combined productivity of naturally spawning and hatchery spawned fish.

In our description of productivity methods and results, we distinguish between the terms “natural spawner” and “natural-origin.” We define “natural spawners” as fish that spawn naturally in the Elwha River and tributaries, regardless of whether they themselves were produced in a hatchery. Natural spawners could be marked or unmarked. We define “natural-origin” as unmarked fish whose parents spawned in the river. Natural origin fish could spawn themselves in the river, or be spawned at the hatchery.

Both productivity metrics required data on the proportion of hatchery-origin salmon returning to the river (pHOS), age structure and abundance. Data sources for hatchery mark and age information were WDFW unpublished, (Anderson et al. 2015), Weinheimer et al. (2015), Weinheimer (2016) and this report. The data source for abundance was Elwha Chinook SONAR reports (Denton et al. 2016 and previous reports). We calculated the total number of hatchery-origin and natural-origin adult salmon within each return year by multiplying total abundance by pHOS and (1 – pHOS), respectively. Hatchery-origin and natural-origin returns were allocated to the cohort that produced them according to the age structure data. Our approach relied to two assumptions, both necessitated by the extremely small number of unmarked, natural-origin salmon encountered over the years:

1. Marked hatchery-origin and unmarked natural-origin Chinook salmon have the same age structure.

2. Hatchery broodstock and Chinook salmon spawning naturally in the Elwha River have the same pHOS value.

Our metrics of productivity did not account for fish harvested in fisheries.

Results

Carcass Recoveries

We sampled a total of 554 Chinook carcasses throughout the sampling season (Table 3). A total of 264 samples (48%) originated from the Elwha River and tributaries. Of the fish sampled outside the hatchery, 88.3% were sampled above the former Elwha Dam site. Thirty four Chinook carcasses were collected between the Glines Powerhouse and ONP boundary and it could not be determined whether they were collected in reach 5 or 6. No carcasses were recovered during the single backcountry survey Sept 20-21.

The highest number of samples collected in one week from the river occurred during the week of Sept 19-23, and over three quarters (86%) of the samples we collected from the river were recovered during the month of September (Table 4). The number of carcasses found dropped significantly after October 7.

Sex data was recorded for each carcass. POH length was recorded for 545 (98.4%) carcasses and fork length for 505 (91.2%) carcasses. Otolith samples were taken from 542 (97.8%) carcasses, readable scale samples from 449 (81.0%) and DNA fin clips from 341 (61.6%). A total of 6 carcasses were sampled in Indian Creek (6) and Little River (0).

Table 3. Total number of Chinook carcasses sampled by survey reach in the Elwha River Watershed 2016.

Reach	Number of Carcasses Sampled	Percent of Total
Reach 1 - Elwha Dam Site to river mouth	31	5.60%
Reach 2 - Gooseneck to former Elwha Dam Site	5	0.90%
Reach 3 - Highway 101 Bridge to Gooseneck	6	1.08%
Reach 4 - ONP Boundary to Highway 101 Bridge	45	8.12%
Reach 5 - Altaire Bridge to ONP Boundary plus Hughes Creek	75	13.54%
Reach 5 and 6 - Powerhouse to ONP Boundary	34	6.14%
Reach 6 - Glines Powerhouse to Altaire	31	5.60%
Reach 7 - Rica to Glines	29	5.23%
Reach 8 - Grand Canyon to Goblins Gate	2	0.36%
Indian Creek	6	1.08%
Little River	0	0.00%
WDFW Hatchery	290	52.35%
Total	**554**	**100%**

Table 4. Number of Chinook carcasses sampled by week for individual reaches during the 2016 season. Zero indicates a survey was completed but no carcasses were sampled. A dash indicates no survey was conducted that week. No surveys were conducted during the weeks October 17-21 and 24-28 due to lack of carcasses.

Week	Reach									Indian Creek	Little River	Hatchery
	1	2	3	4	5	5,6	6	7	8			
Aug 29-Sept 2	0	0	0	0	-	-	-	-	-	-	-	20
Sept 5-Sept 9	13	-	-	0	-	2	-	-	-	-	-	46
Sept 12-Sept 16	9	1	4	7	7	13	-	-	-	-	-	59
Sept 19-Sept 23	5	-	-	21	28	19	-	11	-	-	-	52
Sept 26- Sept 30	4	4	2	16	22	-	19	14	2	5	-	48
Oct 3-Oct 7	0	-	-	0	18	-	12	4	-	1	-	65
Oct 10-Oct 14	-	-	-	1	0	-	-	-	-	-	-	-
Oct 17- Oct 21	-	-	-	-	-	-	-	-	-	-	-	-
Oct 24- Oct 28	-	-	-	-	-	-	-	-	-	-	-	-
Totals	31	5	6	45	75	34	31	29	2	6	0	290

Broodstock collection method

Most of the fish sampled at WDFW Hatchery were net-collected fish rather than volunteers to either the WDFW or LEKT Hatchery (Table 5). We sampled over two thirds of all the LEKT and gill net fish that came to the hatchery in 2016 and just over 62% of all volunteer fish to the WDFW Hatchery (Table 6). We sampled slightly more than 16% of the Chinook salmon gaffed for hatchery broodstock this season.

Table 5. Adult collection method summary for Elwha Chinook salmon carcass sampling 2016.

Sample Location	**Collection Method**	**Number of Carcasses Sampled**	**Percent of Total Carcasses Sampled**
Mainstem and Tributaries	Natural Spawners	234	42.24%
	Gaffed	30	5.42%
WDFW Hatchery	Gill net (N)	215	38.81%
	Lower Elwha Klallam (LEKT)	24	4.33%
	Volunteers (V)	51	9.21%

Table 6. Elwha Chinook salmon broodstock collection summary. Numbers include non-viable females and pond mortalities.

Broodstock collection method	Total Collected	Percent sampled
Gill net	314	68.47%
LEKT Hatchery volunteers	31	77.42%
WDFW Hatchery volunteers	82	62.20%
Gaffed	186	16.13%
Total	613	52.20%

Hatchery mark rates

We collected 542 otolith samples from Chinook salmon over the course of the season. Four hundred and eighty two (88.9%) of the samples had an otolith mark present. Of the remaining 60 samples, 34 had no otolith mark but did have a CWT present, two fish were ad marked but did not carry an otolith mark or CWT, and one fish could not be determined whether it had any external hatchery marks but had a CWT. In addition, an otolith from an undetermined species at the time of collection was identified in the lab as a chum salmon. Thus, 23 fish (4.2%) had no internal (Otolith or CWT) or external hatchery marks (Table 7).

Overall, the proportion of hatchery-origin Chinook salmon was 95.8%. We observed relatively little differences in the mark rates of the different survey reaches and hatchery broodstock sources (Table 7). Only two reaches, reach 7 and Indian Creek, had a mark rate < 90% (Table 7).

Table 7. Hatchery mark rates of Chinook salmon sampled from the Elwha River 2016 based on thermal otolith, adipose and CWT marks.

	Location	Otolith Mark		All Hatchery Marks	
		N	Percent Marked	N	Percent Marked
Hatchery	Net	212	89.62%	212	96.23%
	LEKT	22	81.82%	24	100.00%
	Volunteer	50	84.00%	50	100.00%
Carcass Survey	Reach 1	28	92.86%	28	96.43%
	Reach 2	5	100.00%	5	100.00%
	Reach 3	5	100.00%	6	100.00%
	Reach 4	44	93.18%	45	93.33%
	Reach 5	75	89.33%	75	97.33%
	Reach 5 and 6	34	85.29%	34	100.00%
	Reach 6	31	93.55%	31	93.55%
	Reach 7	29	82.76%	29	82.76%
	Reach 8	2	100.00%	2	100.00%
	Little River	0	0.00%	0	0.00%
	Indian Creek	5	60.00%	5	60.00%
	Total	542	88.93%	546	95.79%

CWT Data

We collected CWTs from 137 fish in the Elwha River watershed during fall 2016. Forty eight of those snouts (33.8%) were found in the river in reaches 3 through 6. We did not find any CWTs below the Gooseneck or above the former Glines dam. The majority of the CWTs originated from releases into the Elwha River, but some were derived from releases into the neighboring Morse Creek (N = 3) or Dungeness (N= 2) watersheds (Table 8). Fish that were released from the Elwha were mostly from the yearling program (66.4%), except for 44 tags from the 2012 brood year when a portion of the subyearling releases were coded-wire tagged (Table 2).

Table 8. Chinook Coded Wire Tag (CWT) data for snouts recovered during spawn year 2016.

	Sampling Location	# of Snouts	Brood Year	Release Location
River	Elwha Dam to Mouth	1	2013	Elwha River
	101 Bridge to Gooseneck	1	2012	Elwha River
	ONP Boundary to 101 Bridge	6	2012	Elwha River
		3	2013	Elwha River
	Altair to ONP Boundary	1	2011	Elwha River
		1	2012	Dungeness River
		16	2012	Elwha River
		1	2012	Morse Creek
		2	2013	Elwha River
		1	2013	Morse Creek
	Glines to ONP Boundary	2	2011	Elwha River
		10	2012	Elwha River
		1	2013	Elwha River
Hatchery	Net	2	2010	Elwha River
		1	2011	Dungeness River
		2	2011	Elwha River
		30	2012	Elwha River
		1	2012	Morse Creek
		10	2013	Elwha River
		1	2013	Morse Creek
	LEKT	4	2012	Elwha River
		14	2013	Elwha River
	Volunteer	8	2012	Elwha River
		18	2013	Elwha River
	Total	137		

Scale Data

Of the 547 scale samples collected, 449 (82.1%) were successfully aged in the laboratory. Age-4 was the dominate age class in each sampling reach and the netted fish at the hatchery, as over 61% of the entire collection was composed of age-4 Chinook salmon (Table 9). The highest percentage of age-5 Chinook salmon were collected from reach 3 which is just upstream of the former Elwha Dam site (Table 9). Only one age-6 fish was sampled at the WDFW Hatchery and was collected by netting. Twenty seven fish were aged as age 2 fish (jacks). Sixty four (14.2%) were identified as fish that migrated to the ocean as age-2 (stream-type Chinook, Table 10). All of these stream-type Chinook were hatchery origin. No scale samples were collected from Little River.

Table 9. Chinook carcass age data from scale samples by reach for the Elwha River 2016.

Sample Location	Collection Method	Number of Samples	Total age				
			2	3	4	5	6
WDFW Hatchery	Net	176	1.70%	8.52%	63.64%	25.57%	0.57%
	LEKT	22	9.09%	45.45%	45.45%	0.00%	0.00%
	Volunteer	48	37.50%	12.50%	45.83%	4.17%	0.00%
Reach 1	Carcass Sample	28*	3.57%	7.14%	50.00%	39.29%	0.00%
Reach 2		4	0.00%	0.00%	75.00%	25.00%	0.00%
Reach 3		2	0.00%	0.00%	50.00%	50.00%	0.00%
Reach 4		35	5.71%	5.71%	60.00%	28.57%	0.00%
Reach 5		62	1.61%	4.84%	74.19%	19.35%	0.00%
Reach 5,6		23	0.00%	0.00%	65.22%	34.78%	0.00%
Reach 6		21	0.00%	9.52%	71.43%	19.05%	0.00%
Reach 7		24	0.00%	8.33%	58.33%	33.33%	0.00%
Reach 8		0	0.00%	0.00%	0.00%	0.00%	0.00%
Indian Creek		4	0.00%	0.00%	100.00%	0.00%	0.00%
Little Creek		0	0.00%	0.00%	0.00%	0.00%	0.00%
All Samples		449	6.00%	9.33%	61.56%	22.67%	0.22%

*Includes 26 Gaffed fish

Table 10. Age at return of hatchery and unmarked subyearling and yearling releases 2016.

Origin	Age at Outmigration	N	Total Age				
			2	3	4	5	6
Unmarked	Subyearling	17	0	2	10	5	0
Unmarked	Yearling	0	NA	NA	NA	NA	NA
WDFW Hatchery	Subyearling	361	26	30	219	85	1
WDFW Hatchery	Yearling	63	0	9	42	12	0

Length

Postorbital-hypural lengths were taken for all but nine carcasses: one each from Reach 1, 6 and Indian Creek, four from Reach 7 and two from Reach 8 (Table 11). We sampled 505 carcasses for fork length (91.2%). All other carcasses we encountered were either too decomposed or torn up from predators to accurately measure. Of the carcasses collected from natural spawners in the river and its tributaries, there was no significant difference between those that were collected above vs. below the Elwha Dam site (above mean = 68.4cm, below mean = 66.3 cm, t-test $p > 0.10$). However, Chinook salmon sampled upstream of the Glines Canyon Dam site were significantly larger than those sampled below it (above mean = 70.8 cm, below mean = 67.8, *t*-test p = 0.02). Similar to both 2015 and 2016, at the hatchery, fish netted from the river were larger than either LEKT or volunteer fish, differences that were statistically significant (*t*-tests, p < 0.001). There was no difference in the size of fish that volunteered to the LEKT hatchery vs. the WDFW Hatchery (*t*-test, p > 0.10).

Table 11. Chinook average length (cm) data by reach for the Elwha River 2016.

	Sample Location	**Total Fish Sampled**		**POH**	
		Male	**Female**	**Male**	**Female**
Below Elwha Dam Site	Hatchery NET	97	118	66.8	71.6
	Hatchery LEKT	17	7	53.3	61.9
	Hatchery Volunteer	41	10	49.1	65.8
	Reach 1	7	23	63.2	67.5
	Below Average	-	-	60.7	70.2
Above Elwha Dam Site	Reach 2	1	4	67.0	71.0
	Reach 3	3	3	70.8	77.5
	Reach 4	24	21	67.0	66.5
	Reach 5	27	48	65.1	67.7
	Reach 5,6	17	17	67.4	68.8
	Reach 6	7	23	70.7	70.7
	Reach 7	10	15	70.0	71.4
	Reach 8	0	0	-	-
	Indian Creek	1	4	79.0	72.5
	Little River	0	0	-	-
	Above Average	**-**	**-**	67.4	69.0

Sonar Adult Abundance Estimate

Escapement of non-jack Chinook was estimated to be 2,628 fish above the SONAR sites (Denton et al. 2016). Fifty percent of the Chinook run had passed the SONAR sites by July 30th. By combining the carcass samples with the SONAR data, we estimate that 108 of the returning non-jack adults were natural-origin (Table 12). The 2016 return was dominated by age-4 hatchery-origin Chinook salmon that were released in 2012 as subyearlings (Table 12).

Table 12. Estimated age composition of returning adults to the Elwha River 2016, based on age data from scales and SONAR abundance estimates (Denton et al. 2016).

Origin	Juvenile life-history	Age				
		2	3	4	5	6
Natural	Sub Yearling	NA	13	63	32	0
	Yearling	NA	0	0	0	0
Hatchery	Sub Yearling	NA	190	1,387	538	6
	Yearling	NA	57	266	76	0

DNA Collection

We collected DNA fin clips from 341 Chinook salmon this season. In addition, fish ID number 800 was also collected for DNA and was identified as a chum after otolith and scale analysis. These samples are stored for future analysis at the WDFW Molecular Genetics Laboratory.

Productivity Metrics

Spawner to spawner ratios for natural spawners and natural plus hatchery spawners are available for complete brood years 2004 through 2011, and returns through age-4 are available for brood year 2012. Natural spawner productivity averaged 0.19, or one returning adult for every five natural spawners, well below the replacement value of 1.0 (Table 13). Hatchery and natural spawners had a combined average of 1.6 returning adults per spawner for complete brood years 2004-2011, and the last four complete brood cycles (2008 - 2011) have each exceeded the replacement value of 1.0 (Table 14). For the four most recent complete cohorts (brood years 2007 – 2011), natural productivity averaged 0.33 (Table 13), whereas the combined productivity of natural plus hatchery spawners averaged 2.5 (Table 14).

Table 13. Spawner per spawner ratio for naturally spawning Chinook salmon in the Elwha River, brood years 2004-2015.

BroodYear	Natural Spawners	Returning adults						Spawners per spawner
		Age-2	Age-3	Age-4	Age-5	Age-6	Total	
2004	2075	NA	16.4	47.4	0.5	0	64.2	0.03
2005	835	2.0	10.5	41.3	22.7	0	76.6	0.09
2006	693	0	2.3	10.1	0.1	0	12.6	0.02
2007	380	0.0	15.8	17.3	5.9	0	39.1	0.10
2008	470	8.6	29.2	66.3	5.9	0	110.0	0.23
2009	678	6.0	147.4	144.8	32.4	1.6	330.6	0.49
2010	569	11.8	47.0	95.1	32.6	0.2	186.4	0.33
2011	852	4.4	38.4	150.6	25.1		218.5	0.26
2012	1480	1.2	46.0	68.1			115.4[A]	0.08[A]
2013	2313	1.9	10.3					
2014	2513	6.6						
2015	2548							

[A] Incomplete cohort, age-5 offspring will return in 2017.

Table 14. Spawner per spawner ratio for all spawners (natural + hatchery origin) Chinook in the Elwha River, brood years 2004-2015.

BroodYear	Hatchery + Natural Spawners	Returning adults						Spawners per spawner
		Age-2	Age-3	Age-4	Age-5	Age-6	Total	
2004	3,439	NA	143	279	23	0	445	0.13
2005	2,231	29	784	2,053	507	0	3,372	1.51
2006	1,920	0	116	226	5	0	347	0.18
2007	1,140	0	354	613	67	0	1,034	0.91
2008	1,137	191	1,034	756	123	0	2,105	1.85
2009	2,192	210	1,680	3,041	846	28	5,806	2.65
2010	1,278	134	986	2,481	576	6	4,183	3.27
2011	1,862	92	1,003	2,660	596		4,351	2.34
2012	2,638	31	813	1,618			2,462[A]	0.93[A]
2013	4,243	34	245					
2014	4,360	158						
2015	4,112							

[A] Incomplete cohort, age-5 offspring will return in 2017.

Fecundity

Over the course of the season we sampled 27 females for fecundity at the hatchery. The POH length of the females ranged between 56 cm and 81 cm and fecundity ranged between 3,037 and 8,373 eggs per female. Larger fish had more eggs (Figure 3) and but unlike the 2015 season, larger fish did not necessarily have larger eggs (Figure 4). We estimate a total PED of 5,981,472 for natural spawning Chinook in the Elwha River for 2016. The hatchery collected 1,052,700 eggs for broodstock from netted, volunteer, gaffed and LEKT fish.

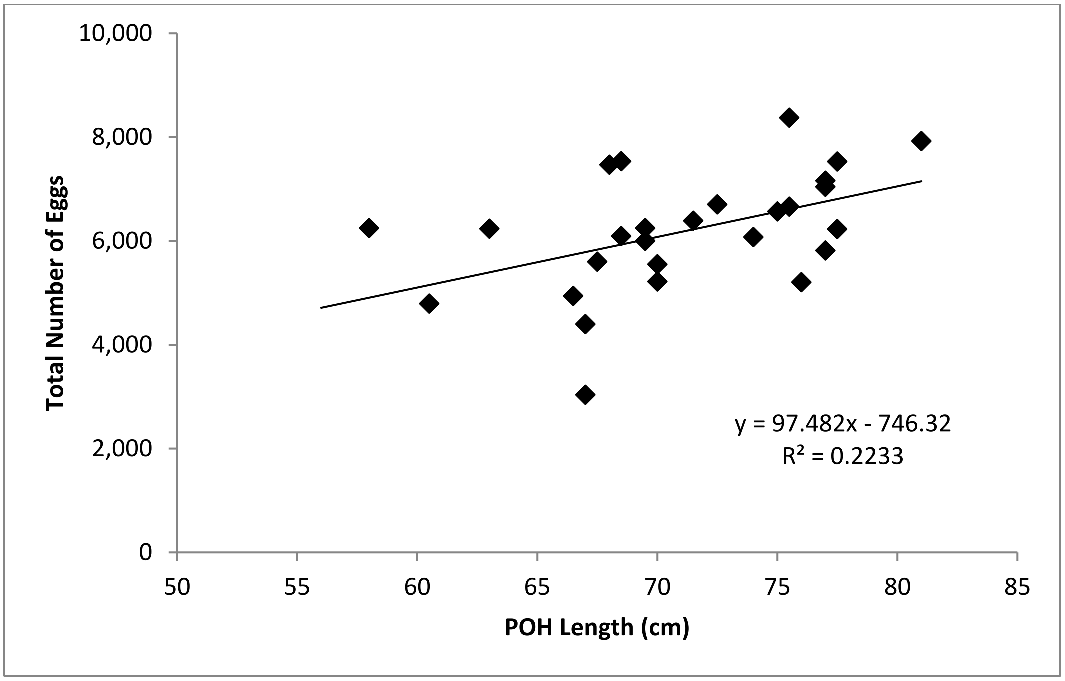

Figure 3. Fecundity and POH length for 27 female Chinook sampled at Elwha River Hatchery, 2016.

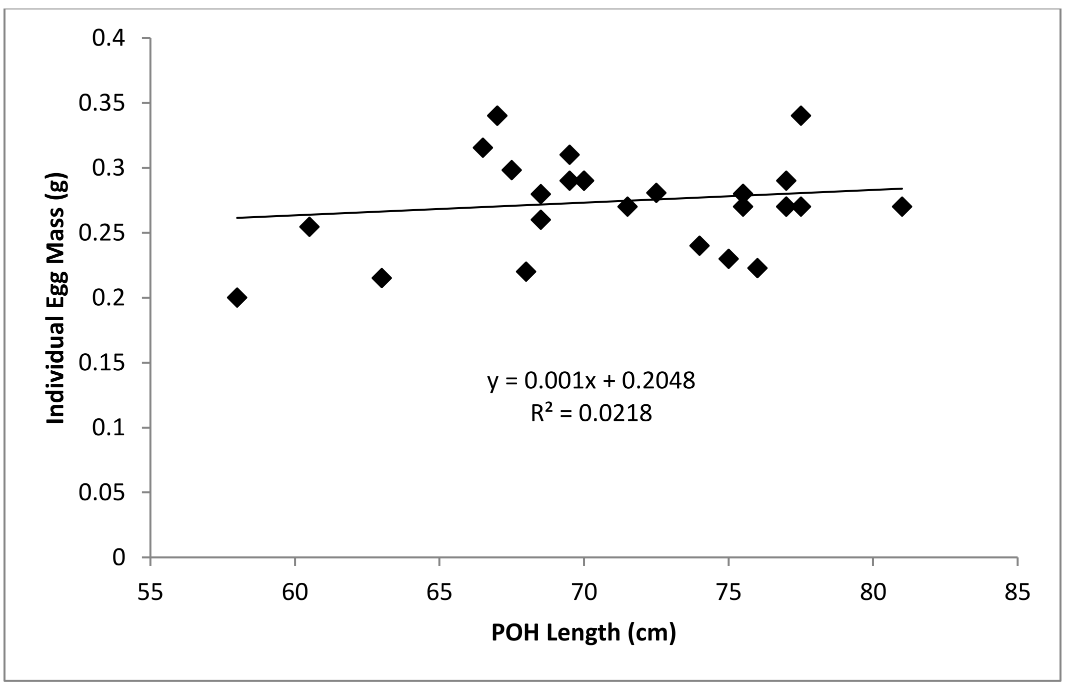

Figure 4. Individual egg mass and POH length for 27 female Chinook sampled at WDFW Hatchery, 2016.

Discussion

The fall of 2016 was the third year of our Chinook carcass recovery project on the Elwha River between the former Glines dam site and river mouth. In 2016, we sampled 300 less fish compared to the 2015 season (Table 15).

Table 15. Total Chinook recoveries for Elwha River, 2014-2016.

Sampling Year	Reach									Hatchery	Indian Creek	Little River	Total Chinook Sampled	Percentage of non-jack Return
	1	2	3	4	5	5,6	6	7	8					
2014	36	41	27	54	40	-	85	-	-	500	19	0	802	18.28%
2015	45	26	49	85	64	-	62	-	-	487	10	26	854	20.62%
2016	31	5	6	45	75	34	31	29	2	290	6	0	554	20.05%

Sampling conditions during 2016 were good during the month of September and more difficult for most of October. In past seasons, turbidity levels of 6 FNU or higher significantly limit our surveyors' ability to see carcasses deeper than 30 cm (Weinheimer et al. 2015, Weinheimer et al. 2016). During 2016, average daily turbidity did not exceed 6 FNU until October 6th. Turbidity only dropped below 6 FNU one time (October 12) for the remainder of October. Average daily river flow did not exceed 1,000 cfs in September; however during the month of October, average daily flow was only below 1,000 cfs for 9 of the possible 31 days.

We recovered 264 carcasses between Idaho Creek in Geyser Valley and the mouth of the river. At the WDFW Hatchery, we successfully sampled 290 (86%) of the 337 spawned fish. Our total sample of 527 non-jack Chinook, represented 20.05% of the fish that were estimated to have passed the sonar site in the lower river (Table 15).

We found that 4.2% of the fish we sampled did not carry any hatchery marks. This is similar to what has been reported from 2010-2014 (Anderson et al. 2015; Weinheimer et al. 2015). Hatchery-origin fish continue to dominate the population demographics of Elwha River Chinook salmon (Figure 5). Currently in the initial Preservation phase of the Elwha Monitoring and Adaptive Management Guidelines, there are no specific objectives for the percent of natural origin spawners (pNOS) to trigger movement to the subsequent Recolonization phase (Peters et al. 2014). The management goal of the Preservation phase is to protect the species from extinction during the period when high sediment loads are expected, at times, to be lethal to fish. Transition to the recolonization phase will largely be triggered by productivity targets, as the spatial distribution trigger ("portion of population accessing above Elwha Dam") has already been met (McHenry et al. 2016), the abundance trigger (natural spawners > 950) has already been met (Denton et al. 2015, and prior SONAR reports) and there are no diversity triggers (Peters et al. 2014).

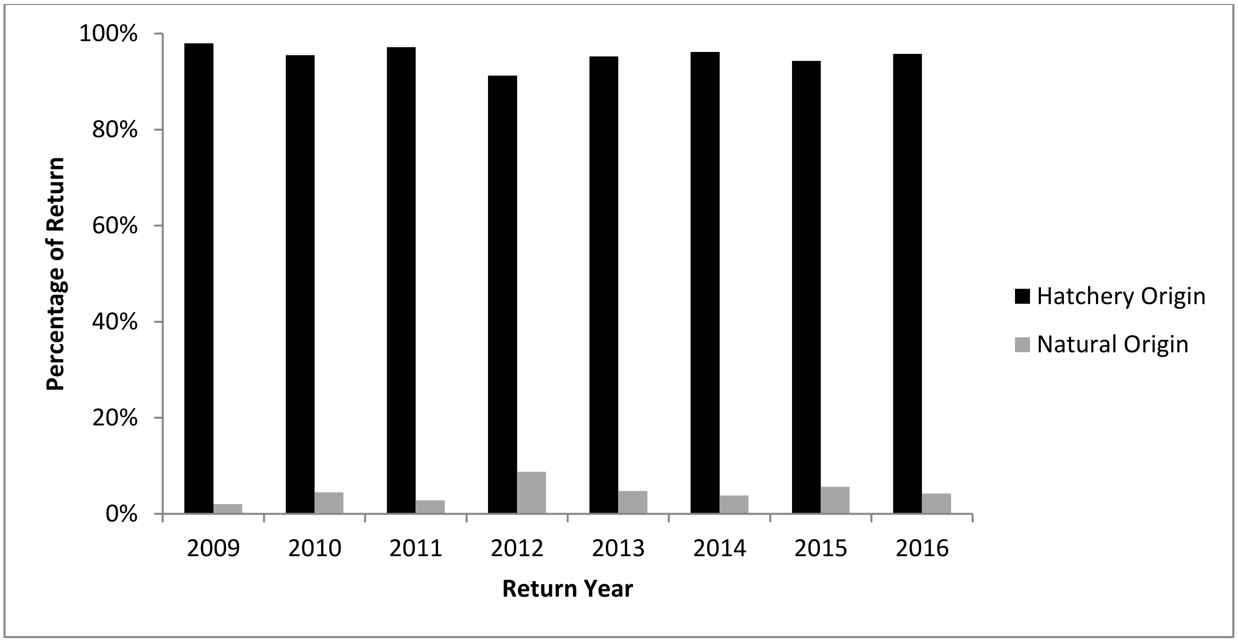

Figure 5. Natural and hatchery origin adult Chinook proportions for the Elwha River, return years 2010-2016.

Similar to 2014 and 2015, we found no support for our two hypotheses regarding the spatial distribution of hatchery mark rates and stream-type life histories. Hatchery mark rates did not consistently decrease in an upstream direction from the WDFW Hatchery in 2016, although we did observe the lowest hatchery mark rate (83%) in the Lake Mills reach 7. This was the first year in which we obtained carcass samples from Chinook salmon upstream from the Glines Canyon dam site; it will be important to continue measuring hatchery mark rate in the upper watershed in future years to determine if this is a sustained pattern or a one year aberration, potential due to a low sample size (N = 29 in Lake Mills reach). Overall, hatchery fish appeared to distribute themselves evenly through all the reaches we sampled with the highest percentage occurring in reaches 2, 3, 5 and 6. We did not observe any stream-type life histories among natural-origin fish, and thus could not evaluate their spatial distribution. We plan to continue to assess these hypotheses via carcass recovery in future years.

The percentage of two year old fish (jacks) was the third highest we have observed since 2010 (Table 16). All of the jacks we sampled were of hatchery origin and were determined to be age-0, based on scale analysis, when they went to the ocean. This marks the third season in a row where no natural-origin jacks have been collected from cohorts whose parents could have spawned above Elwha Dam beginning in 2012.

Table 16. Age composition from scale samples from Elwha Chinook. 2010-2013: Elwha weir, 2014-2016: carcass + hatchery.

Sampling Year	Number Samples	Age				
		2	3	4	5	6
2010	401	14.96%	27.68%	17.71%	39.65%	0.00%
2011	407	11.30%	55.53%	32.92%	0.25%	0.00%
2012	157	5.10%	63.69%	28.66%	2.55%	0.00%
2013	413	2.18%	23.24%	71.67%	2.91%	0.00%
2014	738	0.68%	23.04%	56.91%	19.38%	0.00%
2015	728	0.82%	19.78%	64.70%	14.01%	0.69%
2016	449	6.00%	9.33%	61.56%	22.67%	0.22%

The 2016 season was the first season in which returning age-3 and age-4 natural-origin adults might be progeny of fish that spawned above the Elwha Dam in the fall of 2012. Based on the high volume of river material that was deposited downstream of the dam site following removal, one might hypothesize that survival could have been higher for fish that migrated upstream from the Elwha Dam site, particularly fish that recruited into the middle Elwha tributaries (Little River or Indian Creek) during the fall of 2012 because these areas were unaffected by dam removal. If this were the case, we would expect to observe a higher proportion of unmarked natural-origin adults at age-3 and age-4 for 2016 vs. age-3 prior to 2015 and age-4 prior to 2016. However, the hatchery mark rate for age-3 fish was similar in 2015 and 2016 to previous years; the hatchery mark rate for age-4 in 2016 was also similar to previous years (Table 17). Thus, we do not have any evidence that access to spawning grounds upstream of the former Elwha Dam increased the total number of naturally produced adults returning to the Elwha River to date.

Table 17. Hatchery mark rate from scale samples of Chinook from the Elwha, return year 2014-2016.

Return Year	Number of Age 3	Hatchery Mark Rate	Number of Age 4	Hatchery Mark Rate
2012	73	98.6%	68	92.7%
2013	56	84.9%	183	98.4%
2014	170	97.7%	420	94.8%
2015	144	93.8%	469	95.5%
2016	41	95.1%	271	96.3%

Age-4 were the dominant age class is 2016, with just over 61% of all the carcasses sampled (Table 16). We also sampled 1 otolith marked fish that was aged as a 6 year returner. This is the second year in a row we have sampled an age 6 fish (Table 16). Furthermore, we observed > 10% age-5 fish for the third consecutive year, after three years in which age-5 fish were < 3% of the population (Table 16). Historically, the Elwha River was known for larger size Chinook, which may have been a local adaptation needed to negotiate the high velocity flows created by the steep topography of the watershed. To reach larger sizes, Chinook may have needed to spend extra years in the ocean and returned as age 5 or older adults.

The 2016 season marked the second year in a row we collected fecundity information from females at the hatchery. This information allowed us to estimate a total potential egg deposition (PED) for natural spawning Chinook in the basin. Our estimate suggests that naturally spawning Chinook salmon deposited nearly 6 times as many eggs compared to those spawned at the hatchery. Combining PED with freshwater productivity data from the mainstem smolt trap operated by the Lower Elwha Klallam Tribe (McHenry et al. 2015), we can estimate egg to migrant survival. Increasing egg to migrant survival with fish accessing the more stable river habitats upstream of the former Glines Canyon Dam site would be indicative of progress towards recovery.

Similar to 2015, we also measured egg mass, which we hypothesize to increase in future years if a greater portion of the population is natural-origin. Salmon hatcheries typically relax selection for larger eggs because the hatchery environment is more benign than the more dynamic river, and instead select for greater egg number (Heath et al. 2003). Elwha Hatchery staff have noticed a trend towards smaller eggs over the years. We unfortunately did not sample any natural origin females in either our 2015 or 2016 fecundity samples. The average sizes of individual eggs were similar between the 2015 and 2016 (Table 18). In future years, if selection on the egg size vs. egg number tradeoff is largely shaped by the river rather than the hatchery, we might observe evolution for larger eggs. We hope to continue monitoring Elwha Chinook salmon egg size to test this hypothesis.

Table 18. Average Chinook egg size of fish sampled at the Elwha Hatchery, return years 2015 and 2016. Weight reported in grams.

Return Year	Number Females Sampled	Average Individual Egg Mass (g)	Range Individual Egg Mass (g)
2015	26	0.25	0.19-0.30
2016	27	0.27	0.20-0.34

Finally, in this report, we provided estimates of spawner to spawner productivity. The results for natural spawners are striking, as fish spawning in the river failed to replace themselves in each cohort, and most cohorts fell far short of replacement. All of the complete cohorts for which we reported productivity (brood years 2004 – 2011) spawned before removal of Elwha Dam, and therefore were restricted to poor quality spawning habitats in a reach of the river that had been starved of sediment for almost a century. A crucial question is whether productivity increases once Chinook salmon access habitats upstream of the former dam sites, particularly above Glines Canyon Dam, where the river is not subject to the instability related to the movement of sediment from the former reservoirs.

Conversely, productivity of the combined hatchery and natural spawners exceeded replacement in each of the last four complete cohorts (brood years 2008 - 2011). This contrast to the natural spawner data provides evidence that the hatchery has maintained abundance of the population and is dominating population demographics. The role of the hatchery during the initial Preservation phase is to ensure that the unique genetic diversity of Elwha Chinook salmon does not go extinct during the large-scale disturbance to the Elwha River caused by dam removal (Peters et al. 2014). Our analysis suggests the hatchery has successfully accomplished this goal to date.

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