STATE OF WASHINGTON March 2015

Elwha River Weir Project: 2013 Operations and Final Summary Report

Joseph Anderson, Michael Mizell,
Michael Ackley, Kent Mayer,
Mara Zimmerman (WDFW)
and
Patrick Crain (ONP)

Washington Department of Fish and Wildlife
Fish Program Science

FPT 15-03

Elwha River Weir Project:

2013 Operations and Final Summary Report

Joseph Anderson, Michael Mizell, Michael Ackley, Kent Mayer, Mara Zimmerman (WDFW)

and

Patrick Crain (ONP)

Washington Department of Fish & Wildlife
600 Capitol Way N.
Olympia, WA 98501

Olympic National Park
600 E. Park Avenue
Port Angeles, WA 98362

March 2015

Report# FPT 15-03

Acknowledgements

Many, many technicians and volunteers contributed to the Elwha weir project since its inception in 2010. We are particularly grateful to Andrew Simmons, Noel Ferguson, James Crook, Sean Hildebrandt, Hunter Stansel and James Starr for their dedicated efforts and hard work in very difficult conditions. Dan Spencer (U.S. Fish and Wildlife Service) constructed the first weir components and offered technical assistance. Scott Williams, Troy Tisdale, and Vern Madison generously provided tools, equipment and essential space at the WDFW Elwha Rearing Channel for weir construction, repair and maintenance. We are grateful to Christopher O'Connell, Cheri Scalf, Larry Bennett, Mike Gross, Roger Mosley, Andrew Simmons, and Randy Cooper for sampling carcasses from Chinook salmon at the WDFW Rearing Channel, sampling pink salmon carcasses at the Lower Elwha Klallam Tribe hatchery, and providing Chinook salmon escapement and carcasss data. Keith Denton provided data from the Elwha SONAR project and assisted with weir construction and installation. Jeff Duda (United States Geological Survey), Sam Brenkman (National Park Service), Roger Peters (U.S. Fish and Wildlife Service), George Pess (National Oceanic and Atmospheric Administration), Mike McHenry (Lower Elwha Klallam Tribe) secured funding for the project and providing valuable input on the use of the weir as a monitoring tool. Access to the weir site was granted by the Green Crow Timber Company and an anonymous property owner. Construction and initial operation costs were provided by the United States Geological Survey (USGS) through a USGS-NPS Natural Resource Preservation Program (NRPP) project (PMIS Project # 149053) and flex funds from the Northwest Area office. Subsequent operation funds were provided by NOAA Fisheries, the United States Fish and Wildlife Service (USFWS), the United States Environmental Protection Agency (EPA), the Washington State Recreation and Conservation Office (RCO) and the NPS. George Pess, Mike McHenry, Jeff Duda, Sam Brenkman, Roger Peters, Randy Cooper, Mike Gross, Scott Williams, and Troy Tisdale provided valuable reviews of this report.

Executive Summary

The Washington Department of Fish and Wildlife (WDFW) seasonally operated a floating resistance board weir on the Elwha River (river kilometer 5.9) from 2010 – 2013. Over the course of the project, the weir was adaptively managed, as both the timing of operation and equipment design evolved in response to project results and the dynamic conditions encountered in the river. The Elwha weir's initial goal was to capture, enumerate, and sample the majority of adult salmonids, with a particular focus on Chinook salmon and steelhead trout, which are listed as threatened under the Endangered Species Act. However, in reality, the Elwha weir was unable to estimate either abundance or migration timing of Chinook salmon and steelhead due to low catch of upstream migrating fish. The river flows at which the weir could be safely installed and operated were lower than envisioned at project inception, especially when sediment accumulation following dam removal substantially reconfigured the channel at the weir site, concentrating discharge in a high velocity slot. As a result, the weir was operated for a narrow range of dates in the spring and summer, and even during these periods, often fished at low efficiency due to panels continually sunk by debris accumulation. As the project progressed, it increasingly focused on Chinook salmon because this species' summer migration timing coincided with the period of lowest flow in the Elwha River. However, Chinook salmon appeared reluctant to enter the upstream traps, raising concerns that the weir impeded upstream migration and thus delayed natural colonization following dam removal. The weir did capture large numbers of Chinook salmon moving downstream, both live and dead. These downstream moving fish were difficult to interpret in the context of abundance and migration timing, but provided a large collection of biological data including body size, scale, otolith and DNA samples, and hence important information on age structure, life history diversity and the proportion of hatchery marked fish. Ultimately, the restricted operational season and low capture efficiency of upstream migrating fish limited the weir's effectiveness as a monitoring tool. We recommend that the activities supported by the weir be replaced by other actions already approved for use in the Elwha River under NOAA and USFWS Biological Opinions and permits. Specifically, we recommend that the existing Elwha SONAR operation and its associated species composition net sampling program, which has proven successful at enumerating upstream migrating adult fish, be used as the primary tool for future estimates of adult abundance and run-timing for ESA listed Chinook salmon and steelhead. Stock composition (e.g., hatchery vs. natural origin, age structure, life history diversity) can be informed by intensive carcass surveys for Chinook salmon, and by opportunistically sampling during fish capture events such as the netting efforts for SONAR species composition and implanting radio telemetry transmitters.

Table of Contents

List of Tables

List of Figures

Introduction

The Elwha River poses significant challenges for traditional methods used for evaluating abundance and run-timing of adult salmonids. Over 80% of the watershed is located within Olympic National Park (ONP), most of which is inaccessible by road. For a portion of the year, water clarity limits traditional spawner counts in the mainstem channel. High flows, which occur when many salmon species are present, lead to unsafe conditions for snorkeling and wading. These conditions were exacerbated in the lower Elwha River by the effects of dam removal.

The Washington Department of Fish and Wildlife (WDFW) seasonally operated a floating resistance board weir with multiple fish traps on the Elwha River from August 2010 to September 2013. The weir supported the National Park Service (NPS) Elwha River Restoration Project and was located at river kilometer 5.9. The structure was one of the largest resistance board weirs ever operated in Washington State, spanning a 60 meter wide channel. At the outset, the weir offered a promising method of intercepting adult salmonids on their upstream migration in a largely inaccessible watershed. When feasible to operate, adult capture weirs can provide a nearly complete census of upstream migrating adult salmonids (Zimmerman and Zabkar 2007). However, due to the large scale of the project and the challenges presented by the Elwha River, most collaborators considered the weir experimental. The period from 2010 – 2013 was used to evaluate whether or not it could effectively enumerate and sample adult salmonids.

The purposes for the weir, as stated in an initial project proposal (Duda and Brenkman 2008), were to:

1) Provide the best estimate for numbers of returning federally listed and non-listed salmonids;
2) Determine return rates of hatchery versus wild fish;
3) Determine migration timing of Elwha River salmonids;
4) Provide a foundation apparatus and data set for research and monitoring questions related to the recovery via dam removal of Elwha River salmonids; and
5) Monitor bull trout populations migrating within the Elwha River to determine whether anadromy returns to portions of the population that have been isolated above the dams for over 95 years.

Additional potential uses for the weir emerged after initiation of the project including collection of broodstock for the WDFW Chinook hatchery program (NMFS 2012), assistance with the removal of non-native early winter segregated hatchery steelhead, and species composition information to complement the counts of fish determined by the SONAR project operating near the river mouth (ONP 2013).

Monitoring goals for the weir were developed to contribute to the investigation of Viable Salmonid Population (VSP) parameters associated with ESA-listed species: abundance, productivity, spatial structure and diversity (McElhany et al. 2000; Peters et al. 2014). The original objective was to provide a nearly complete census count of adult salmonid abundance as fish migrated upstream past the weir site. A second method explored for adult salmonid enumeration was SONAR technology; the relative proportions of species encountered at the weir would aid the SONAR program by providing the direct visual observations needed to translate sonic imagery lacking species identification into abundance estimates. The weir would contribute to productivity metrics by providing a) the age data needed to reconstruct spawner to spawner recruits from an abundance time series, and b) estimates of smolts per spawner when combined with Lower Elwha Klallam Tribe (LEKT) smolt trap data. In terms of diversity, the weir was intended to provide data on migration timing, the proportion of hatchery origin spawners (pHOS), relative frequencies of stream vs ocean-type Chinook salmon juvenile life histories via scale samples, age structure via scale samples, and DNA samples for genetic analysis. For spatial structure, the weir was intended to provide a capture and tagging platform for telemetry studies designed to track dispersal and distribution of fish within newly accessible upstream habitats.

There are significant logistical challenges in operating a weir on a river as large as the Elwha River. Some of these challenges were foreseen (e.g., maintenance of the large structure), while others became apparent after one or more seasons of operation. The Elwha weir was originally envisioned to operate at flows below 2000 cubic feet per second (cfs), with a capability of being rapidly removed when flows threatened to exceed 2000 cfs and immediately deployed when flows dropped back below that level. Based on observed flows, it was originally estimated that the weir would be operational for more than 80% of the run time for Elwha River salmonid stocks (Duda and Brenkman 2008). However, once the weir was installed, operation proved to be more limited than anticipated due to rapid changes in the channel during dam removal, complications due to gravel accumulation at the site, heavy debris loading, and other related issues. By the 2012 season, it was recognized that operation of the weir was only feasible during the spring (approximately March to May) and summer (approximately July – October), outside periods of peak flow (see Figure 1.15 in Duda et al. 2011). Even under this operational schedule, high flow hindered installation and operation of the weir, limiting the number of effective capture days.

In 2013, the lower Elwha River was rapidly responding to the removal of Elwha Dam such that the changes in river geomorphology, turbidity, and flow impacted the potential for weir operations (East et al. 2015). Due to the extremely difficult conditions encountered at the site, no attempt was made to install and operate the weir during the spring. The summer season was the only period during which it was feasible to operate the weir, and so monitoring objectives were narrowed to primarily focus on a single ESA-listed species in the Elwha River: Chinook salmon. In 2013, our primary objectives were to:

1) Estimate abundance of Chinook salmon
2) Estimate migration timing of Chinook salmon
3) Collect biological samples (sex/length, scales, DNA, otoliths) from Chinook salmon

Our secondary objectives in 2013 were to:

4) Collect broodstock for Chinook and pink salmon hatchery programs
5) Collect biological data on salmonids other than Chinook salmon

In this report, we describe operational logistics for the 2013 season, summarize data collected by the weir between 2010 and 2013, evaluate the Elwha weir's effectiveness as a monitoring tool, and offer suggestions for modifying monitoring approaches to provide data essential to the implementation of the Elwha River Restoration Project.

Methods

Operational protocols of the Elwha River weir are described in other reports (Mayer et al. 2011; Mayer and Zimmerman 2012; Mayer et al. 2015). In the following section, we primarily describe modifications made to the weir to improve its function during the 2013 trapping season.

Weir redesign for 2013

In the summer/fall 2013, several features of the weir were completely redesigned from previous trapping seasons. The new features included a (1) contour conforming rail, (2) “winged” resistance boards, (3) carabineer attachments between the panels and substrate rail, (4) a “snow” anchor system, and (5) an experimental trap design that could be configured in an upstream or downstream direction. Redesign elements were necessitated by the dramatic changes in channel configuration at the weir site caused by sediment deposition and were intended to improve catch of adult Chinook salmon travelling in an upstream direction.

A new contour conforming rail made it possible to install the weir in 2013. By spring of 2013, the river cross-section at the weir site had changed dramatically from the start of the weir project in 2010. The original substrate rail was buried in up to 2 m of sediment, rendering it non-functional. A new substrate rail composed of steel H-beam links was fabricated and installed (Figure 1 and 2). The linked rail conformed to the newly developed contours of the river bottom, including two large gravel bars and two deep channels that had emerged during the course of the project. The links were fitted with tabs so that they could be bolted together and deployed in a line using a high powered winch. A rail was welded along the long axis of each steel beam to facilitate the panel attachment.

Figure 1. Newly designed, channel conforming substrate rail exposed on central gravel bar, looking from left bank channel across to right bank channel. Photo taken July 24 2013, discharge = 1,050 cfs (USGS gage 12045500).

Figure 2. Link substrate rail system, visible in the foreground, with attached weir panels. Photo taken Aug 7, 2013, discharge = 760 cfs (USGS gage 12045500). Photo taken from central gravel bar looking back toward left bank channel.

New winged panels on the resistance boards increased the weir's ability to effectively fish at the water velocities observed in 2013 (Figure 3). Resistance boards, made of 5.1 cm foam insulation sandwiched between two 46 x 91 cm pieces of 0.95 cm high molecular weight polyvinyl chloride, were attached to the downstream (i.e., floating) end of each panel. "Wings" were added to the resistance boards in 2013 which created more lift and effectively doubled the efficiency (water speeds) that the panels could remain fishing. Heat bendable acrylonitrile butadiene styrene (ABS) plastic was bent longitudinally at a 40 degree angle and attached using a piece of aluminum round stock to the existing resistance boards. The outer three bolts holding the sandwiched material together were changed to eye bolts of similar length, and the rod was passed through the eye bolts after the molded wings were placed over them.

Modifications were also made to facilitate weir operations despite the increased debris loads experienced following upstream dam removals. Panels were attached to the substrate rail using new stainless steel carabineers, which eliminated the use of "P" or "J" hooks. This new attachment method allowed for quick panel attachment or removal, even while the weir was fishing. In addition, an Amsteel line was run on the downstream end of the trap and "bridles" were attached to the resistance board stringers on panels under the greatest stress from high flow conditions. This approach helped keep the panels above water overnight when staff could not safely use manual labor to remove the accumulated debris.

Figure 3. Winged resistance boards.

A new “snow” anchor system was adopted in order to effectively anchor weir components in the river. We found that “duckbill” anchors used in previous seasons were not effective for anchoring equipment in stream due to the unconsolidated composition of the sediment. Despite burial to depths of five feet, the “duckbill” anchors were easily removed manually. New anchoring units were developed along the principles of snow anchors used in mountaineering, as the loose accumulated sediment acted more like snow than solid substrate (Figure 4). Two pieces of 5 cm by 7.6 cm steel angle were welded together and a small piece of steel pipe was welded on top. The steel pipe was designed to receive a steel rod used to hammer the anchors into the substrate. The new anchors held effectively through all flow conditions.


Figure 4. Redesigned “snow” anchor used to secure weir components in loose sediment.

An experimental trap design was explored that would fish interchangeably in an upstream or downstream direction. The newly designed trap used a pipe attached to a panel with a special insert that converted the structure into either an upstream or downstream trap (Figure 5). This design did not perform as well as expected (although it did capture a few fish) due to a constant accumulation of gravel under the pipe opening and the shallow placement of the panel. The design concept warrants further testing as this structure may be useful in a more normal river setting where sediment transport and accumulation is not as extreme as the Elwha River following dam removal. We also fished standard traps during the 2013 season, one located near each bank of the Elwha River. For all traps, capture boxes were constructed from aluminum and measured 1.8 m x 1.2 m x 1.1 m.

Figure 5. Experimental "pipe" trap oriented in downstream direction to capture fish moving in an upstream direction. Photo taken Aug 15 2013, discharge = 750 cfs (USGS gage 12045500), from central gravel bar looking towards right bank channel.

Weir operations 2013

We planned to operate the weir continuously between August and September 2013. The weir operates most effectively when all panels are floating on the water surface. Significant staff time was allotted to manually removing debris and ensuring that the panels remained floating. Despite these efforts, sediment, debris, and river flows contributed to several periods where the panels were submerged during the season.

The weir site in 2013 was much different from previous years due to the formation of two large gravel bars. This created two main channels, with the left bank channel receiving approximately 40% of the flow and the right bank channel receiving approximately 60% of the flow (Figure 6). Due to the two channel formation of the site in 2013, water velocities were much greater in 2013 than experienced at the weir site in the 2010-2012. During typically trapping days between August and September 2013, water velocity in the right bank channel was approximately two meters per second. This was approximately equivalent to the velocity of 1400 cfs spread over the full bank width in 2012. In the descriptions that follow, all river discharge values refer to USGS stream flow gage 12045500 at McDonald Bridge.

In 2013, the Elwha weir was installed on August 5 at a flow of 814 cfs and was considered fish tight on August 7. The weir was removed on September 28 in response to a large storm that caused discharge to exceed 10,000 cfs on the day of removal.

Figure 6. Elwha weir site during summer 2013 trapping period. The left bank channel (approximately 40% of flow) is in the foreground and right bank channel (approximately 60% of flow) is in the background. Note exposed central gravel bar mid-channel. Photo taken Aug 15, discharge = 750 cfs (USGS gage 12045500).

Two high flow events during the 2013 trapping season compromised the fishing efficiency of the Elwha weir. The first event, with a peak flow of 1,570 cfs, occurred between August 28th and 31st. Weir panels were submerged for approximately 43 hours between August 28th at 1700 and August 31st at 1200. The second event occurred between September 22nd and 25th and had a peak flow of 1,620 cfs. During this event, weir panels were submerged for approximately 62 hours. Although the panels were submerged during these two events, the traps continued to catch some fish.

Intermittent panel submersion occurred on nearly a daily basis due to the nighttime build-up of debris on the weir. Over the course of each night, debris would build up to the point that the river would sink one to three panels in the highest velocity section of the river channel. The panels would not sink more than a few centimeters below the surface. Night cleanings were performed during the worst of the debris and flow periods, until the water levels dropped enough that the panels would stay up overnight. In addition, bridles connected from the weir to a high line run across the width of the channel provided additional lift intended to increase the height of the weir panels relative to the water surface (Figure 7). Netting was attached to the downstream ends of the panels to make it difficult for upstream migrants to navigate the breach.

Figure 7. Weir panels with bridles and winged resistance boards, partially sunk from debris loading. Photo taken Aug 13 2013, discharge = 652 cfs (USGS gage 12045500), from central gravel bar looking towards right bank channel.

Fish collection

When in operation, the weir fished 24 hours a day and trap boxes were checked several times a day, depending on the number of fish present, stream flow, and debris loads. Personnel remained at the weir site for most of the day in order to enumerate and collect samples from carcasses and live fish. One anomaly for the 2013 season was that upstream moving Chinook and pink salmon were able to swim through a near nightly small breach in the weir due to a panel (sometimes two or three) dipping due to debris buildup. Based on observation of this behavior, many of these fish would subsequently rest in front of the weir, finning slowly back and forth across the panels. These fish were easily dip-netted from the upstream side of the weir. Live fish migrating downstream were also netted from the upstream side of the weir or captured in a downstream trap. Carcasses or senescent post-spawners were recovered after drifting downstream onto weir panels.

Biological data collected from adult salmonids included species, sex, spawn condition, fork length, presence of coded-wire tag, presence of PIT tag, fin mark (adipose clip), scale samples, and DNA samples. The direction of travel (upstream or downstream) and condition (live or carcass/dead) were recorded.

Fish were handled using a cradle hung on the inside of the trap and partially submerged in the river in order to keep fish stable, hydrated and oxygenated. Data collection from live fish generally took 3-4 minutes. Following data collection, fish were either held as broodstock or placed back into the river in the same direction they were traveling when captured.

All fish were scanned for the presence of coded wire tags (CWT) using a wand detector manufactured by Northwest Marine Technology, Inc. (Shaw Island, WA) and passive integrated transponder (PIT) tags using a detector manufactured by Biomark, Inc. (Boise, ID). Scale samples were obtained using surgical hemostats from the left or right rear quadrant of the fish between the lateral line and the dorsal and the adipose fin. DNA samples were obtained with a hole punch or fin clip (generally from the opercle or dorsal fin), stored in ethyl alcohol, and archived in individually marked vials. When possible, fin condition (adipose and dorsal fin morphology) was also noted on fish which appeared to be of hatchery origin. Otoliths were collected from carcasses only. Pictures were generally taken of fish having unique features.

Scales and otoliths were read by the WDFW Ageing Laboratory and CWTs were processed by the WDFW Coded-Wire Tag Laboratory according to standard protocols. DNA samples have not been analyzed but are housed by the WDFW Molecular Genetics Laboratory.

Results

Period of weir operation

Operation of the Elwha weir from 2010 to 2013 occurred during the spring (February to May) and summer (August to October) seasons (Table 1). The spring season covered a small fraction of the steelhead migration period, as there were long periods prior to installation and after removal during which we expect steelhead migrated past the weir site (Table 1, Figure 8). The summer season matched the later portion of the Chinook salmon migration season as SONAR and WDFW broodstock collection indicated that Chinook salmon were typically observed in the river more than two months prior to weir installation. Pink salmon migration timing generally corresponded to the period of weir operation, though some of the early returning fish may have been missed (Table 1, Figure 8). The weir provided little opportunity to capture coho and chum salmon due to their late fall and winter migration timing (Table 1, Figure 8), which was expected based on flows during this period (Duda and Brenkman 2008).

Table 1. Periods of operation for the Elwha weir, 2010 – 2013.

	Spring season		Summer season			Combined
Calendar year	Install complete	Removal	Install complete	Removal	Total days	Percent of year
2010	None	None	Sept 9	Oct 12	33	9%
2011	Apr 27	May 13	Aug 18	Oct 20	79	22%
2012	Feb 16	Apr 16	Aug 2	Oct 21	140	38%
2013	None	None	Aug 7	Sept 28	52	14%

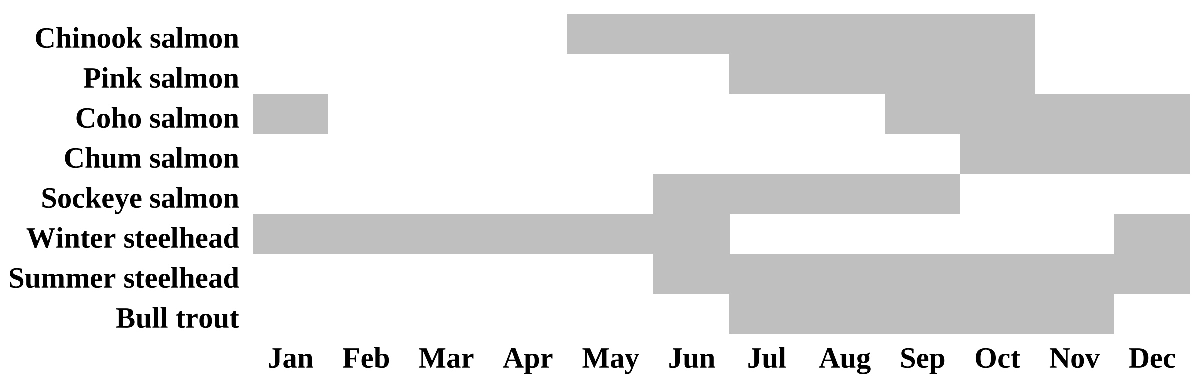

Figure 8. Expected periods of presence for salmonid species in the Elwha River based on general life history patterns and observations from the basin. Modified from Mayer et al. (2015).

Abundance

Across all years, Chinook salmon were the most numerous species caught at the weir (Table 2). However, in all years that the weir operated, Chinook salmon catch was dominated by fish captured moving downstream, with the majority of the downstream capture events being carcasses rather than live fish. Adult Chinook salmon were observed to congregate downstream of the weir, but appeared to resist entering the weir traps. Relatively few (< 100 per year) Chinook salmon were captured moving upstream, severely limiting the weir's utility in estimating abundance and raising concerns that the weir interfered with natural migration behavior. The downstream capture events, both live and dead, are difficult to interpret in the context of overall population abundance. Furthermore, the large number of downstream captures relative to upstream captures indicates that many Chinook salmon bypassed the weir site without being sampled, either prior to weir installation or during periods that weir panels were submerged by high flows and debris.

Pink salmon were the next most numerous species within the weir catch totals and were the most numerous upstream captured species during odd years (Table 2). Notably, in addition to observing odd-year pink salmon typical for Washington populations, the weir also captured pink salmon in even years (Table 2). Relatively few steelhead were captured across all years, with the highest catches occurring during the 2012 spring and summer trapping seasons (Tables 2, 3). Bull trout catch was greatest in summer 2012 and conspicuously absent in summer 2013 (Table 2). Catches of coho salmon were greatest in summer 2012 and minimal during other trapping seasons (Table 2). Catches of chum salmon, sockeye salmon, and cutthroat trout were minimal in all trapping seasons (Table 2).

Table 2. Elwha weir catch totals during summer trapping seasons (August to October), 2010 – 2103. Numbers represent unique fish capture events, exclusive of recaptures of fish previously marked and released from the weir.

Species	Direction	Condition	Summer 2010	Summer 2011	Summer 2012	Summer 2013
Chinook salmon	Upstream	Live	18[A]	23	77	18[A]
	Downstream	Live	51[A]	58	12	159
	Downstream	Dead	394	357	85	291
Steelhead	Upstream	Live	4	1	9	0
	Downstream	Live	0	1	8[B]	0
	Downstream	Dead	2	1	9	0
Bull trout	Upstream	Live	1	1	29	0
	Downstream	Live	3	2	3	0
	Downstream	Dead	0	0	1	0
Pink salmon	Upstream	Live	4	60	5	101[C]
	Downstream	Live	2	69	16	117
	Downstream	Dead	6	55	55	81
Coho salmon	Upstream	Live	1	0	28	0
	Downstream	Live	2	1	4	2
	Downstream	Dead	0	0	3	0
Chum salmon	Upstream	Live	1	0	2	1
	Downstream	Live	0	0	1	2
	Downstream	Dead	0	1	0	1
Sockeye salmon	Upstream	Live	1	3	3	4
	Downstream	Live	0	2	1	1
	Downstream	Dead	3	1	0	1
Cutthroat trout	Upstream	Live	1	0	0	0
	Downstream	Live	0	0	0	0
	Downstream	Dead	0	0	0	0

[A] Includes one trap mortality
[B] Includes one presumable rainbow trout (fork length = 34 cm, captured 10/14/2012)
[C] Includes three trap mortalities

Table 3. Catch totals during spring trapping seasons (February to May), 2011 – 2012.

Species	Direction	Condition	Spring 2011	Spring 2012
Steelhead	Upstream	Live	5	17
	Downstream	Live	5	2
	Downstream	Dead	2	1

Sample collection

The Elwha weir successfully collected a large number of biological samples from Chinook salmon (Table 4). Among other salmonid species, pink salmon samples were most numerous (Table 4). The weir also provided samples of several other species that had not been as frequently sampled in the Elwha River prior to the weir project such as steelhead trout, sockeye salmon and bull trout.

Table 4. The number of unique samples collected from adult salmonids at the Elwha weir 2010 – 2013, exclusive of recaptures of fish marked on prior capture at weir. Otolith numbers include only those samples taken from carcasses at the weir. The number of otolith samples deviates slightly from the "weir carcass" totals provided in Table 5 because not all otoliths collected were readable.

		Number of samples collected			
Species	Return year	Length/Sex	Scales	DNA	Otoliths
Chinook salmon	2010	463	459	461	NA
Chinook salmon	2011	438	437	437	356
Chinook salmon	2012	174	173	172	80
Chinook salmon	2013	468	467	467	291
Pink salmon	2010-2013 pooled	571	396	569	0
Coho salmon	2010-2013 pooled	41	39	39	0
Steelhead	2010-2013 pooled	67	66	67	4
Chum salmon	2010-2013 pooled	9	9	9	2
Sockeye salmon	2010-2013 pooled	20	20	20	1
Bull trout	2010-2013 pooled	40	40	40	1
Total, all species	**2010-2013 pooled**	**2,291**	**2,106**	**2,281**	**829**

Chinook salmon, steelhead, and pink salmon hatchery mark rates

The proportion of hatchery-origin Chinook salmon was determined via a combination of thermal otolith, CWT, and adipose marks. For the brood years returning to the Elwha River in 2010 – 2013, thermal otolith marks were the primary marking strategy for hatchery Chinook salmon. By using an alternative to the adipose fin clip, this approach reduced vulnerability to mark-selective fisheries. However, in some years, malfunction of chillers at WDFW hatchery facilities limited the number of fish receiving otolith marks. Chinook salmon that did not receive otolith marks were selectively placed into the yearling release program with a target of 100% CWT. Thus, for brood years expected to return 2010 – 2013, all hatchery Chinook salmon released into the Elwha River were given an otolith mark, a CWT, or both. Marking via CWT is associated with a small degree of tag loss or mis-tagging, generally this rate is ≤ 2%. In order to provide a comprehensive data set of hatchery mark rates in adult Chinook salmon, we compiled data from all collection sources in the Elwha River watershed 2010 – 2013, including sites other than the weir.

The vast majority of Chinook salmon returning to the Elwha River in 2010 – 2013 were hatchery produced, as the overall hatchery mark rate exceeded 90% in all four years of study (Table 5). We found minimal differences in the hatchery mark rates from different collection sources (Table 5). The use of PIT tags, inserted upon capture and transfer to the Elwha Rearing Channel, increased our ability to evaluate different capture locations in 2013, but we observed similar mark rates across all methods of broodstock capture (Table 5). Of the marked hatchery fish with unmarked otoliths, most carried CWTs indicating they were released from the Elwha Rearing Channel as yearlings (data not shown). CWT data also indicated the presence of strays, most commonly from the neighboring Dungeness River watershed.

A consistently low proportion of Chinook salmon encountered at the Elwha weir carried adipose clip and coded wire tag marks that could be detected externally in the field (Table 6). These low rates were not surprising given that the majority of hatchery Chinook salmon returning to the Elwha River in 2010 – 2013 did not receive either of these marks. For brood years 2005 – 2011, no hatchery produced Chinook salmon had been adipose clipped and only a small proportion of total releases (predominantly yearlings) were coded-wire tagged.

A total of 67 steelhead were captured in all years and trapping seasons combined. Of these, 11 were adipose clipped, for an overall mark rate across all trapping seasons of 16%. Interestingly, most of the marked hatchery fish (N = 9) were captured during the summer trapping seasons: two in 2010, one in 2011 and six in 2012. The origin of these fish is unknown. A now-terminated early winter segregated steelhead program employing adipose marks operated in the Elwha River through smolt releases in spring 2011; this last plant would have returned primarily through the 2012-13 winter season. The neighboring Dungeness basin has a small early winter segregated program targeting 10,000 smolts, all adipose clipped. The most recent releases of summer steelhead in the Strait of Juan de Fuca were in 2009 from a now-terminated program in the Lyre River. None of the steelhead encountered at the Elwha weir had a CWT mark.

In 2013, the hatchery mark rate of adult pink salmon was determined by thermal otolith mark analysis of fish sampled at the LEKT hatchery following spawning. The majority, but not all, of these fish were originally captured at the Elwha weir (see *Broodstock collection* section below). Of the 188 pink salmon that were sampled, 10.6 % (N = 20) carried the thermal otolith mark indicative of hatchery production (data provided by WDFW Otolith Thermal Mark Laboratory).

Table 5. Hatchery mark rates of Chinook salmon sampled from the Elwha River 2010 – 2013 based on thermal otolith, adipose and coded wire tag (CWT) marks. For brood years expected to return 2010 – 2013, all hatchery Chinook salmon released into Elwha River were marked; some carried CWT but not otolith marks due to chiller malfunction during hatchery rearing. The Lower Elwha is defined as the area downstream from the Elwha Dam site; Middle Elwha is the area between the Glines Canyon and Elwha Dam sites. Data provided by WDFW Otolith Thermal Marking Laboratory and Randy Cooper (WDFW).

		Otolith mark only		All hatchery marks[A]	
Return year	**Collection source**	**N**	**Percent marked**	**N**	**Percent marked**
2010	Gaffed broodstock from spawning grounds	149	96.6%	149	96.6%
	Carcass from spawning grounds (Lower Elwha)	38	97.4%	38	100%
	WDFW Rearing channel[B]	81	85.2%	81	91.4%
	Unknown	7	42.9%	NA[C]	NA[C]
	Total, all sources 2010	**275**	**92.0%**	**268**	**95.5%**
2011	Gaffed broodstock from spawning grounds	425	95.3%	425	97.2%
	Carcass from spawning grounds (Lower Elwha)	24	95.8%	24	100%
	WDFW Rearing Channel[B]	127	70.9%	127	94.5%
	Weir live capture[D]	58	84.5%	58	98.3%
	Weir carcass	356	94.7%	356	97.8%
	Total, all sources 2011	**990**	**91.3%**	**990**	**97.2%**
2012	Gaffed broodstock from spawning grounds	5	100%	5	100%
	Carcass from spawning grounds (Lower Elwha)	2	100%	2	100%
	WDFW Rearing Channel[B]	1	100%	1	100%
	Weir live capture[D]	25	64.0%	25	92.0%
	Weir carcass	79	87.3%	79	89.9%
	Unknown	2	100%	2	100%
	Total, all sources 2012	**114**	**83.3%**	**114**	**91.2%**
2013	Carcass from spawning grounds (Middle Elwha)	60	96.7%	NA[C]	NA[C]
	Carcass from spawning grounds (Lower Elwha)	21	100%	21	100%
	WDFW Rearing Channel[B]	46	97.8%	46	100%
	Netted from river[D]	220	95.0%	220	95.0%
	Volunteer to WDFW rearing channel[D]	134	96.3%	134	96.3%
	Volunteer to LEKT hatchery[D]	33	93.9%	33	100%
	Weir live capture[D]	118	94.9%	118	94.9%
	Weir carcasses	289	93.1%	289	93.4%
	Total, all sources 2013	**921**	**94.9%**	**861**	**95.2%**

[A] Fish considered marked if they carried one or more of an otolith, adipose or CWT mark
[B] Original collection method combination of netted from river, weir live capture, WDFW Rearing Channel volunteers, and LEKT Hatchery volunteers
[C] Adipose and CWT mark status data not available
[D] Spawned and otolith sampled at WDFW Rearing Channel, original capture location known from PIT tag

Table 6. Chinook salmon adipose clip and coded wire tag (CWT) mark rates encountered at the Elwha weir 2010 – 2013, including both live and dead fish.

Season	Sample size (N)	Percent adipose clipped	Percent CWT
2010	463	0.43%	3.67%
2011	438	0.68%	5.71%
2012	174	0.57%	6.32%
2013	468	0.21%	1.92%

Migration timing

Relatively low catches of Chinook salmon moving upstream limited the weir's ability to estimate migration timing (Figure 9). Similar to abundance, it is difficult to interpret downstream captures at the weir, as these fish had bypassed the weir at an earlier date, either prior to weir installation or during periods of weir panel breach. With the exception of 2012, upstream weir catches showed a relatively flat distribution without a discernable peak during the period of weir operation. Large gaps in migration timing data occurred in 2013 due to periods of high flow that compromised the weir's capture efficiency mid-season (Figure 9).

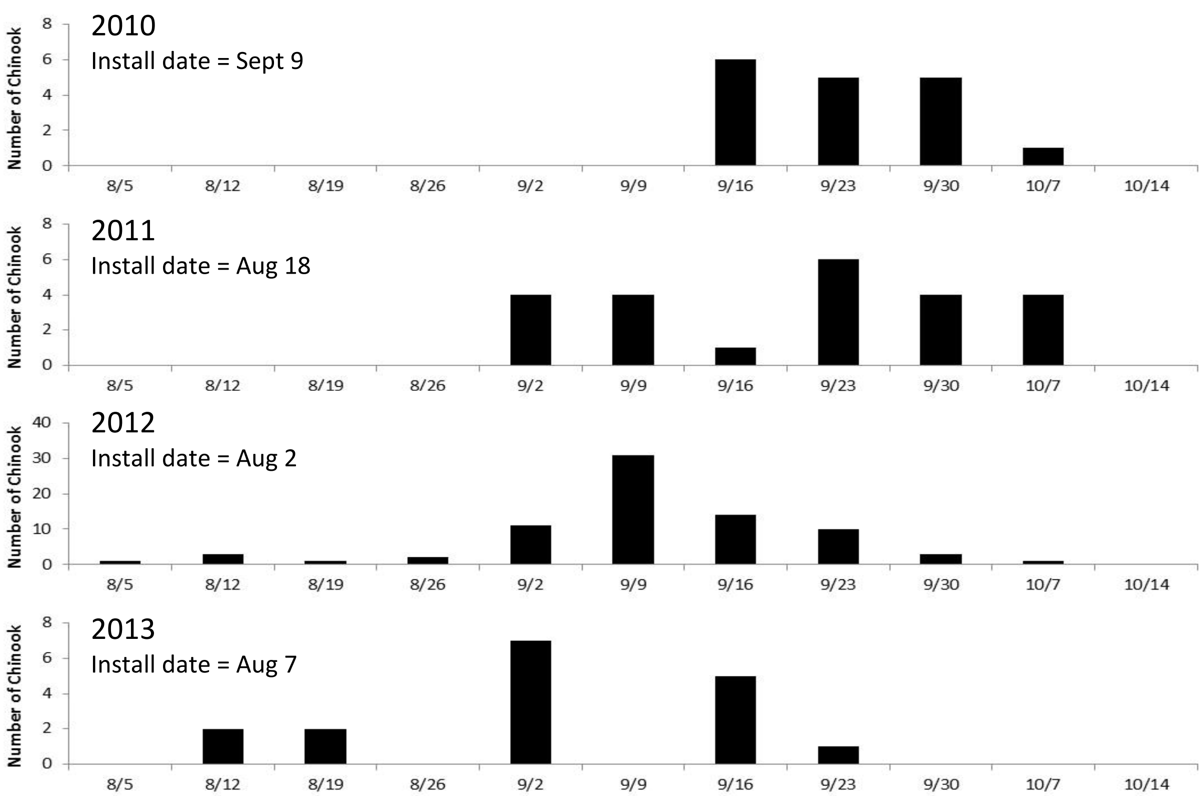

Figure 9. Migration timing of Elwha River Chinook salmon, expressed as the number of fish captured live moving upstream each week.

Catches of pink salmon were relatively uniform across the sampling season (Figure 10). Although no clear peak in migration was observed, the majority of fish were captured during September. This information on Elwha River pink salmon migration timing was noteworthy primarily because it had not previously been available.

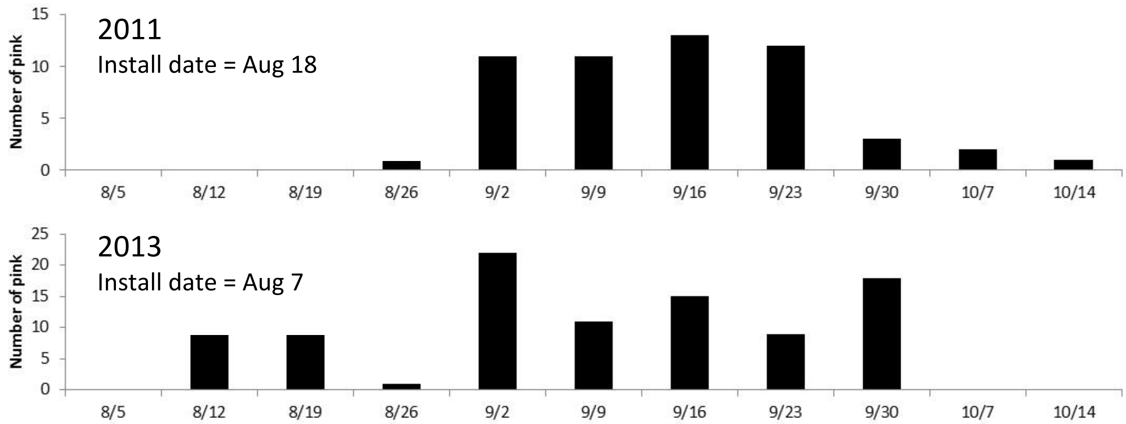

Figure 10. Migration timing of odd-year pink salmon, expressed as the number of fish captured live moving upstream each week.

Broodstock collection

The weir provided a only small proportion of the total Chinook salmon broodstock collected by WDFW, but a large proportion of pink salmon broodstock collected by LEKT (Table 7). In 2013, a large number of the Chinook salmon collected for broodstock were captured via seine net from the Elwha River directly downstream from the weir.

Table 7. Chinook and pink salmon broodstock provided by the Elwha weir in relation to total number of fish collected by WDFW (Chinook salmon, data courtesy of Troy Tisdale) and LEKT (pink salmon, data courtesy of Larry Ward).

			Provided by weir	
Return year	Species	Total broodstock collected	N	Percent
2010	Chinook	815	8	1.0%
2011	Chinook	1027	62	6.0%
2011	Pink	NA[A]	113	NA
2012	Chinook	1,186	80	6.7%
2013	Chinook	1,955	176	9.0%
2013	Pink	220	163	74.1 %

[A] A total of 85 pink salmon were spawned in 2011 from various sources, including the weir, volunteer returns to the LEKT hatchery facility, and volunteer returns to the WDFW facility.

Weir Evaluation

The Elwha River weir was initially intended to operate at flows of less than 2,000 cfs, or approximately 82% of the run time for all salmonid species in the Elwha River, based on the average annual hydrograph for the Elwha River (Duda and Brenkman 2008). In reality, flows limited effective operation to the latter part of the winter steelhead (April and May) and Chinook salmon (August and September) returns. The fishing periods were most limited by the flows required for installation. Prior to dam removal, the weir could be fished at flows up to and exceeding 2,000 cfs (Mayer et al. 2011; Mayer et al. 2015), but it could not be installed at this level. Given the pattern of the annual hydrograph, the onset of both the spring and summer fishing periods required waiting for the Elwha River to drop to flows permitting installation.

The reconfiguration of the channel due to the accumulation of sediment following dam removal proved to be a major obstacle to weir operation. By 2013, multiple channels had emerged, and flow was concentrated in a high velocity slot. This configuration reduced the flows at which the weir could be installed and effectively operated, further shortening fishing periods and decreasing capture efficiency. No attempt was made to fish the weir in spring 2013. As a result of the narrow period of operation, as the project progressed, its goals increasingly focused on Chinook salmon because their migration timing matched seasonally low flows and due to their threatened status under the Endangered Species Act. For Chinook salmon, we had three primary objectives: estimate abundance, estimate migration timing and collect biological samples.

The weir did not successfully estimate Chinook salmon abundance in any of the four years of operation, as it caught relatively few upstream migrating fish compared to other abundance estimation methods employed in the Elwha River (Table 8). When employed as an enumeration tool, weirs are intended to count fish as they migrate upstream past a fixed point. Thus, there is no clear method to use the large number of fish captured moving downstream, either alive or dead, to estimate abundance. Even when including both upstream and downstream captures, the weir catch was a small fraction of the abundances estimated by other methods.

Although partial-capture weirs have been coupled with carcass surveys to successfully estimate Chinook spawner abundance elsewhere (Lamperth et al. 2013), a mark-recapture study design was not feasible in the Elwha River. The low numbers of live fish captured at the weir would have severely limited the sample size of a potential mark group. Due to the restricted period of weir operation, any fish captured at the weir and released with a mark would not be representative of the entire spawning population, violating an important assumption of a closed-population mark-recapture estimator (Seber 1982).

Table 8. Comparison of Chinook abundance estimation methods. SONAR estimate provided by Denton and Liermann (2011), Denton and Liermann (2013) and Denton et al. (2014A); redd-based estimate provided by Randy Cooper, WDFW.

Species	Year	Weir live upstream capture	SONAR estimate	Redd-based estimate
Chinook	2010	18	1,121 – 1,624	1,278
Chinook	2011	23	NA	1,863
Chinook	2012	77	2,638 (2,263 – 3,170)	2,186
Chinook	2013	18	4,243 (3,739 – 4,749)	5,510

As a result of high flows, the weir could not be installed early enough in the season to sample in the entire Chinook salmon migration period (Figure 11). As estimated from SONAR (Denton and Liermann 2013; Denton et al. 2014A), a large proportion of the Chinook migration had already entered the river prior to installation dates of August 2, 2012 (53% complete) and August 7, 2013 (77% complete). During 2013, an unknown but presumably large number of Chinook salmon bypassed the weir and were not sampled during periods when weir panels were submerged.

Fish behavior also contributed to our inability to measure abundance or migration timing for Chinook salmon. In all four years, Chinook salmon appeared reluctant to enter weir traps. A large number of fish were encountered immediately downstream of the weir during broodstock collection efforts. Despite major changes to trap location and design in 2013, catch efficiency did not appreciably increase. Due to the low catches and late deployment, the weir did not provide the data needed to characterize Chinook migration timing. In short, the weir did not achieve two of its three primary objectives for Chinook salmon, goals that had been significantly narrowed from the original project vision.

The weir successfully collected a large number of biological samples for Chinook and pink salmon. The downstream captures, including carcasses, were useful for sample collection if not for abundance and migration timing. These samples provided crucial information on hatchery mark rates, age structure, and life history diversity needed for VSP monitoring during and following the Elwha River Restoration Project (Peters et al. 2014). Samples from steelhead, sockeye salmon, and bull trout provided information on species of interest in the Elwha River watershed.

The narrow period of weir operation during the spring season prevented an estimate of steelhead abundance or migration timing. Furthermore, a significant number of natural origin steelhead recruited to the clear water outflow from the two hatcheries downstream of the weir, perhaps to avoid turbid conditions encountered in the river. Many of these fish were captured and transported upstream of the weir to Little River and Indian Creek, bypassing the weir even when it was operational.

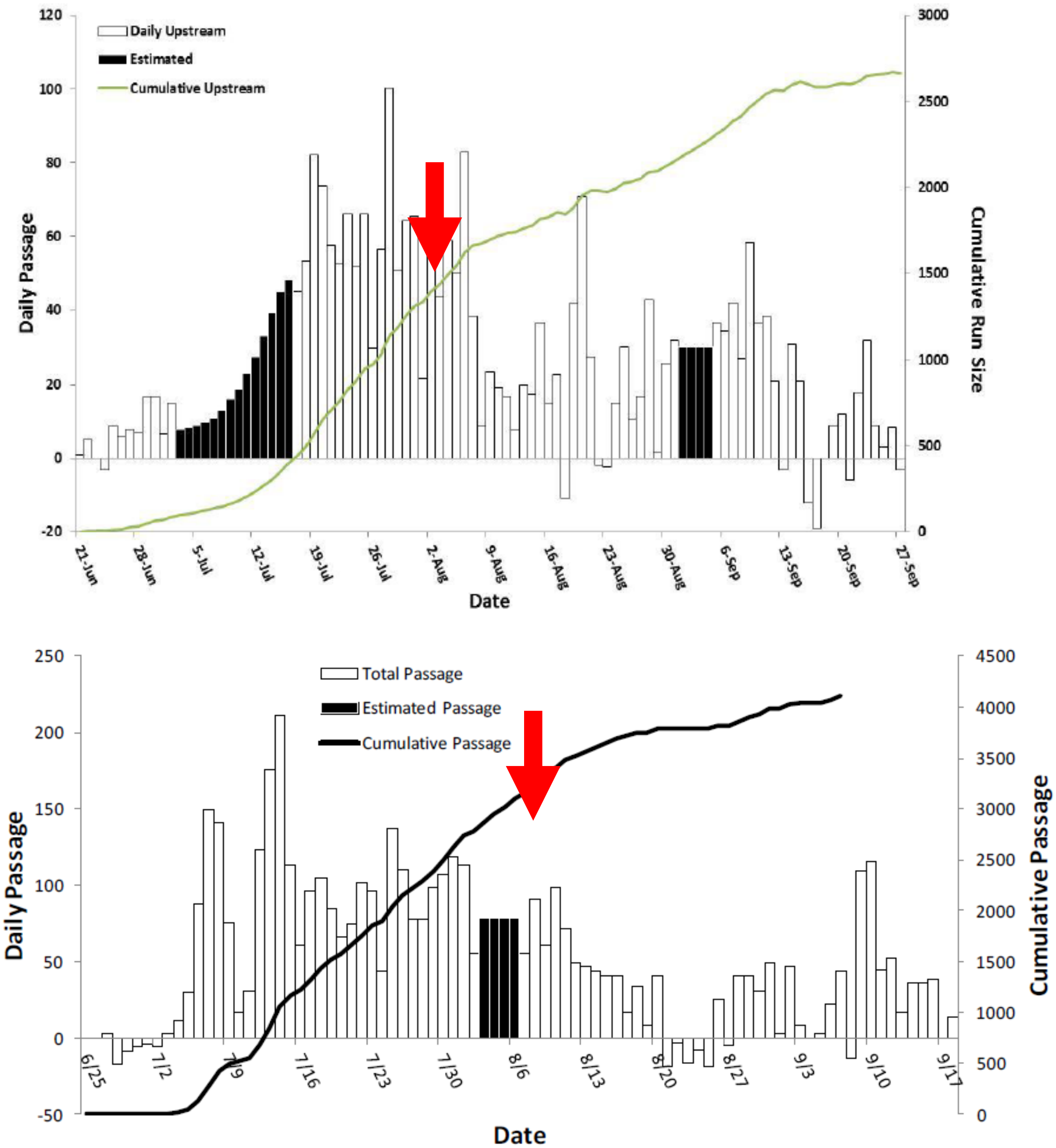

Figure 11. Migration timing of Chinook salmon determine from SONAR in relation to weir installation dates (red arrows) in 2012 (top) and 2013 (bottom). SONAR data and figure from Denton and Liermann (2013) and Denton et al. (2014A).

Accurate and unbiased relative species composition data was needed to aid the interpretation of SONAR imagery. SONAR provides information on fish size but not species, complicating abundance estimation during periods when multiple species of overlapping size are present. Body size data collected at the weir during the summer trapping season were used to differentiate jack Chinook and pink salmon from adult Chinook during SONAR data analysis (Denton 2014A). Unfortunately, the weir did not provide the species composition data when it was most needed in May/June (Chinook salmon and steelhead overlap) because it was not in operation and September (Chinook and Coho salmon overlap) because it had low capture efficiency.

Between 2010 and 2013, early winter segregated hatchery steelhead, marked by adipose fin clip, returned to the Elwha River and a management objective was to limit the interactions between this hatchery stock and the wild spawning population. It was initially envisioned that the weir would be a useful tool to reduce the number of segregated hatchery steelhead spawning naturally. However, in the first year (2011) of the fishing moratorium planned by state, tribal, and federal managers, it became clear that flows would not permit the deployment of the weir during the majority of the steelhead run.

For Chinook salmon, only a small proportion of adult hatchery fish returning to the Elwha River 2010 – 2013 were externally marked (adipose clip or CWT), preventing use of the weir as a tool to exclude hatchery fish from upstream habitats. In the future, a higher percentage of hatchery produced Chinook salmon may be externally marked. However, the poor Chinook salmon capture efficiency observed in 2010 – 2013 (Table 8) suggests that the weir would not be effective as a fish sorting platform intended to remove hatchery fish.

Fisheries biologists involved in the Elwha project also expressed concern that the weir impeded upstream migration by Chinook salmon. Weirs can adversely affect migrating fish, notably by delaying upstream migration, inducing spawning downstream of the trap, physically harming fish as they attempt to circumvent the weir or are confined within traps, among other impacts (Murauskas et al. 2014). In this case, Chinook salmon consistently held immediately downstream of the weir, as evidenced by the large number of broodstock collected from this reach. In its final configuration, the weir would likely slow natural colonization of spawning areas upstream of Elwha Dam by restricting movements of Chinook salmon.

Weir operation also presented personnel safety concerns that increased as dam removal activities progressed. Installation, maintenance, and removal of the Elwha weir required daily, near constant physical labor in a swift, turbid river. Footing was soft and uncertain due to accumulated sediment following dam removal. Large pieces of woody debris were frequently transported downstream below the surface of the turbid river, unseen to personnel working in the river. The demanding nature of the work, which required lifting, pulling, pushing, hauling, scraping, and wrenching heavy, awkward objects within the river led to chronic crew fatigue, increasing the chance of injury.

In summary, despite a narrowing of project objectives and a major redesign in 2013, the Elwha weir was unable to estimate the abundance and migration timing of Chinook salmon or any other species. River flows and channel reconfiguration limited the period of operation and trapping efficiency of the weir. However, the Elwha weir did successfully collect a large number of length, otolith, scale, and DNA samples from adult salmonids, particularly from Chinook salmon. The weir thus provided important data on the proportion of hatchery marked fish and life history diversity of Chinook salmon, as well as samples from infrequently observed species such steelhead, sockeye salmon, and bull trout.

Recommendations

Following the 2013 season, WDFW provided an evaluation of the weir to the NPS, NOAA Fisheries, USFWS, USGS and LEKT (Anderson, Powerpoint presentation, November 7, 2013). Based on the evaluation, all of the agencies recognized that information provided by the weir could be better supplied through alternative monitoring activities already approved under the NOAA and USFWS Biological Opinions and/or permits. The recommendations provided below are primarily intended to address VSP parameters for ESA-listed adult Chinook salmon and steelhead, as described in the Elwha River Monitoring and Adaptive Management Guidelines (Peters et al. 2014), in the absence of a functional weir.

Abundance and migration timing

The Elwha River SONAR project has proved to be exceptionally effective at estimating adult Chinook salmon and steelhead abundance, as well as providing information on run timing for both species (Denton et al 2014A, Denton et al 2014B). We recommend that the SONAR project be implemented in future years as the primary method for estimating adult abundance and migration timing for Chinook salmon and steelhead returning to the Elwha River.

SONAR projects can provide accurate and precise estimates of migrating fish (Cronkite et al. 2006; Ehzenhofer et al. 1998; Holmes 2006). However, the raw imagery produced by the SONAR unit does not identify fish by species. The SONAR data does provide estimates of individual fish length, but using these data to allocate targets to species can introduce bias in situations where there is significant overlap in size among two or more species. Therefore, we suggest the gillnetting effort initiated in 2013 within the lower Elwha River continue to be used to complement the SONAR imagery by providing information on species composition, similar to the approach used in most other SONAR projects.

Such species composition sampling should occur during periods when multiple species are migrating within the Elwha River. Important time periods include a) February and March (differentiate coho salmon from steelhead), b) June (differentiate Chinook salmon from steelhead) and c) July – August (differentiate adult Chinook salmon, jack Chinook salmon, pink salmon and coho salmon). Other species, including summer steelhead, sockeye, bull trout, and chum salmon, are also present during the summer, as evidenced from catches at the Elwha weir.

We recommend that gillnet sampling occur every week whenever multiple species are expected to be present. It is possible that fewer gillnet sampling events will be necessary, depending upon the time of year and the observed stock composition. Finally, it is important that the netting be conducted at or near the locations of the SONAR units to ensure that the species composition data are representative of the SONAR imagery.

The species composition netting may be one of relatively few opportunities to collect scale samples from several species in the Elwha River. This is particularly true for steelhead trout, which are elusive but important to sample due to their listing as threatened under the Endangered Species Act. Furthermore, opportunistic marking of captured fish should also be considered, in order to evaluate fish movement within the system, evaluate rates of recapture, and understand the ultimate distribution of fish in the watershed. Marking could include radiotags, Floy ® tags, PIT tags, or other non-lethal marks.

Stock composition

We recommend intensive carcass sampling for Chinook salmon to measure the proportion of hatchery origin spawners, determine age structure, and describe life-history diversity. At this point in time, thermal otolith marking is the primary marking strategy for Chinook salmon released from the WDFW Elwha Rearing Channel. A robust carcass sampling effort is needed to identify hatchery fish and sample scales, which provide information on age structure and the relative proportion of stream-type and ocean-type juvenile life histories. The age structure data, when combined with annual abundance estimates, are particularly important for productivity analyses (i.e., recruits per spawner).

Sampling carcasses from a range of locations will provide important information on the spatial dynamics of the recolonization process. For example, one might predict a greater proportion of stream-type juvenile life-histories in the cold water habitats located further upstream in the Elwha watershed. Thus, in future years, we suggest that Chinook salmon carcasses be collected from five different locations: a) volunteers into WDFW hatchery, b) lower Elwha River below the previous Elwha Dam site, c) middle Elwha River between dam sites, d) middle river tributaries Little River and Indian Creek, and e) Elwha River above the Glines Canyon Dam site. For collections from the WDFW hatchery, it is important to collect samples from known volunteers into the hatchery in addition to fish netted from the river during broodstock collection. Netted fish are not necessarily returning to the location from which they were collected and might be destined for spawning grounds upstream. The hatchery volunteers are an important collection, as they will permit direct comparison of the hatchery population to the naturally spawning population. At each location, Chinook salmon carcasses should be identified by species and sex, measured for length, sampled for adipose marks, scanned for CWTs, and sampled for otoliths, scales, and DNA. Carcasses from other species besides Chinook salmon should be sampled when encountered, particularly for those species which may have a CWT and/or adipose clip (steelhead and coho) or may have an otolith mark (pink, chum).

Opportunistic sampling during fish capture events provides another means to collect biological samples such as scales, DNA, CWT and adipose mark status. Potential sampling events include the species composition netting associated with the SONAR project, netting efforts associated with implanting radio transmitters or relocation efforts for volunteers to one of the two Elwha River hatchery facilities. Under these situations, fish will be caught and released live, so biologists should carefully consider whether samples can be collected while maintaining safe handling conditions with minimal risk to the fish. These events present the best opportunity to collect samples from species that are rarely observed as carcasses on the spawning grounds including ESA-listed steelhead and bull trout.

Hatchery operations

The Elwha weir was ineffective as a tool for collecting Chinook salmon broodstock for the Elwha River restoration program. It is recommended that WDFW continue to collect Chinook utilizing a combination of volunteer returns to the hatchery facilities, netting, and gaffing. Pink salmon collected at either of the hatchery facilities or the netting operation can also be incorporated into the pink salmon restoration program as appropriate. No changes are recommended for hatchery programs for other species, as the weir was not envisioned as a critical tool for collection of broodstock.

References

Cronkite, G.M.W., H.J. Enzenhofer, T. Ridley, J. Holmes, J. Lilja, and K. Benner. 2006. Use of high-frequency imaging sonar to estimate adult sockeye salmon escapement in the Horsefly River, Britsih Columbia. Can. Tech. Rep. Fish. Aquat. Sci. 2647.

Denton, K. and M. Liermann. 2011. Estimation of the 2010 summer Chinook escapement in the Elwha River using BlueView multi-beam sonar technology.

Denton, K. and M. Liermann. 2013. Estimation of the 2012 Chinook escapement in the Elwha River using DIDSON multi-beam Sonar technology.

Denton, K., M. McHenry, R. Moses, M. Liermann, and G. Pess. 2014A. 2013 Elwha River Chinook escapement estimate based on DIDSON/ARIS multi-beam SONAR data.

Denton, K., R. Moses, M. McHenry, J. McMillan, M. Liermann, and G. Pess. 2014B. 2013 Elwha River steelhead escapement estimation based on DIDSON multi-beam SONAR data.

Duda, J.J. and S.J. Brenkman. 2008. Estimating how many threatened and non-threatened Pacific salmonids return to the Elwha River before, during, and after removal of two large hydroelectric dams. Proposal submitted to National Park Service, USGS-Biological Resources Discipline, NRPP-Research.

Duda, J.J., J.A. Warrick, and C.S. Magirl, 2011. The Coastal and Lower Elwha River Prior to Dam Removal: History, Status, and Defining Characteristics. *In* J.J. Duda, J.A. Warrick, and C.S. Magirl (eds.), Coastal Habitats of the Elwha River: Biological and Physical Patterns and Processes Prior to Dam Removal. U.S. Geological Survey Scientific Investigations Report 2011-5120.

East, A. E., G. R. Pess, J. A. Bountry, C. S. Magirl, A. C. Ritchie, J. B. Logan, T. J. Randle, M. C. Mastin, J. T. Minear, J. J. Duda, M. C. Liermann, M. M. McHenry, T. J. Beechie and P. B. Shaforth. 2015. Large-scale dam removal on the Elwha River, Washington, USA: river channel and floodplain geomorphic change. Geomorphology 228:765-786.

Enzenhofer, H. J., N. Olsen, and T.J. Mulligan. 1998. Fixed-location riverine hydroacoustics as a method of enumerating migrating adult Pacific salmon: comparison of split-beam acoustics vs. visual counting. Aquat. Living Resour. 11:61-74.

Holmes, J. A., Cronkite, G. W., Enzenhofer, H. J., Mulligan, T. J. 2006. Accuracy and precision of fish-count data from a "dual-frequency identification sonar" (DIDSON) imaging system. Journal of Marine Science. 63:543-555.

Lamperth, J., M. S. Zimmerman, D. J. Rawding, L. Campbell, B. G. Glaser, and C. Sharpe. 2013. Coweeman River Salmonid Production Evaluation: 2011 Completion Report. FPA 13-01. Washington Department of Fish and Wildlife, Olympia, Washington.

Lower Elwha Klallam Tribe (LEKT). 2012. Hatchery and genetic management plan Lower Elwha Fish Hatchery native steelhead enhancement program. Lower Elwha Klallam Tribe. Port Angeles, Washington.

Mayer, K, M. Zimmerman, and T. Ritchie. 2011. Elwha River salmonid assessment: adult weir project, 2010 annual report. FPA 11-04. Washington Department of Fish and Wildlife, Olympia, Washington.

Mayer, K. and M. Zimmerman. 2012. Elwha River salmonid assessment: adult weir project, 2011 annual report. FPA 12-05. Washington Department of Fish and Wildlife, Olympia, Washington.

Mayer, K, M. Mizell, and M. Ackley. 2015. Elwha River salmonid assessment: adult weir project, 2012 annual report. FPA 15-02. Washington Department of Fish and Wildlife, Olympia, Washington.

McElhany, P., M. H. Ruckelshaus, M. J. Ford, T. C. Wainwright and E. P. Bjorkstedt. 2000. Viable salmon populations and the recovery of evolutionary significant units. U.S Department of Commerce, NOAA Technical Memorandum, NMFS-NWFSC-42, Seattle, Washington.

Murauskas, J. G., J. K. Fryer, B. Nordlund and J. L. Miller. 2014. Trapping effects and fisheries research: a case study of sockeye salmon in the Wenatchee River, USA. Fisheries 39:408-414.

National Marine Fisheries Service (NMFS). 2012. Endangered Species Act (ESA) Section 7 Biological Opinion and Magnuson-Stevens Fishery Conservation and Management Act Essential Fish Habitat Consultation: Elwha Channel Hatchery Summer/Fall Chinook salmon Fingerling and Yearling, Lower Elwha Fish Hatchery Steelhead, Lower Elwha Fish Hatchery Coho Salmon, Lower Elwha Fish Hatchery Fall Chum Salmon, and Elwha River Odd and Even Year Pink Salmon Programs. NMFS Consultation Number: NWR-2012-9426.

Olympic National Park (ONP). 2013. Elwha River Restoration Project – Chinook and Steelhead Monitoring Plan. Submitted to NOAA Fisheries in partial fulfillment of the requirements of the Amended Incidental Take Statement for the Elwha River and Fisheries Restoration Project Biological Opinion (NMFS 2011/03769).

Peters, R.J., J.J. Duda, G.R. Pess, M. Zimmerman, P. Crain, Z. Hughes, A. Wilson, M.C. Liermann, S.A. Morley, J.R. McMillan, K. Denton, D. Morrill, and K. Warheit. 2014. Guidelines for monitoring and adaptively managing restoration of Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead (*O. mykiss*) on the Elwha River. U.S. Fish and Wildlife Service report.

Seber, G. A. F. 1982. The estimation of animal abundance and related parameters. Charles Griffin and Company Limited, London.

Zimmerman, C.E., and L.M. Zabkar. 2007. Weirs. *In* D.H. Johnson, B.M Shrier, J.S. O'Neal, J.A. Knutzen, X. Augerot, T.A. O'Neil, and T.N. Pearsons (eds), Salmonid field protocols handbook: techniques for assessing status and trends in salmon and trout populations. American Fisheries Society, Bethesda, Maryland.