

U.S. Fish and Wildlife Service

**Spring Chinook Salmon Passage at the
Leavenworth National Fish Hatchery, 2013, with
Summary of Data from 2011-2013.**



Mathew Hall

U.S. Fish and Wildlife Service
Mid-Columbia River Fisheries Resource Office
Leavenworth, WA 98826

On the cover: Leavenworth National Fish Hatchery workers inspecting Structure 2 on Icicle Creek. USFWS.

The correct citation for this report is:

Hall, M.R. 2014. Spring Chinook Salmon Passage at the Leavenworth National Fish Hatchery, 2013, with Summary of Data from 2011-2013. U.S. Fish and Wildlife Service, Leavenworth WA.

Spring Chinook Salmon Passage at the Leavenworth National Fish Hatchery, 2013, with Summary of Data from 2011-2013.

Authored by

Mathew Hall

U.S. Fish and Wildlife Service
Mid-Columbia River Fisheries Resource Office
7501 Icicle Road
Leavenworth, WA 98826

Final
January, 2014

Disclaimers

Any findings and conclusions presented in this report are those of the authors and may not necessarily represent the views of the U.S. Fish and Wildlife Service.

The mention of trade names or commercial products in this report does not constitute endorsement or recommendation for use by the federal government.

Spring Chinook Salmon Passage at the Leavenworth National Fish Hatchery, 2013,
with Summary of Data from 2011-2013.

Mathew Hall

*U.S. Fish and Wildlife Service
Mid-Columbia River Fisheries Resource Office
7501 Icicle Rd.
Leavenworth WA 98826*

Executive Summary- The Leavenworth National Fish Hatchery (LNFH) was constructed as partial mitigation for anadromous fish loss associated with the construction of Grand Coulee Dam. Located on Icicle Creek, the LNFH produces spring Chinook salmon, and has historically used in-stream structures to meet its operational needs. Guided by a U.S. Fish and Wildlife Service Biological Opinion, an Adaptive Management Group was convened to explore means of improving and monitoring fish passage opportunities through these structures in Icicle Creek adjacent to LNFH. Using a Dual-frequency Identification Sonar (DIDSONTM) camera, we were able to monitor the movement of fish through one of these structures during the spring Chinook salmon run. The camera provided timing, direction, and approximate size of the fish passing the structure. In 2013, more fish moved upstream through the structure, and they did so earlier than in either 2011 or 2012. This annual variation in movement patterns is likely caused by annual differences in Icicle Creek discharge, with lower discharges allowing earlier and more frequent upstream movement.

Page intentionally left blank for 2-sided printing

Table of Contents

List of Tables	ii
List of Figures.....	ii
Introduction.....	1
<i>Historic Production</i>	<i>2</i>
<i>Current Production</i>	<i>3</i>
Fish Passage at the LNFH	4
<i>Returning Spring Chinook Salmon</i>	<i>4</i>
<i>LNFH Structure Operation.....</i>	<i>4</i>
<i>Monitoring</i>	<i>6</i>
<i>DIDSON Acoustic Camera</i>	<i>6</i>
<i>DIDSON File Viewing</i>	<i>7</i>
<i>Fish “Counting”</i>	<i>7</i>
<i>Fish Length</i>	<i>8</i>
<i>Species Identification</i>	<i>8</i>
<i>Data Entry and Reporting</i>	<i>9</i>
<i>Site Selection.....</i>	<i>9</i>
<i>Deployment Dates</i>	<i>10</i>
Icicle Creek	11
<i>Icicle Creek Discharge</i>	<i>11</i>
2013 Fish Passage Monitoring Results.....	12
<i>Movement Events</i>	<i>12</i>
<i>Lengths</i>	<i>13</i>
Summary of Data Collected from 2011-2013	15
<i>Pattern of Movement Events</i>	<i>15</i>
<i>Run Size</i>	<i>16</i>
<i>Run Timing.....</i>	<i>16</i>
<i>Discharge.....</i>	<i>17</i>
<i>Lengths of Passing Fish.....</i>	<i>20</i>
Discussion	22
<i>Pattern of Movement Events</i>	<i>22</i>
<i>Lengths of Passing Fish.....</i>	<i>22</i>

Acknowledgments	23
Literature Cited	23
Personal Communications	24

List of Tables

Table 1. LNFH spring Chinook salmon adult returns, 2004-2013.	3
Table 2. Deployment dates and total hours monitored, 2011-2013.	15
Table 3. Movement events and 50% passage dates for fish passing S2 from 5/15 through 7/27, 2011-2013.	15

List of Figures

Figure 1. Wenatchee River watershed.	1
Figure 2. The Leavenworth National Fish Hatchery and Icicle Creek.....	2
Figure 3. Lower Icicle Creek with LNFH, structures, and Boulder Falls.	5
Figure 4. Structure 2 (S2) in the open position (left, from upstream), and in the closed position (right, from downstream). Photos by USFWS.	6
Figure 5. Screenshot of a DIDSON file.	7
Figure 6. Example of a DIDSON .txt file output.	8
Figure 7. Aerial photo of S2 with insonified area in yellow. Courtesy of Google Maps.....	10
Figure 8. Mean daily Icicle Creek discharge and calculated discharge through S2 from 5/15 through 7/31, 2013.	11
Figure 9. Movement events and discharge at S2 during the BCP, 2013.....	12
Figure 10. Movement events and discharge at S2 during the 2013 monitoring period.	13
Figure 11. Length/frequency distribution of fish measured during the entire 2013 monitoring period.....	14
Figure 12. Plot of movement events and their corresponding length over the entire 2013 monitoring period, with red indicating events during the BCP.	14
Figure 13. Cumulative net movement events at S2 during the 2011-2013 monitoring periods, with total adult return to the LNFH in ().	16
Figure 14. Passage dates of LNFH-origin PIT tags detected at the LNFH adult ladder and net movement of fish passing S2 during the 2011-2013 monitoring periods.	17
Figure 15. Discharge through S2 during the passage monitoring period, 2011-2013.	18
Figure 16. Number of days within each monitoring year that discharge through S2 fell within the given 100 cfs frequency bins.	18
Figure 17. Rate of upstream movement through S2 at 100 cfs frequency bins.	19
Figure 18. Cumulative net movement events at S2 during the 2011-2013 monitoring periods, with total adult return to the LNFH in (). Blackened lines indicate days when discharge through S2 was 700 -1,300 cfs.....	19

Figure 19. Temporal distribution of movement events and length in 2012 and 2013. 20
Figure 20. Temporal distribution of movement events and length of fish <40cm when 2012 and 2013 data
is combined. 21
Figure 21. Length/frequency distribution of fish >40 cm passing S2 during the 2012 and 2013 monitoring
seasons. 21

Introduction

The Leavenworth National Fish Hatchery (LNFH) was constructed as partial mitigation for anadromous fish loss associated with the construction of Grand Coulee Dam, and is operated by the U.S. Fish and Wildlife Service (USFWS). The LNFH is located adjacent to Icicle Creek near the town of Leavenworth in central Washington State (Figure 1). Icicle Creek is a tributary to the Wenatchee River, which flows into the Columbia River, at Wenatchee, Washington. The LNFH is approximately 800 rkm (river-kilometers) from the Pacific Ocean, and upstream of seven hydroelectric dams, all located on the Columbia River (Figure 1).

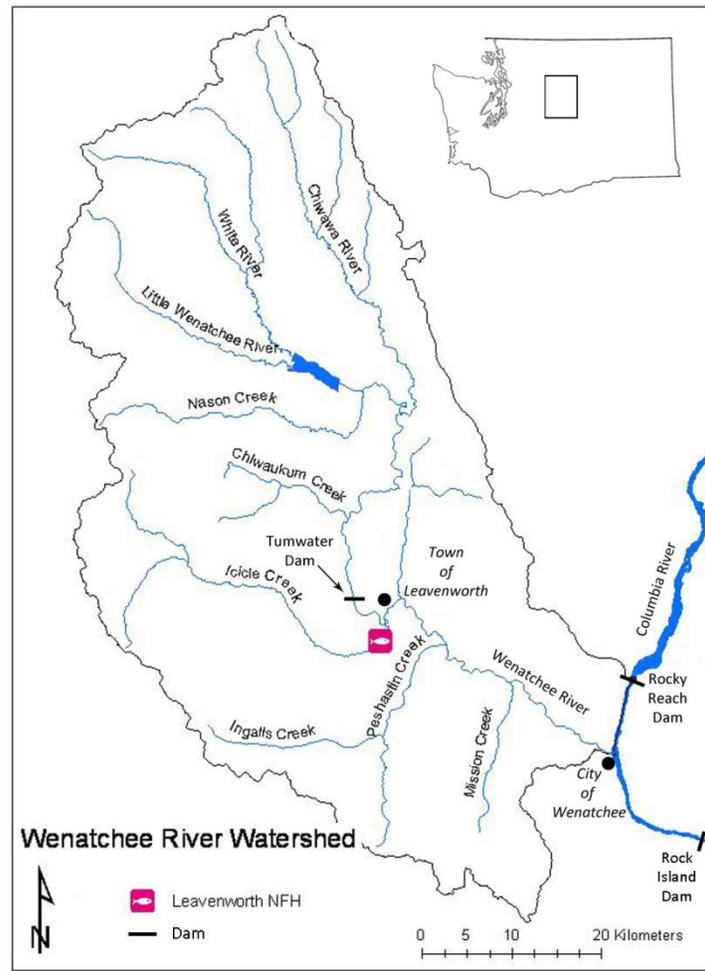


Figure 1. Wenatchee River watershed.

The LNFH is situated on approximately 85 hectares of ponderosa pine/pinegrass forest in the central Cascade mountains (Figure 2). Icicle Creek, a fifth-order stream draining high relief mountains, provides water for hatchery operations as well as the release and collection point for the cultured fish.



Figure 2. The Leavenworth National Fish Hatchery and Icicle Creek.

Historic Production

The LNFH has produced several trout and salmon species since production began in 1940. Species have included spring and summer/fall Chinook salmon (*Oncorhynchus tshawytscha*), steelhead and rainbow trout (*O. mykiss*), and sockeye salmon (*O. nerka*).

Spring Chinook salmon have been the primary species produced since the hatchery was constructed. From 1940-1943, spring Chinook were collected from upriver-bound stocks captured at Rock Island Dam. Some early imports of spring Chinook salmon from the lower Columbia River (1942) and McKenzie River, Oregon (1941) were part of homing studies, and probably few, if any, contributed to future production. The LNFH has occasionally imported eggs from other Columbia River hatcheries, including Carson, Cowlitz, and Little White Salmon National Fish Hatcheries. Fish and/or eggs have not been imported to the LNFH since 1985 (Cooper 2006).

Current Production

The LNFH operates a segregated-harvest program producing spring Chinook salmon, and aids in the production of and provides rearing space for coho salmon (*O. kisutch*) for the Yakama Nations' Mid-Columbia Coho Restoration Program. The LNFH also has a few rainbow trout on station for educational purposes.

The number of adult spring Chinook salmon returning to the LNFH from 2004 to 2013 is given in Table 1. The stock utilized by the LNFH is not included in the Endangered Species Act-listed Upper Columbia River spring Chinook salmon Evolutionarily Significant Unit. Genetic analysis indicates that the current broodstock is more closely related to the lower Columbia River stocks than the natural population in the Wenatchee River (Ford et al. 2001). The spring Chinook salmon produced at the LNFH are commonly referred to as “Carson stock”, referring to the Carson NFH, where the majority of imported eggs originated.

The Mid-Columbia River Fisheries Resource Office (MCRFRO) conducts monitoring and evaluation of the LNFH spring Chinook salmon program. The MCRFRO is located on USFWS property adjacent to the LNFH, and is responsible for the marking, biological sampling, and special studies with regards to the produced fish.

Table 1. LNFH spring Chinook salmon adult returns, 2004-2013.

Year	LNFH Adult Returns
2013	2,135
2012	4,037
2011	4,970
2010	11,366
2009	3,045
2008	3,229
2007	1,708
2006	1,957
2005	2,560
2004	2,307

Fish Passage at the LNFH

Returning Spring Chinook Salmon

Spring Chinook salmon that enter the Icicle Creek basin are extensively monitored by a variety of entities. When a salmon enters Icicle Creek, it is either harvested by Tribal or sport anglers, captured at the LNFH, or attempts to spawn in the lower 9.1 rkm of the creek. The harvest efforts are monitored by the respective Tribal fisheries agencies and the Washington Department of Fish and Wildlife (WDFW) through creel surveys. All fish captured at the LNFH are sampled by the MCRFRO. Icicle Creek is subject to thorough spawning ground surveys and snorkel surveys conducted by the Chelan County Public Utility District (CCPUD) and the MCRFRO, respectively.

Any salmon that stray out of the Icicle Creek basin have few escapement opportunities. The majority of the spawning habitat available to them exists above Tumwater Dam in the upper Wenatchee River. At Tumwater Dam, differentially-marked LNFH-origin spring Chinook salmon are trapped and transferred to the LNFH. At the current marking rate, 80% of the potentially straying LNFH-origin salmon are prevented from moving onto the upstream spawning grounds.

Given these efforts, accounting for LNFH-origin spring Chinook salmon adults returning to Icicle Creek is possible with a high degree of accuracy.

LNFH Structure Operation

Since its construction beginning in 1939, the LNFH has operated up to 5 water diversion structures within Icicle Creek to meet its operational needs (Figure 3). These structures were constructed to withdraw water, regulate flows, and collect returning adult salmon. Structure 1 (Hatchery Intake, rkm 7.2) is a low-head dam that acts as a withdraw diversion for both the LNFH and the Cascade Orchards Irrigation Company. A fish ladder was installed there in the early 1990's to improve fish passage. Structure 2 (S2) is a channel spanning dam consisting of 2 radial gates that have the capacity to divert Icicle Creek into the Hatchery Channel, bypassing a 1.6 km section of Icicle Creek known as the Historical Channel (Figure 4). Structures 3 and 4 were weirs used to hold and sort adult salmon within the Historical Channel, and were completely removed in 2003. Structure 5 (S5) is a channel spanning bridge capable of supporting weir pickets, and can be used to prevent passage of large (salmon-sized) fish.

A velocity barrier at the downstream end of the Hatchery Channel prevents adults from swimming up the Hatchery Channel. Fish can, theoretically, move down this barrier, although downstream movement of fish over this barrier is unknown.

Through 2000, seasonal operation of S2 and S5 impeded fish passage within Icicle Creek (USFWS 2011). In 2001, the LNFH began adaptively managing the structures to improve passage opportunities, and in 2006, an Adaptive Management Group (AMG) was formed to guide the operation of these structures (USFWS 2006). From 2006-2010, S2 and S5 were operated to provide passage for most of the year. Passage was restricted during the spring Chinook salmon run (May-July) to safeguard the collection of hatchery broodstock and to increase fishing opportunities by concentrating fish in a section of Icicle Creek below S5.

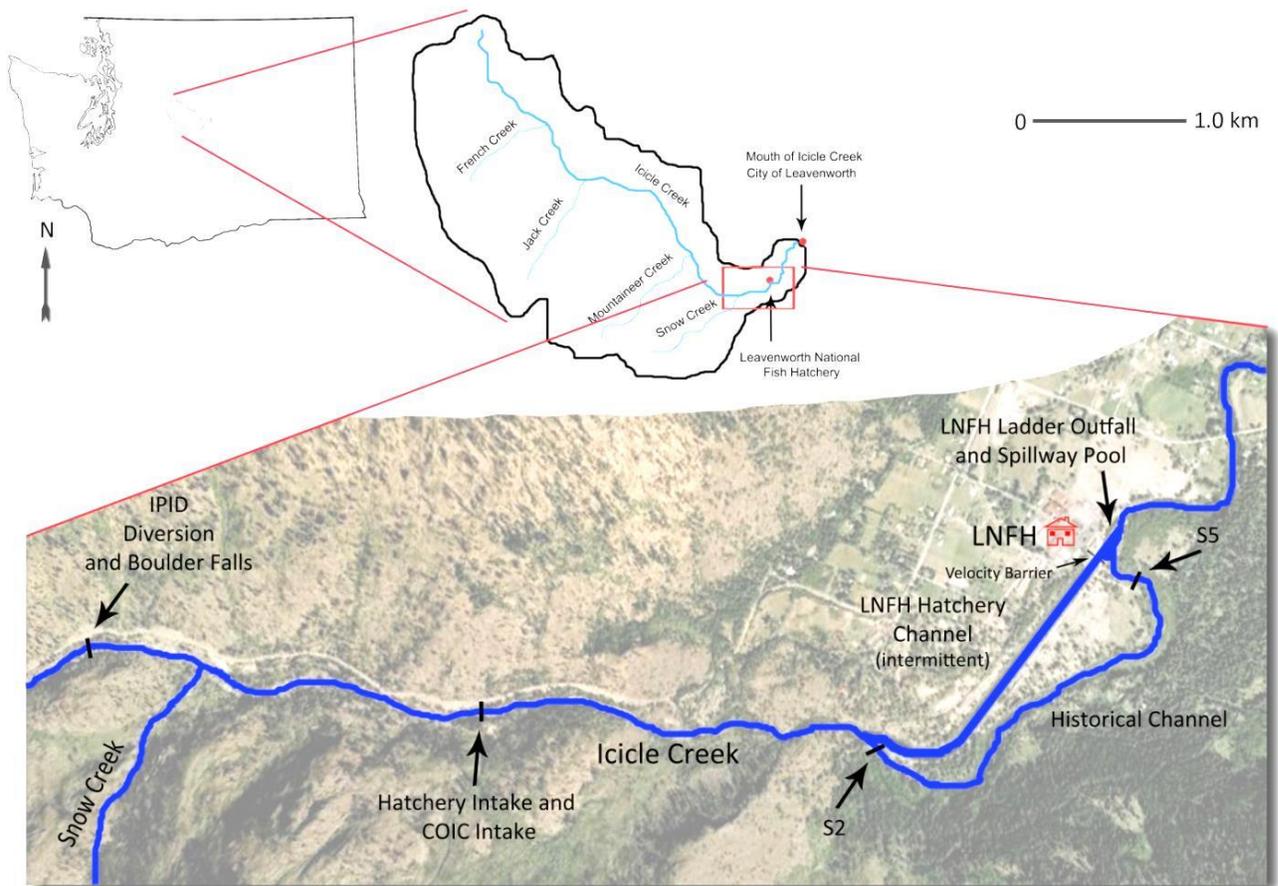


Figure 3. Lower Icicle Creek with LNFH, structures, and Boulder Falls.



Figure 4. Structure 2 (S2) in the open position (left, from upstream), and in the closed position (right, from downstream). Photos by USFWS.

Monitoring

In 2011, the USFWS issued a Biological Opinion for the Operations and Maintenance of the Leavenworth National Fish Hatchery (2011 BiOp), requiring (with Conditions) that S2 and S5 be left in the fully open position for the entire year, offering the least impediment to fish passage in over 70 years. While unobstructed passage of native species was the goal of the 2011 BiOp, it was recognized that there were concerns with regards to spring Chinook salmon escaping the Tribal fishery and potential disease transmission originating from adults spawning and dying upstream of the Hatchery Intake. As a result, a Condition of operating the Structures in this manner included the monitoring of spring Chinook salmon passage above the LNFH during the Broodstock Collection Period (BCP), which is defined as May 15 to July 7 (USFWS 2011).

DIDSON Acoustic Camera

The primary method used for monitoring spring Chinook salmon passage at the LNFH is a Dual-frequency Identification SONAR (DIDSON™), manufactured by Sound Metrics Corp. A DIDSON is an acoustic camera that uses SONAR to insonify an underwater region at a high frame rate, allowing for a “video-like” image to be recorded (www.DIDSON.com). The video is recorded in a proprietary file format that can then be viewed with camera-specific software (Figure 5).

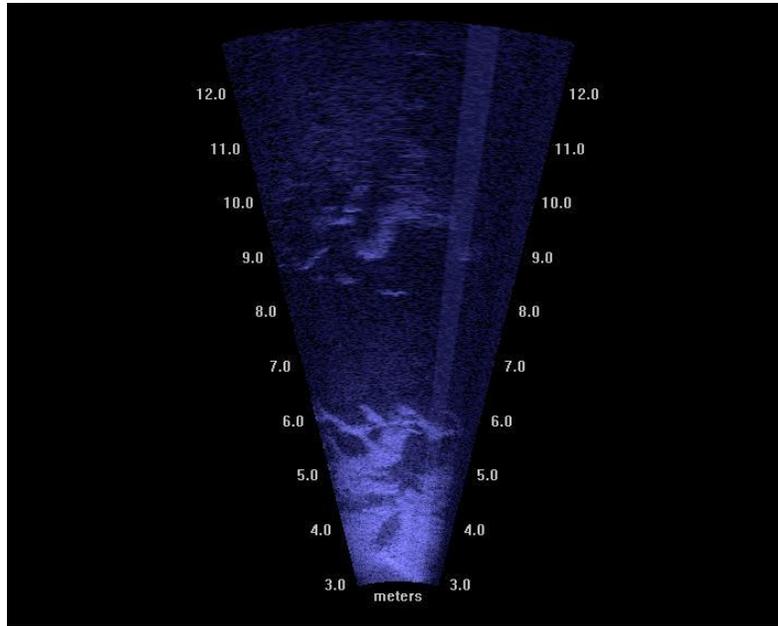


Figure 5. Screenshot of a DIDSON file.

When an object moves through the insonified area, sound waves are reflected back to the camera, creating the image. The software reinterprets the image to appear as it would from above (90° from actual orientation). It is the responsibility of the viewer to determine the nature of the object. In most cases, determining an object as a fish (as opposed to a piece of wood) is easy, with an obvious swimming motion observed.

DIDSON File Viewing

Files are recorded in 1 hr. segments throughout the 24 hr. day, beginning a new file at the start of each hour. The files can then be played at-will, and various software tools can be used to increase the viewing frame rate and eliminate frames with no useful images. These tools allow the viewer to review 1 hour files in as little as a few minutes. Not all files can be reduced equally, and file viewing remains a tedious process.

Fish “Counting”

The DIDSON software has no way of identifying an individual fish that moves into and out of the insonified area. A unique fish could swim into and out of the insonified area multiple times, confounding any attempts to count unique fish. As a result, each viewing instance is more accurately described as a “movement event” rather than a “count”. If the movement corridor directs all movement through a defined area (i.e. a “closed” corridor), and a zero count has been established, a “net count”, defined as fish movement in one direction, minus fish movement in the opposite direction, can be estimated. This method assumes equal viewability of both

upstream and downstream movements. However, fish swimming against the current (upstream) likely move more slowly, and spend more time in the insonified area. This may present a positive bias toward upstream movement events.

In Icicle Creek, the movement corridor being monitored with the DIDSON camera is not closed. A fish *could* swim upstream through the insonified area, and swim downstream through the Hatchery Channel, bypassing camera recording (Figure 3). This would result in a positive bias in upstream counts. However, because of the design of the Hatchery Channel, this effect is assumed to be minimal.

Fish Length

The length of the fish is determined using the softwares’ “Mark Fish” tool. With this tool, the fish’s length is measured and the direction of the swimming motion can be recorded by drawing a digital line along the axis of the fish in the direction of motion. The lengths of the resulting line, along with the direction, are recorded onto a .txt file that is saved in the desired directory (Figure 6). Burwen et al (2010) found a 90% correlation between DIDSON measured lengths and known lengths, with a Standard Error of 5.76cm. To be conservative, we have reported a +/- 10 cm accuracy with the length measurements taken.

```

Total Fish      =      1
Upstream       =      0
Downstream     =      1
??            =      0

Upstream Motion = Left to Right
Count File Name: C:\didson Data\FC_CSOT_2011-06-28_210001_P1038.txt
Editor ID      = hall
Intensity      = 77 dB
Threshold      = 11 dB
CSOT Min Cluster = 100 cm^2
CSOT Min Threshold = 39 dB

Window Start   = 1.67 m
Window End     = 11.67 m

*** Manual Marking (Manual Sizing: Q = Quality, N = Repeat Count) ***
File Total Frame# Dir R (m) Theta L(cm) T(cm) L/T Aspect Time Date Latitude
-----
1 1 196 Dn 2.63 1.9 87.5 0.0 0.00 13.7 21:04:08 2011-06-28 N 00 d 0.000000 m

*** Source File Key ***
1: Source File Name: M:\Hatchery Evaluation Program\LNFH\Didson\CSOT June-28-2011\CSOT_2011-06-28_210001.ddf
   Source File Date: 2011-06-28
   Source File Start: 21:00:14
   Source File End: 21:59:56

```

Figure 6. Example of a DIDSON .txt file output.

Species Identification

In most cases, determining the species of the fish observed is not possible using the DIDSON camera alone. However, with the ability to determine length, combined with other information such as run timing, species identification can be surmised. For the majority of the time period monitored, spring Chinook salmon are the only species in Icicle Creek that exceed 60cm in

length. In May and early June, a small run of steelhead is found in Icicle Creek, and migratory sub-adult and adult bull trout (*Salvelinus confluentus*), including some >60cm, use lower Icicle Creek in summer (Hillman et al 2009, Nelson et al 2011).

Data Entry and Reporting

Movement events, time, date, and direction of motion are first recorded on a bench sheet, and then entered into a Microsoft Access™ database for analysis. Length file outputs (.txt's) are saved with the original DIDSON file. An informal, weekly update is sent to the AMG at the end of each week, allowing the AMG to make in-season management decisions regarding S2 and S5 operation.

Site Selection

The DIDSON camera insonifies a field at 30° horizontal and 14° vertical, for up to 20 meters. The camera must be tethered to a personal computer located within 500ft. Both the camera and the personal computer must be continuously powered throughout the monitoring period. The DIDSON camera is also very expensive and must be protected from objective hazards. These specifications require careful site selection to maximize data quality and minimize risk. In 2010, numerous sites were considered for DIDSON deployment. The camera was deployed for several weeks at a site approximately 200m upstream of S5. This site provided an inadequate viewing area, poor solar performance, and exposure to debris.

In late 2010, a site on the upstream side of S2 was identified to have many of the characteristics needed for successful monitoring (Figure 7). This site provided a good viewing window because the nature of S2 funnels fish into the viewing area. It also has the required solar exposure and complete protection for the camera. This site has the disadvantage of limiting the insonified area to the bottom 1m (approximately) of the water column. Because salmon are most likely to swim near the bottom of the channel while negotiating S2, the effects of this limitation is thought to be minimal. This site was used for the entire 2013 monitoring season.



Figure 7. Aerial photo of S2 with insonified area in yellow. Courtesy of Google Maps.

Deployment Dates

The 2011 BiOp requires the monitoring of spring Chinook salmon passage above the LNFH during the BCP. In 2013, monitoring occurred from May 15 until July 27, with no data collected on July 10 (partial), 11, 13 (partial), 14, 15 (partial), 20 (partial), 21, and 22 (partial).

Icicle Creek

Icicle Creek Discharge

In 2013, the Icicle Creek basin experienced a warm spring followed by a hot summer (Hall 2013). Icicle Creek experienced high discharge early in the spring, leaving little water available for the summer months (Figure 8). Total Icicle Creek discharge was measured at a Washington Department of Ecology station gauge (ID# 45B070), and S2 discharge is calculated from total discharge measurements (M. Lindenberg, pers. comm.). The S2 discharge (Q^{S2}) is calculated from the total discharge of Icicle Creek (Q^{total}) using the following regression:

$$Q^{S2} = -0.0001(Q^{total(2)}) + 0.9897(Q^{total}) - 48.0605$$

Below approximately 300 cfs, all of the discharge of Icicle Creek flows through S2 and the Historical Channel. From 300 to 1000cfs, a portion of Icicle Creek discharge fills the Hatchery Channel. Above 1,000 cfs, the portion of Icicle Creek within the Hatchery Channel begins to spill over its velocity barrier, reconnecting with the Historical Channel immediately downstream.

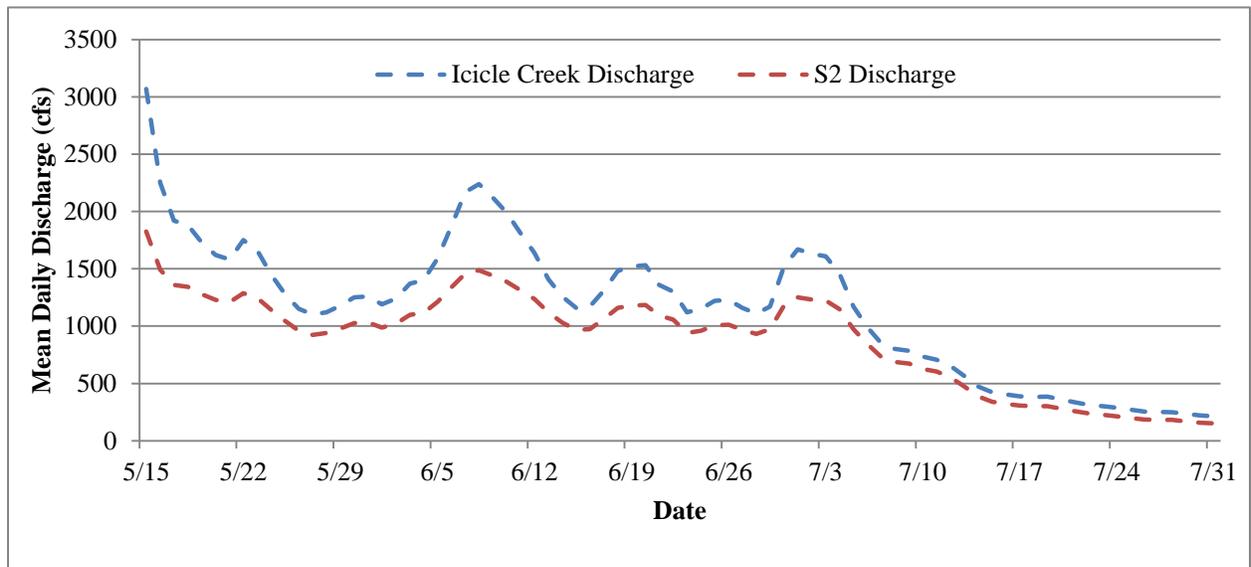


Figure 8. Mean daily Icicle Creek discharge and calculated discharge through S2 from 5/15 through 7/31, 2013.

2013 Fish Passage Monitoring Results

Movement Events

During the BCP (May 15 to July 7), 337 upstream movement events occurred, and 117 downstream movement events occurred, resulting in a net of 220 upstream movement events at the end of the BCP (Figure 9).

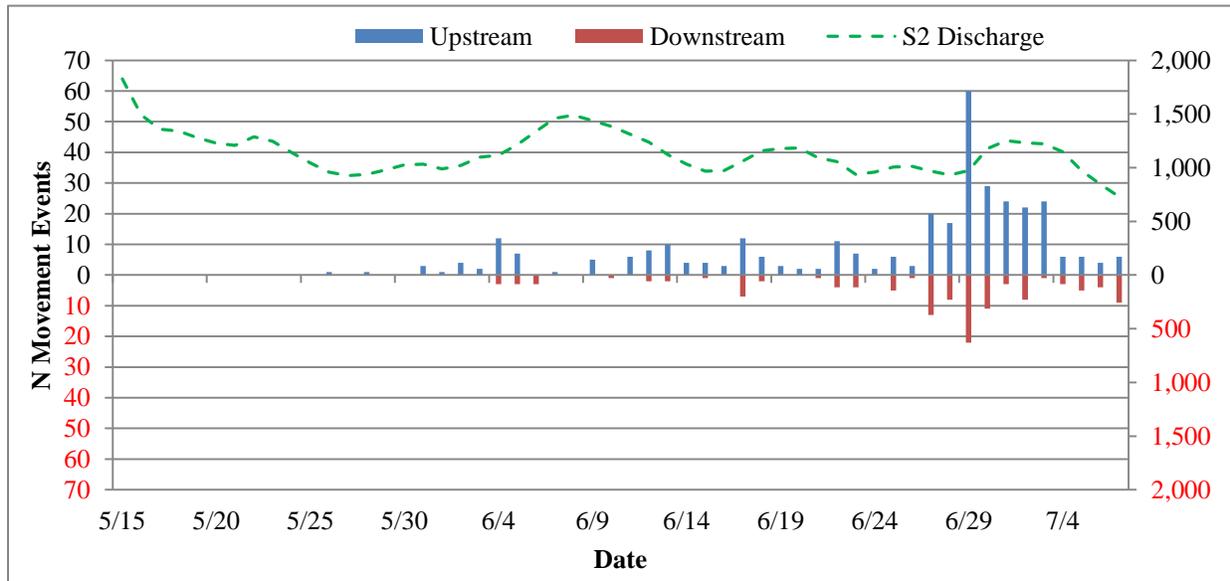


Figure 9. Movement events and discharge at S2 during the BCP, 2013.

Monitoring of fish passage at S2 continued through July 27 (with a few days of no data collection, see page 10). For the entire 2013 monitoring period, 547 upstream movement events occurred, and 257 downstream movement events occurred, resulting in a net of 290 upstream movement events at the end of the monitoring period (Figure 10).

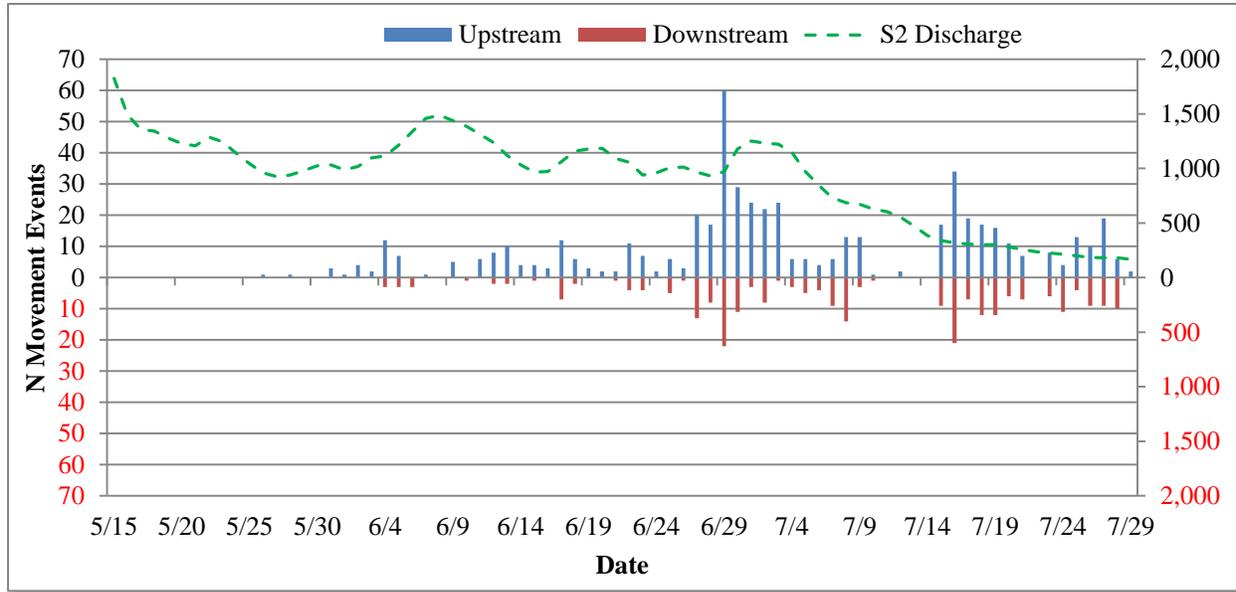


Figure 10. Movement events and discharge at S2 during the 2013 monitoring period.

Lengths

Length measurements were taken on 454 movement events during the BCP. Of these, 47 fish (10%) were measured to be <60 cm. This falls within the range of 3-year-old (“jack”) salmon, but is also within the range of resident fish known to be present in Icicle Creek. The remaining 407 fish were of a size commensurate with adult (4+year old) salmon, anadromous steelhead, or adult bull trout.

During the entire 2013 monitoring period, length measurements were taken on 804 movement events. Of these, 192 (24%) were measured to be <60cm. The length/frequency distribution of fish measured during the entire 2013 monitoring period is shown in Figure 11. The temporal occurrence of fish of a given length is shown in Figure 12.

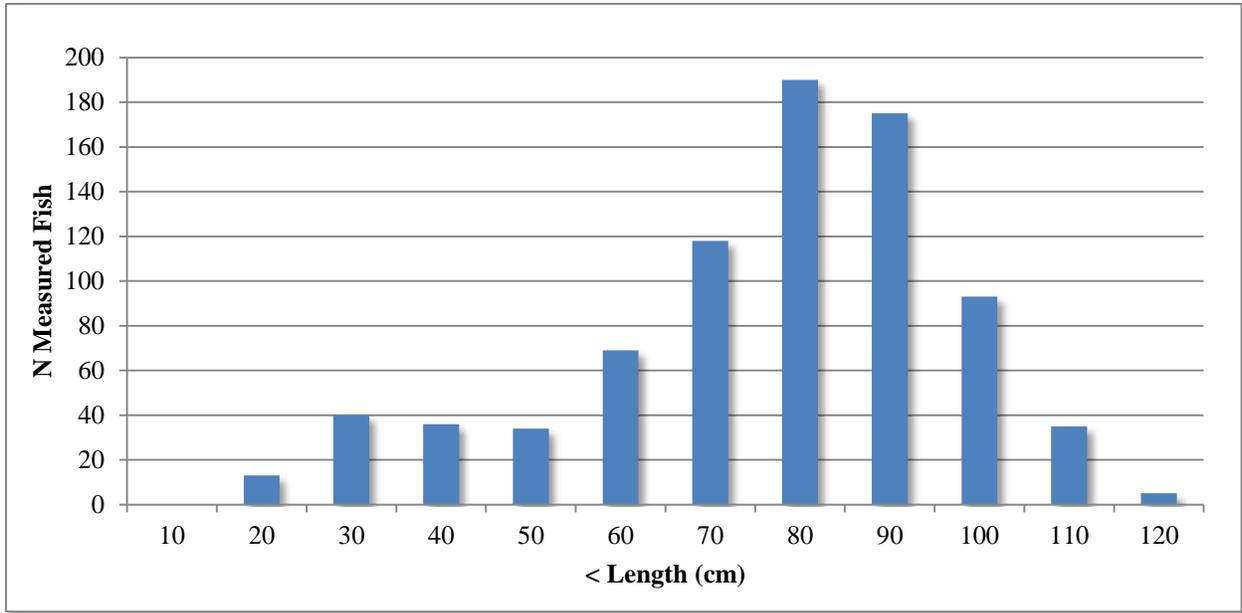


Figure 11. Length/frequency distribution of fish measured during the entire 2013 monitoring period.

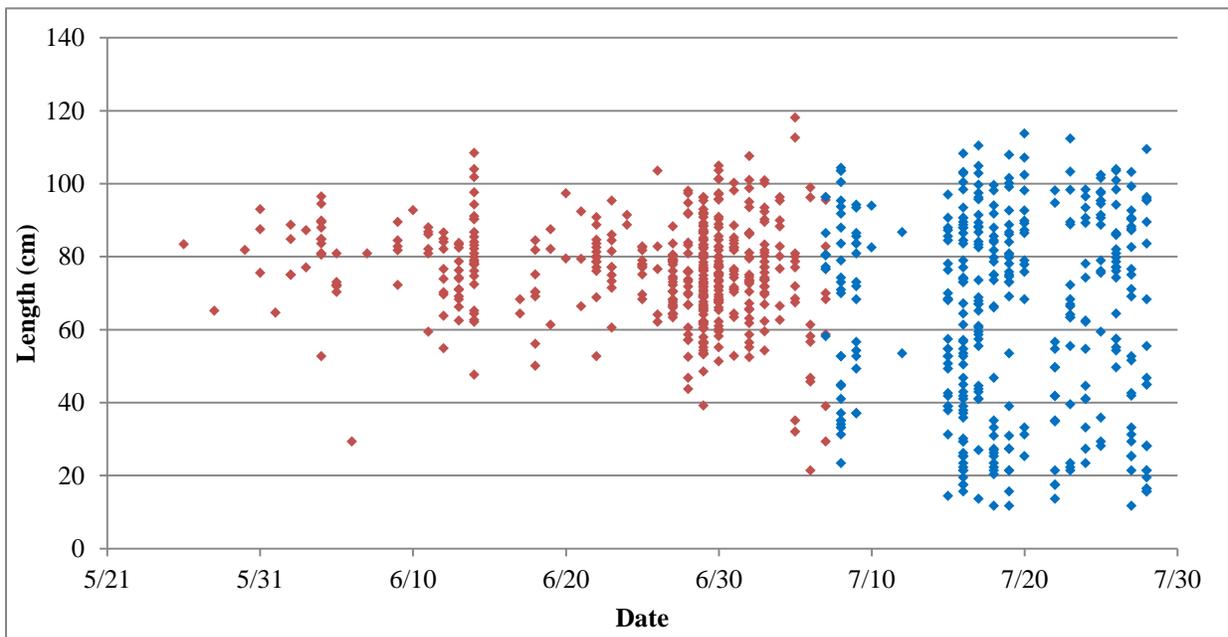


Figure 12. Plot of movement events and their corresponding length over the entire 2013 monitoring period, with red indicating events during the BCP.

Summary of Data Collected from 2011-2013

In 2011, 2012, and 2013 fish passage at S2 was monitored from May 15 through July 27 using a DIDSON sonar camera (Table 2). During this monitoring, upstream and downstream movement events, and their associated times of occurrence were documented (Table 3). Lengths of the fish associated with the movement events were recorded in 2012 and 2013.

Table 2. Deployment dates and total hours monitored, 2011-2013.

Year	Start Date	End Date	Total Hours	Hours Monitored	% of Time Monitored	Comments
2013	5/15	7/27	1,752	1,609	91.8	
2012	5/15	7/27	1,752	1,648	94.1	
2011	5/15	7/27	1,752	1,400	79.9	Icicle Creek mudslides resulted in approx. 14 days without monitoring

Table 3. Movement events and 50% upstream passage dates for fish passing S2 from 5/15 through 7/27, 2011-2013.

Year	# Upstream Movement	# Downstream Movement	Net Movement Events	50% Upstream Passage Date
2013	547	257	290	7/1
2012	393	106	287	7/17
2011	828	629	199	7/23

Pattern of Movement Events

Ending the monitoring of fish passage at S2 on July 27 was arbitrary, as the intent of this monitoring was to enumerate passing fish during the LNFH's BCP. While the absolute number of fish passing by the end of the BCP is of regulatory interest, the pattern of fish passage in the months of May, June, and July has more research and predictive importance.

The monitoring of fish passage at S2 reveals three distinct movement patterns (Figure 13). In 2011, upstream movement did not begin to accumulate until mid-July. In 2012, this pattern began in early July. And in 2013, upstream movement begins to increase in mid-June. The pattern of movement in 2011 and 2012 were much more similar between years, whereas 2013 showed a much earlier accumulation of upstream movement.

In an attempt to explain the differences in patterns of movement between years, I examined the influence of run size, run timing, and discharge through S2 on these movement patterns. All of

these variables could affect the availability and ability of fish to move upstream through S2, and all of these variables differed from year to year.

Run Size

To determine if the pattern of movement events is related to run size, the total adult return to the LNFH was used as an index for the run size in Icicle Creek. During the three monitoring years, the LNFH's adult ladder was open for the entirety of the monitoring periods, and the LNFH was the source nearly all spring Chinook salmon found in Icicle Creek. Among the years monitored, the largest adult return to the LNFH occurred in 2011 (4,970), and the smallest occurred in 2013 (2,135, Figure 13), with 2012 having a run size of 4,013 fish. In the three years monitored, increased run size alone does not appear to result in the earlier or more rapid increase in upstream movement events.

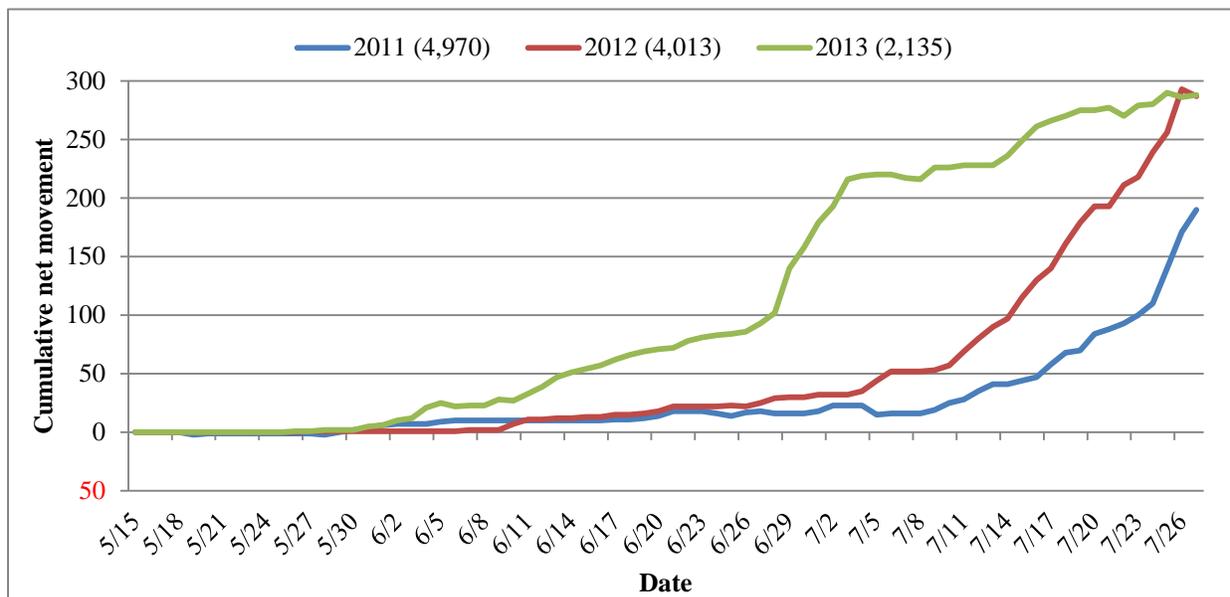


Figure 13. Cumulative net movement events at S2 during the 2011-2013 monitoring periods, with total adult return to the LNFH in ().

Run Timing

Even with variability in run size, the timing of the fish run may also influence the movement patterns observed. If fish arrived into Icicle Creek at different times between the three monitoring years, their pattern of movement through S2 may reflect this variability. To determine if the pattern of movement is related to run timing, unique, LNFH-origin Passive Integrated Transponder (PIT) tags detected at the LNFH adult ladder were used as an index for the arrival timing of fish into Icicle Creek. The largest number of PIT tags detected at the LNFH

adult ladder occurred in 2011 (42), and the smallest occurred in 2013 (20). The discrepancy in the number of PIT tags detected is related to run size, with larger run sizes resulting in more detections.

The 3 years of monitoring had progressively earlier passage dates for LNFH-origin fish entering the adult ladder (Figure 14). A similar pattern of progressively earlier passage dates are seen in net movement events at S2. The mean difference between LNFH adult ladder entry and S2 passage within years is 26 days (SD=4.6). Also, for movement through S2, later passage (2011) has a more compressed timeline for passage (9 days to move from 25% to 75% passage), while earlier passage had a longer timeline (19 days). This may be an artifact of arbitrarily cutting off the monitoring dates at June 27.

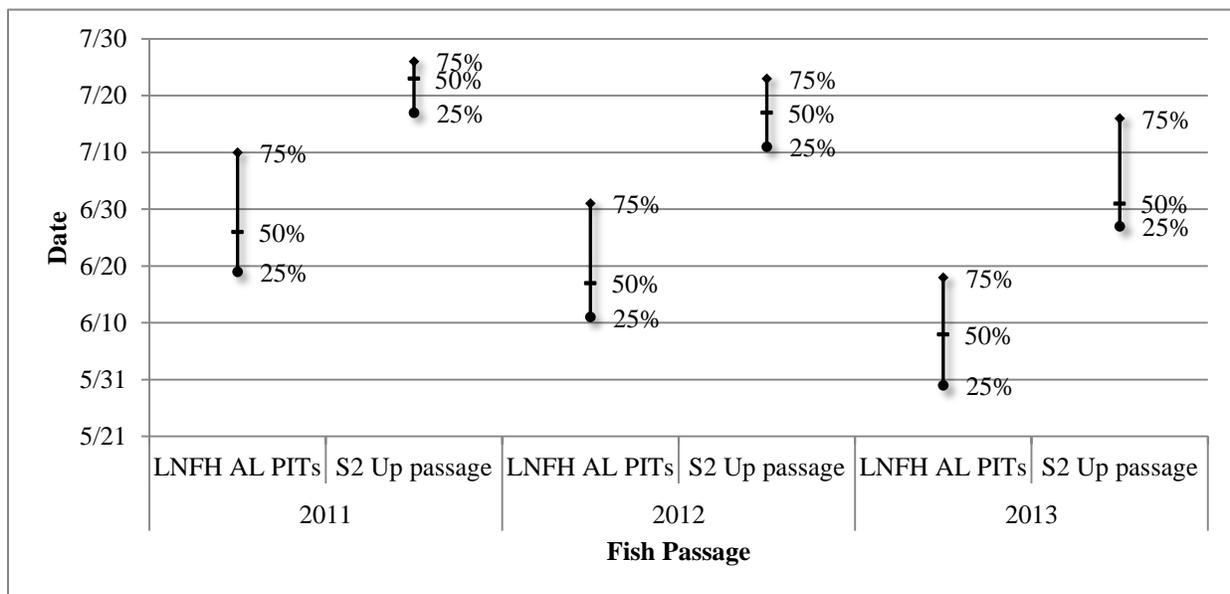


Figure 14. Passage dates of LNFH-origin PIT tags detected at the LNFH adult ladder and net movement of fish passing S2 during the 2011-2013 monitoring periods.

With net movement at S2 appearing to relate to arrival timing of fish at the LNFH, factors that influence the arrival timing of fish to the LNFH become relevant. Keefer et al (2008) suggest that most of the variation in run timing of Columbia River Chinook salmon can be explained by in-river discharge and temperature, with earlier migration timing being associated with low discharge and warm temperatures. These findings are almost identical to those found by Hodgson et al (2006) in Sockeye salmon runs throughout North America.

Discharge

The final variable examined for influence over the pattern of movement events was discharge through S2. Because of the design of S2, the constriction in discharge through the structure may

set up a barrier to passage, either with too little water depth or too high of discharge, and this could delay or prevent upstream movement events.

For the 2011-2013 monitoring periods, the discharge pattern at S2 did not differ between 2011 and 2012 ($P > 0.05$, ANOVA on Ranks), but was different in 2013 ($P < 0.05$), with more days spent at lower discharges (Figures 15). Distributing the discharge through S2 into 100 cfs frequency bins, ranging from <100 to <2,000 cfs, the number of days spent in each discharge bin is shown in Figure 16.

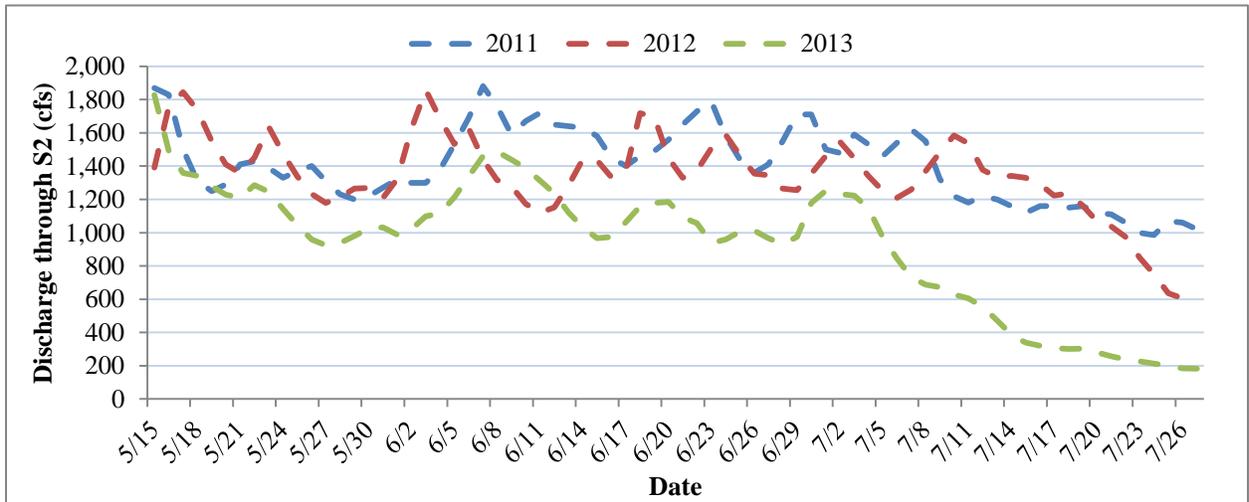


Figure 15. Discharge through S2 during the passage monitoring period, 2011-2013.

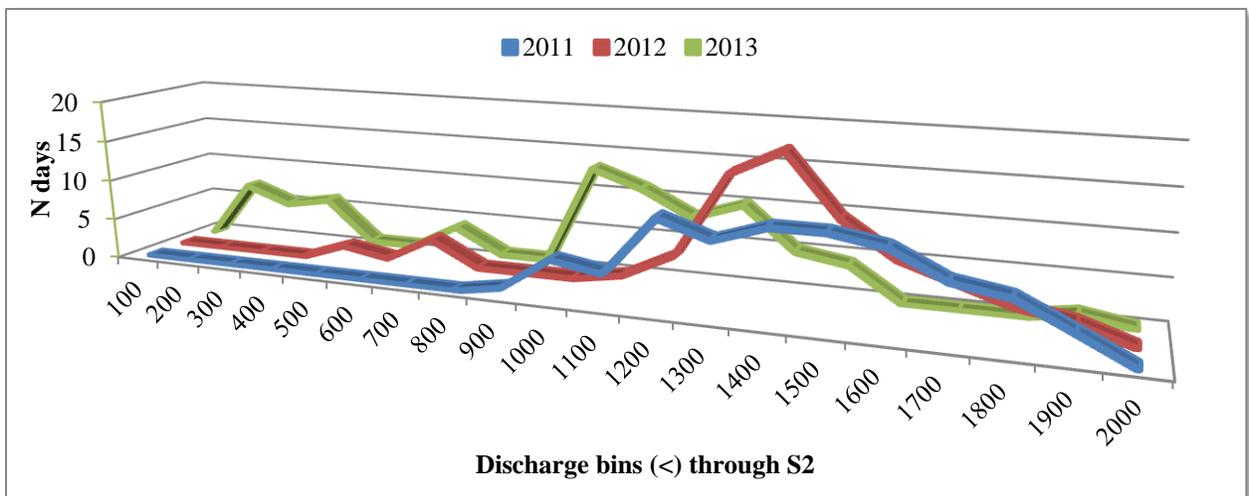


Figure 16. Number of days within each monitoring year that discharge through S2 fell within the given 100 cfs frequency bins.

To relate the number of upstream movement events to the discharge patterns observed, the year-to-year bias in the number of days spent in each discharge bin must be addressed. To do this, the total upstream movement events from all years were converted to a rate of upstream movement events per day. When this rate was related to the discharge frequency bins, it was revealed that the highest rate of upstream movement occurred between 700 and 1,300 cfs (Figure 17). When this range of discharges is imposed on the movement patterns seen in each of the three monitoring periods, we see that the movement patterns appear to be influenced by the timing and duration of this range of discharges (Figure 18). In each year, the rate of upstream movement is highest on the days when discharge through S2 is within the 700-1,300 cfs range, and in 2013, this occurred earlier in the season and lasted longer than in either 2011 or 2012.

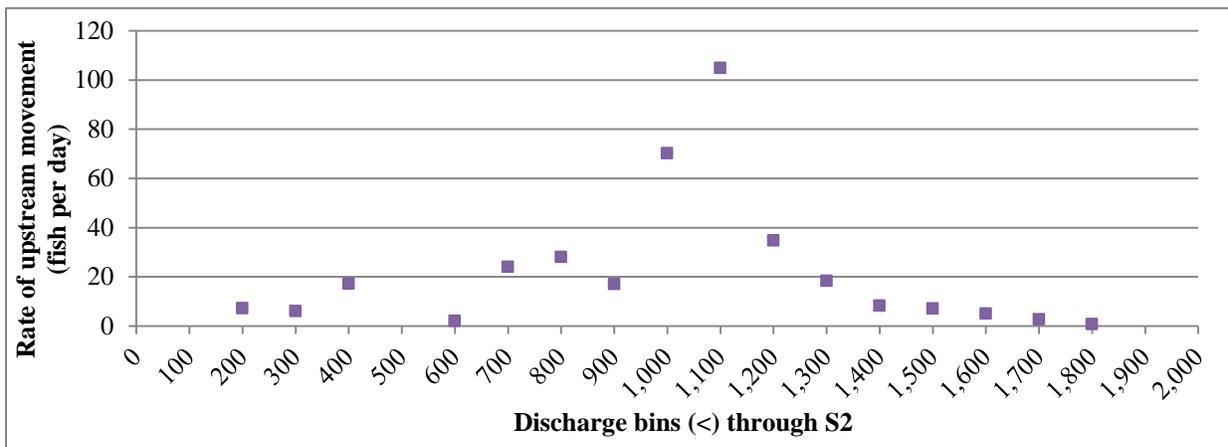


Figure 17. Rate of upstream movement through S2 at 100 cfs frequency bins.

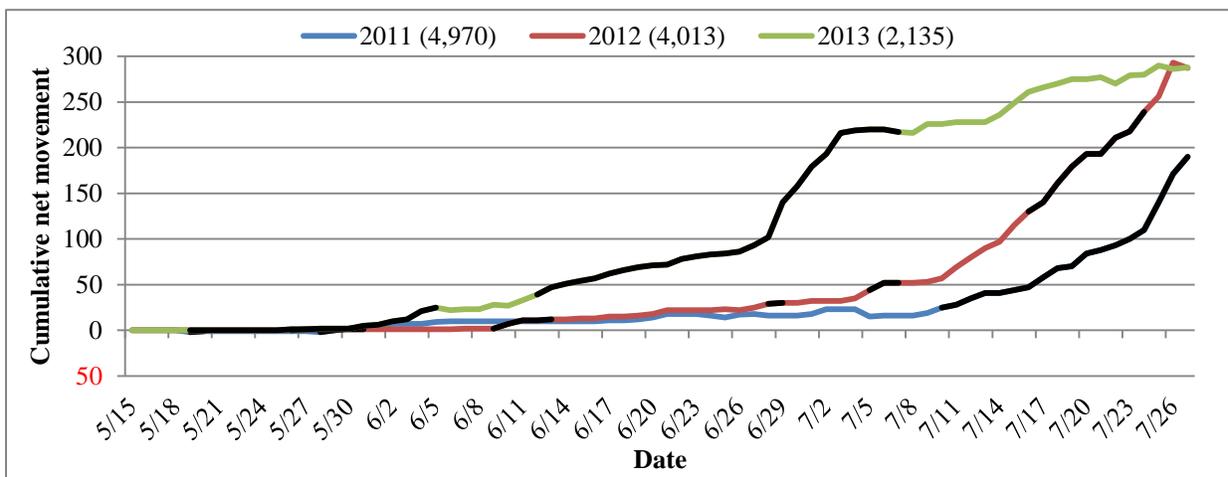


Figure 18. Cumulative net movement events at S2 during the 2011-2013 monitoring periods, with total adult return to the LNFH in (). Blackened lines indicate days when discharge through S2 was 700 -1,300 cfs.

Lengths of Passing Fish

During the 2012 and 2013 monitoring seasons, lengths of the passing fish, along with their associated dates of passage and direction of movement, were taken using the DIDSON software's "Mark Fish" tool. Lengths were taken from 1,268 fish. Of these, 105 (8%) were <40cm. Both years show a similar temporal pattern of movement-at-size, with most of the fish <40cm passing after June 29 (Figures 19-20). Most of the fish of lengths <40cm were moving downstream (N=68), and of the 37 that were measured moving upstream, all were doing so at discharges of under 1,100 cfs, and 34 of them were doing so under 600 cfs.

The length distribution of the 1,163 fish measured to be >40cm was similar to what would be expected of a spring Chinook salmon run (Figure 21). The mean length was 78.9cm (SD=14.7). This is comparable to the mean length of the adult return to the LNFH in 2012 and 2013 of 74.5cm (SD=10.1).

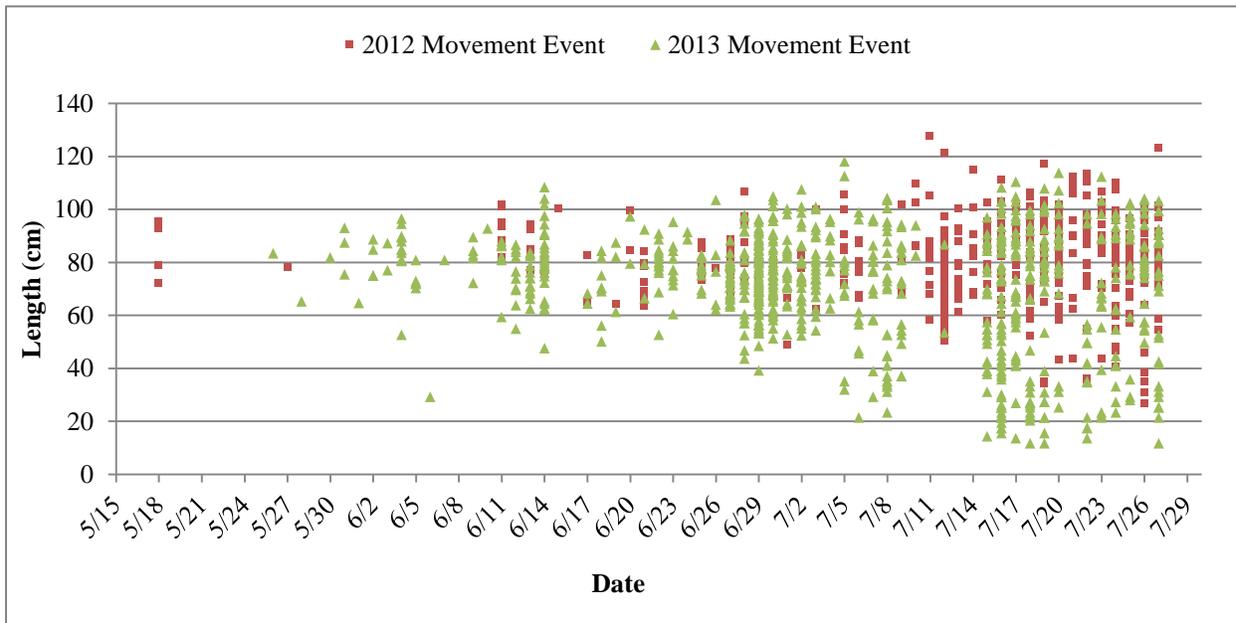


Figure 19. Temporal distribution of movement events and length in 2012 and 2013.

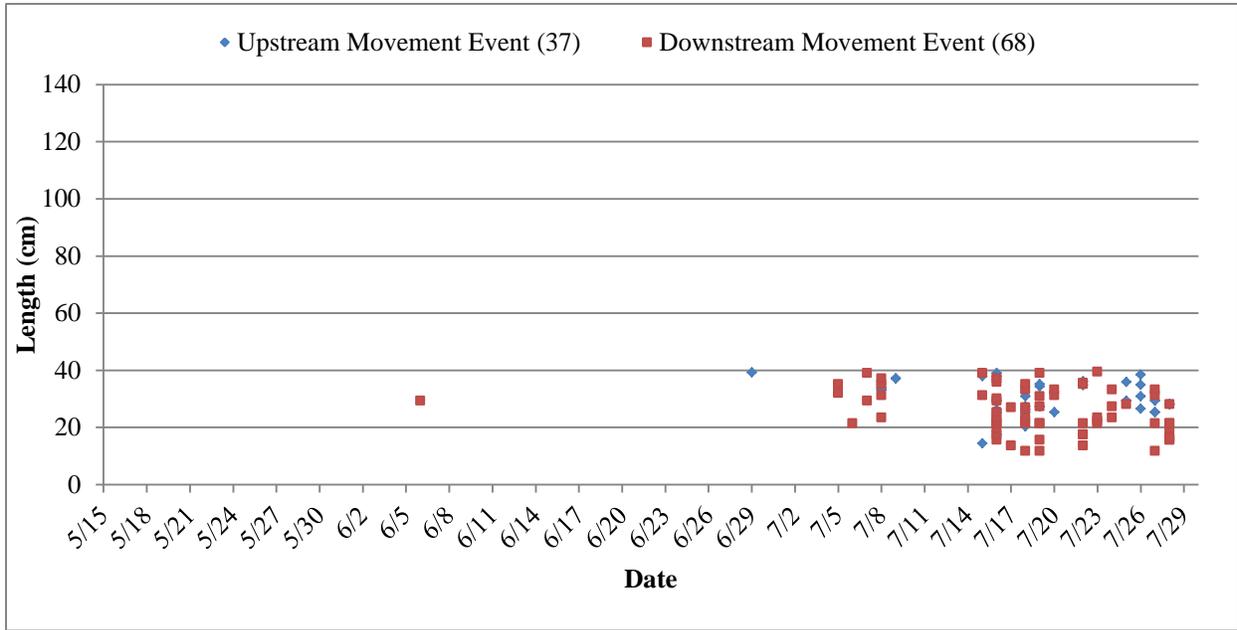


Figure 20. Temporal distribution of movement events and length of fish <40cm when 2012 and 2013 data is combined.

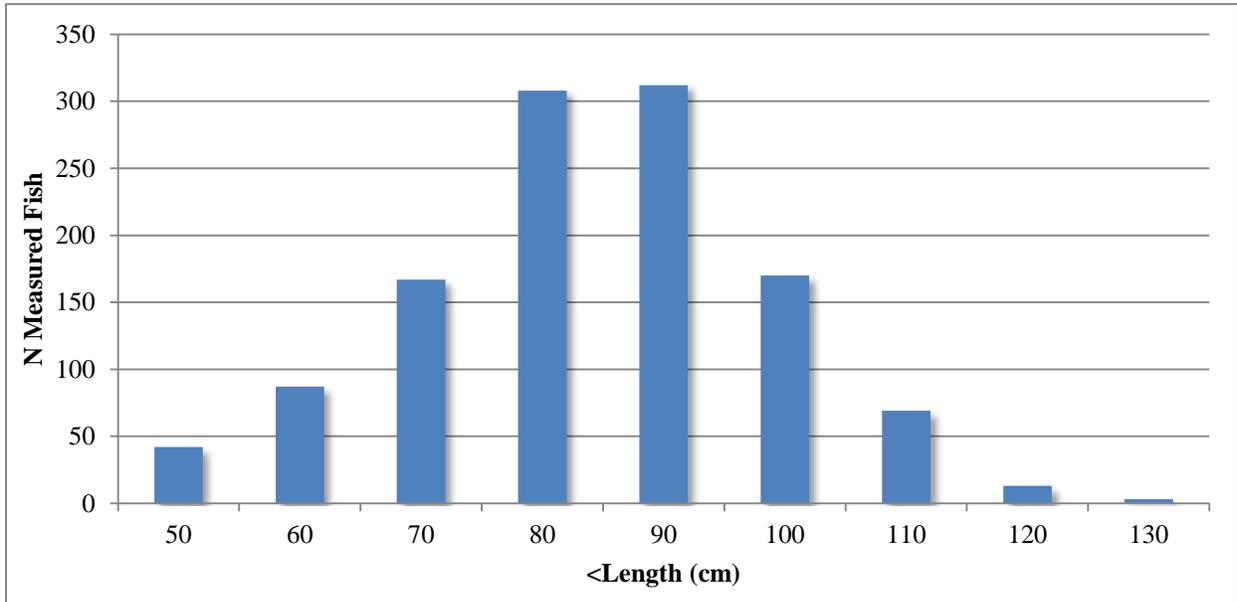


Figure 211. Length/frequency distribution of fish >40 cm passing S2 during the 2012 and 2013 monitoring seasons.

Discussion

Pattern of Movement Events

The pattern of fish movement at S2 from 2011-2013 is best explained by the amount of time S2 spends at a discharge of between 700-1,300 cfs. At these discharges, fish pass S2 at the highest rates in each of the years monitored. Because 2013 spent the most time at these discharges, upstream movement accumulated earlier and more rapidly than in 2011 and 2012. When combining all 3 years of monitoring, S2 spent 46% of its time in this discharge range, however it only spent a total of 56% of its time under 1,300 cfs. In future years, if more time is spent at lower discharges, this range of optimal passage may expand to include lower discharges.

While the run size did not appear to influence the pattern of movement in 2011-2013, the range of run sizes experienced during these 3 years of monitoring (2,135-4,970) do not represent the range of run sizes that Icicle Creek may experience. Recently, run sizes in excess of 13,000 have occurred. Likewise, a paired comparison of equal run sizes and differing discharges (or vice versa) has not been made. Logically, a large run size, paired with a low discharge, may result in significant upstream movement early in the Icicle Creek salmon run.

Lengths of Passing Fish

Of the few fish <40cm that pass S2 during the monitoring season, most did so late, and at low discharges. These fish could be resident fish that have either limited ability to pass at high discharge, or a behavioral interest in moving at a later date. These fish may also be 2-year-old “minijack” salmon that are known to have later run timing.

The majority of the fish measured during the monitoring seasons were >40cm, and the size range is commensurate with a spring Chinook salmon run. There are a few summer steelhead of this size range that use Icicle Creek in May, and a few bull trout of this size range may also be present.

Acknowledgments

The author would like to thank the technicians that spent countless hours analyzing files and entering data. As Peter Galbreath noted in 2005, “Reviewing DIDSON files is a tiresome and boring task.” Also appreciated is the logistical support of the LNFH maintenance staff.

Literature Cited

- Burwen, D. L., Steven J. Fleischman and James D. Miller. 2010. Accuracy and precision of salmon length estimates taken from DIDSON sonar images. *Transactions of the American Fisheries Society*. 139:5, 1306-1314.
- Cooper, M. 2006. Fish Production Review of the Leavenworth National Fish Hatchery Complex, 2005. U.S. Fish and Wildlife Service, Mid-Columbia River Fishery Resource Office, Leavenworth, WA.
- Ford, M., P. Budy, C. Busack, D. Chapman, T. Conney, T. Fisher, J. Geiselman, T. Hillman, J. Lukas, C. Peven, C. Toole, E. Weber, and P. Wilson. 2001. Final report of the Upper Columbia River Steelhead and Spring Chinook Salmon Biological Requirements Committee, March 2001. National Marine Fisheries Service, Northwest Fisheries Science Center, Seattle, WA.
- Hall, M. R. 2013. Summary of Icicle Creek Temperature Monitoring, 2013. U.S. Fish and Wildlife Service, Leavenworth WA.
- Hillman, T., M. Miller, C. Peven, M. Tonseth, T. Miller, K. Truscott, and A. Murdoch. 2009. Monitoring and Evaluation of the Chelan County PUD Hatchery Programs, 2008 Annual Report. Chelan County Public Utility District. Wenatchee, WA.
- Hodgson, S., T.P. Quinn, R. Hilborn, R.C. Francis, and D.E. Rogers. 2006. Marine and freshwater climatic factors affecting interannual variations in the timing of return migration to fresh water of sockeye salmon (*Oncorhynchus nerka*). *Fisheries Oceanography*. 15:1, 1-24.
- Keefer, M.L., C.A. Peery, and C.C. Caudill. 2008. Migration timing of Columbia River spring Chinook salmon: Effects of temperature, river discharge, and ocean environment. *Transactions of the American Fisheries Society*. 137:4, 1120-1133.
- Nelson, M.C, A. Johnsen, and R.D. Nelle. 2011. Seasonal movements of adult fluvial bull trout and redd surveys in Icicle Creek, 2009 Annual Report. U.S. Fish and Wildlife Service, Leavenworth WA.

USFWS. 2006. Biological Assessment for the Operation and Maintenance of the Leavenworth National Fish Hatchery through 2011.

USFWS. 2011. Biological Opinion for the Operation and Maintenance of the Leavenworth National Fish Hatchery.

Personal Communications

Lindenberg, M. Personal Communication. U.S. Fish and Wildlife Service. Region 1. Portland, OR.

**U. S. Fish and Wildlife Service
Mid-Columbia River Fisheries Resource Office
7501 Icicle Road
Leavenworth, WA**



January 2014