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Spring Chinook Salmon Passage at the Leavenworth National Fish Hatchery, 2011

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***On the cover**: Spring Chinook salmon passing Structure 2 and the Leavenworth National Fish Hatchery. USFWS.*

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Abstract- The Leavenworth National Fish Hatchery (LNFH) was constructed and operates under the authority of Section II of the Rivers and Harbors Act of August 30, 1935 (49 Stat. 1028) as partial mitigation for 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 DIDSON sonar camera, we were able to monitor the movement of "salmon-sized" fish through one of these structures during the LNFHs' Bloodstock Collection Period. The camera provided timing, direction, and approximate size of the fish passing the structure. Using data collected with the DIDSON camera, as well as additional survey data, we can account for most of the adult spring Chinook salmon in Icicle Creek.

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Table of Contents

List of Tables

List of Figures

Introduction

The Leavenworth National Fish Hatchery (LNFH) was constructed and operates under the authority of Section II of the Rivers and Harbors Act of August 30, 1935 (49 Stat. 1028) as partial mitigation for the construction of Grand Coulee Dam. 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).

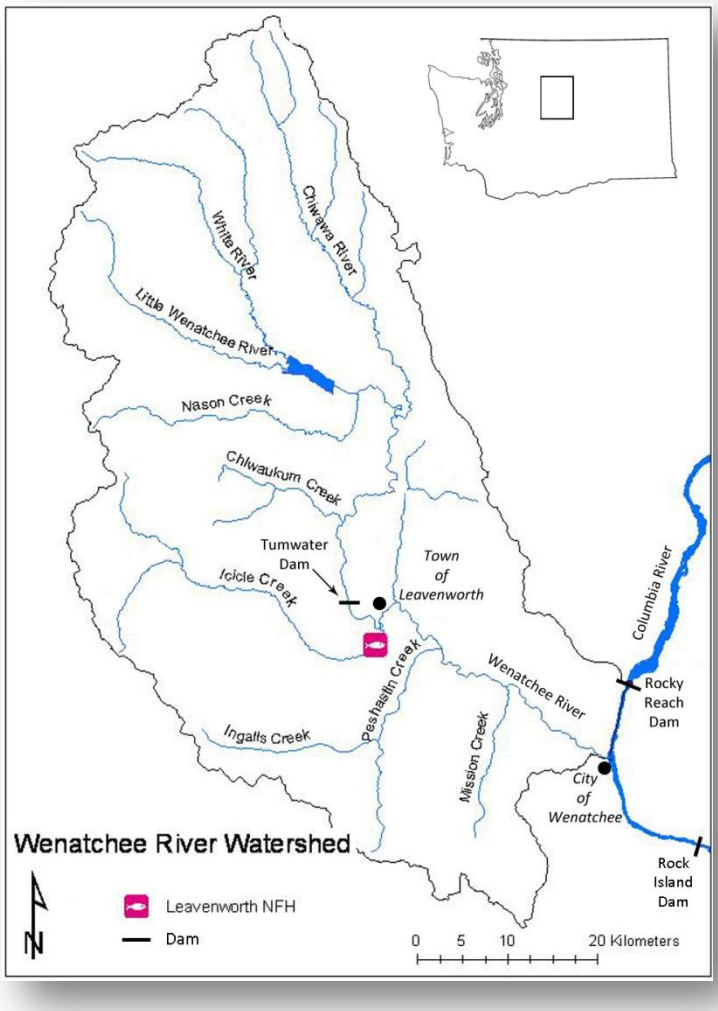

Figure 1. Wenatchee River watershed.

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 Operations

The LNFH has produced several trout and salmon species since production began in 1940. Species have included spring and summer/fall Chinook (*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.

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. 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. S2 and S5 are structures of concern with regard to fish passage, and are the focus of this report.

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 2006a).

Current Operations

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 adults returning to the LNFH from 2001 to 2011 is shown in Table 1. The stock utilized by the LNFH is not included in the ESA-listed UCR spring Chinook salmon ESU. 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 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.

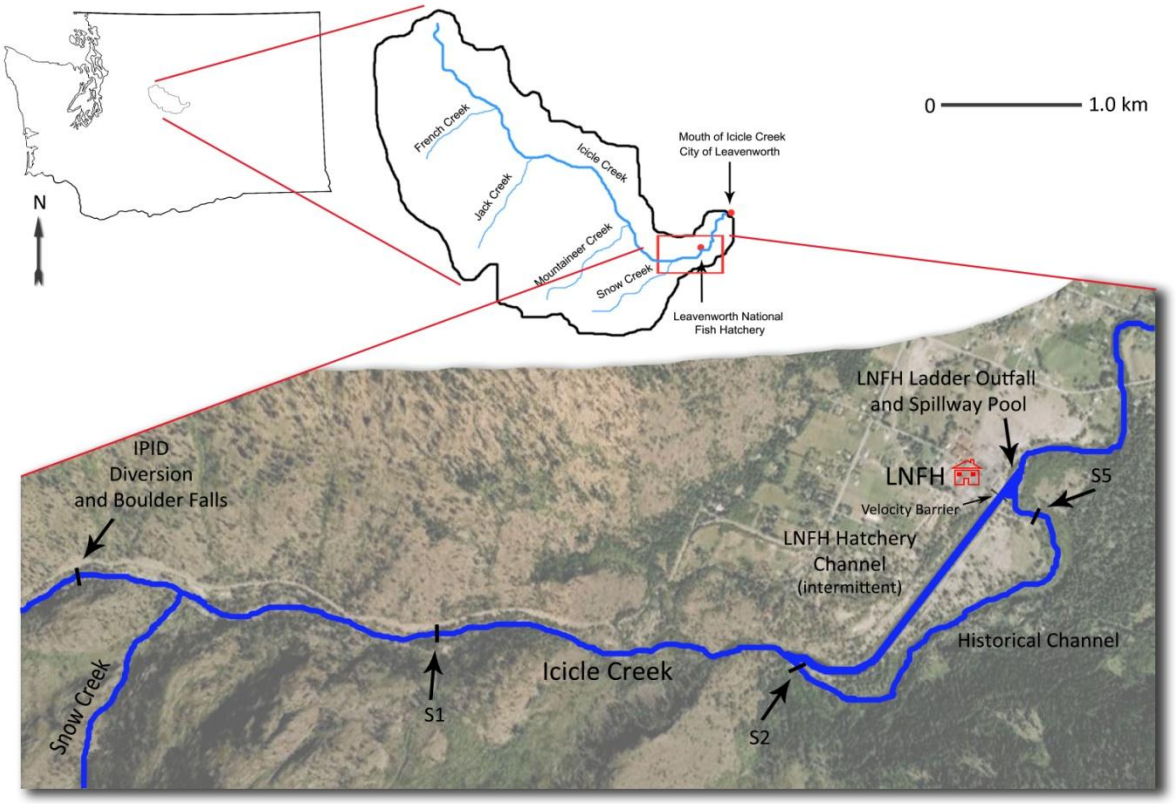

Figure 3. Lower Icicle Creek with LNFH, structures, and Boulder Falls.

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

Table 1. LNFH adult returns, 2001-2011.

Year	LNFH Adult Returns
2001	6260
2002	6459
2003	4825
2004	2307
2005	2560
2006	1957
2007	1708
2008	3229
2009	3045
2010	11366
2011	4970

Salmon Passage

Spring Chinook Salmon

Spring-run Chinook salmon that enter the Wenatchee 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 river. 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 euthanized. At the current marking rate, 80% of the potentially straying 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.

Monitoring

In 2011, the AMG recommended that S2 and S5 be left in the fully open position during the Broodstock Collection Period (BCP), offering the least impedance to fish passage in over 70 years. While unobstructed passage of native species is a desire of the AMG, the Group also

recognized the concern of escapement of spring Chinook salmon from the tribal fishery and disease transmission originating from adults spawning 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 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).

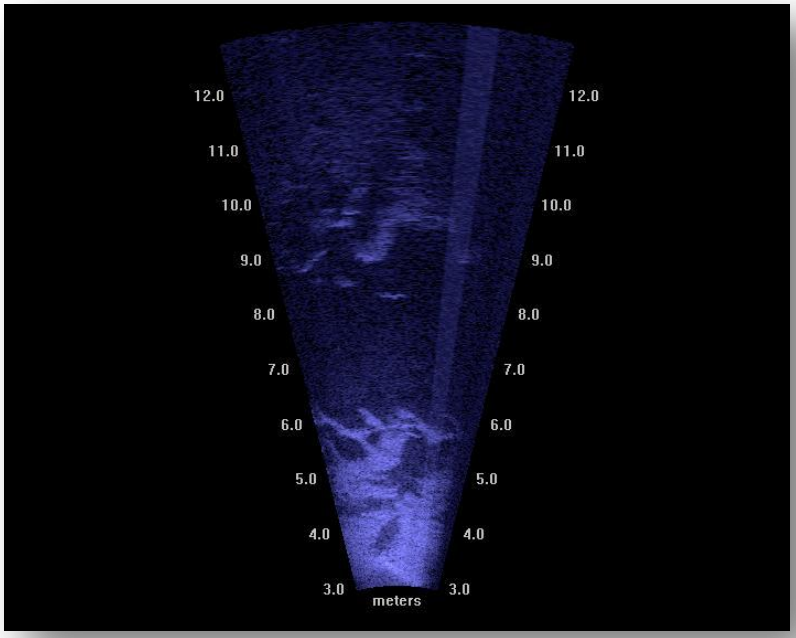

Figure 5. Screenshot of DIDSON file.

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^{o} 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, inflating any attempts to "count" fish. If the movement corridor is "closed", 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 reach 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. However, as a result, each viewing instance is more accurately described as a "movement event" rather than a "count".

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 cmA2
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 .txt file output.

Speciation

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 can be estimated. For the majority of the 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 (Miller 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 30^0 horizontal and 14^0 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 2011 monitoring season.

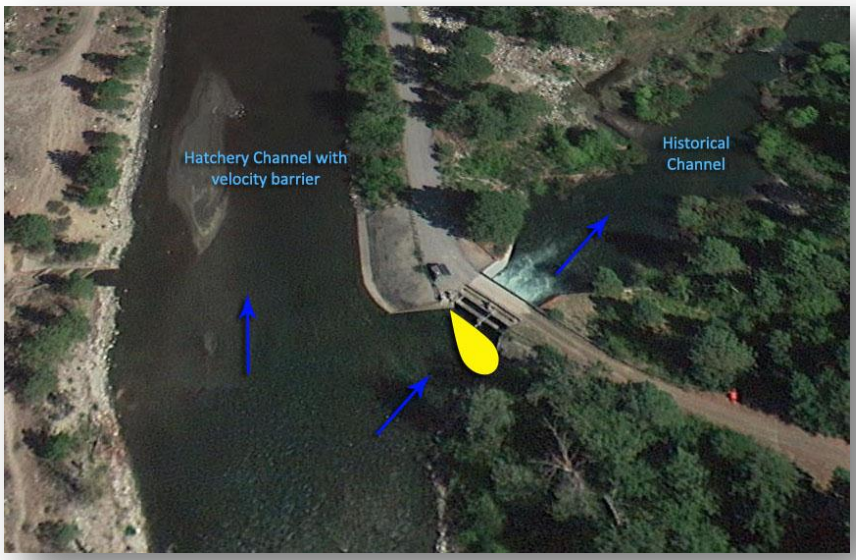

Figure 7. Aerial photo of S2 with insonified area in yellow. Courtesy of Google Maps.

Deployment Dates

The 2011 Biological Opinion requires the monitoring of spring Chinook salmon passage above the LNFH during the BCP. In 2011, monitoring was continued until 9-Sept., with a few periods of downtime due to maintenance and environmental conditions (Table 2).

Table 2. Dates with no DIDSON monitoring.

2011 Dates with No Monitoring
6/10 - 6/15
7/30 - 7/31
8/13 - 8/14
8/28 – 8/29

Icicle Creek Conditions

Icicle Discharge

The Icicle Creek basin experienced a cool and wet year in 2011 (Hall and Henry 2012). Icicle Creek discharge was protracted throughout the late spring and summer months (Figure 8). Below 300cfs (approx.), 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 Canal. Above 1000cfs, the portion of Icicle Creek within the Hatchery Canal begins to spill over its velocity barrier, reconnecting with the Historical Channel immediately downstream. Total Icicle Creek discharge is measured at a Washington Department of Ecology station gauge (ID# 45B070), and S2 discharge is calculated from total discharge measurements.

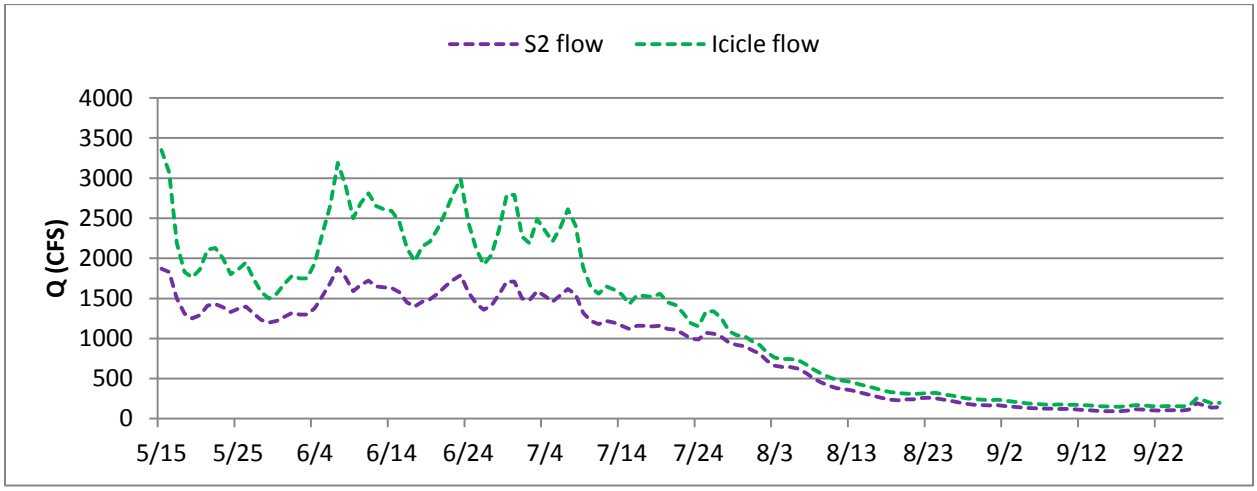

Figure 8. Icicle discharge and calculated discharge through S2 in 2011.

Mudslides

On 10-June 2011, a mudslide in upper Icicle Creek deposited large amounts of debris into the watershed. This event impaired monitoring for approximately 5 days. No data was collected between 10-June and 15-June.

DIDSON Monitoring Results

Broodstock Collections Period Totals

During the BCP (15-May to 7-July), 120 upstream "movement events" occurred at S2, and 104 downstream "movement events" occurred, resulting in a net movement of 16 upstream "events" (Figure 9).

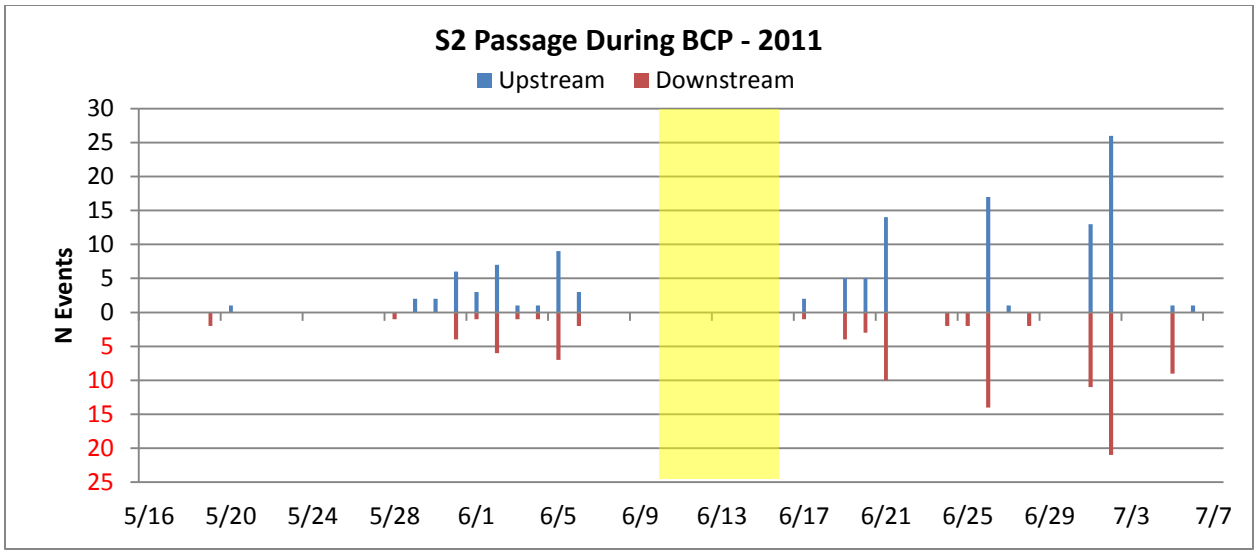

Figure 9. "Movement events" at S2 during the BCP, 2011, with area in yellow indicating period of no monitoring.

Season Totals

Monitoring of fish passage at S2 continued through 9-Sept. For the entire 2011 monitoring season, 6,335 upstream "movement events" occurred at S2, and 5,646 downstream "movement events" occurred, resulting in a net movement of 689 upstream "events" (Figure 10).

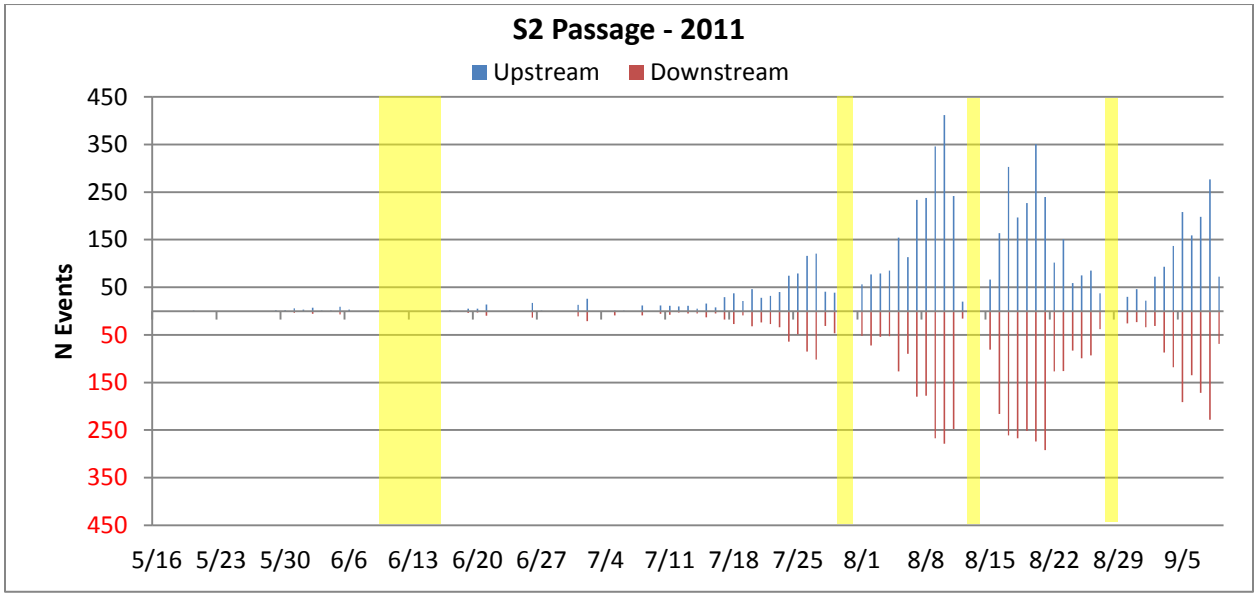

Figure 10. "Movement events" at S2 in 2011, with area in yellow indicating period of no monitoring.

Lengths

Each "movement event" was measured as if it were a unique fish. During the BCP, length measurements were taken on 218 fish. Of these, 12 fish (6%) were measured to be <60cm. These fall within the range of 3-year old (YO) (or "Jack") salmon, but also are within the range of other fish known to be present in Icicle Creek. The remaining 206 fish were of a size commensurate with "adult" (4+YO) salmon, anadromous steelhead, or adult bull trout.

During the entire 2011 season, length measurements were taken on 11,312 "movement events". Of these, 3261 (29%) were measured to be <60cm. The length/frequency distribution for the entire 2011 season is shown in Figure 11. The temporal occurrence of a fish of a given length is shown in Figure 12.

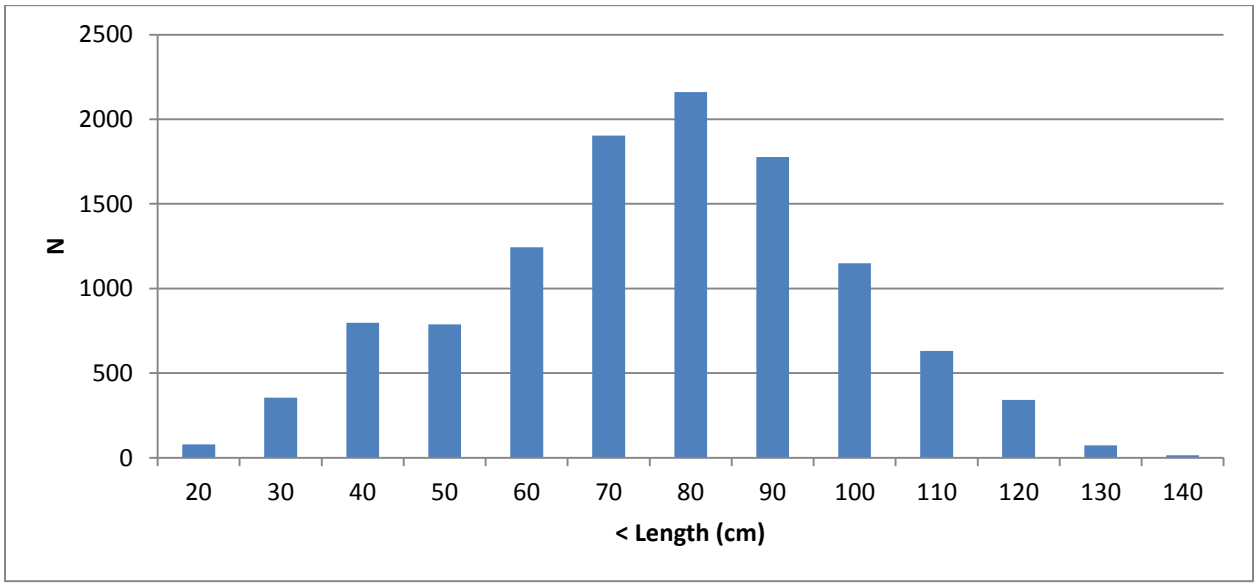

Figure 11. Length/frequency distribution of fish measured during the entire 2011 monitoring season.

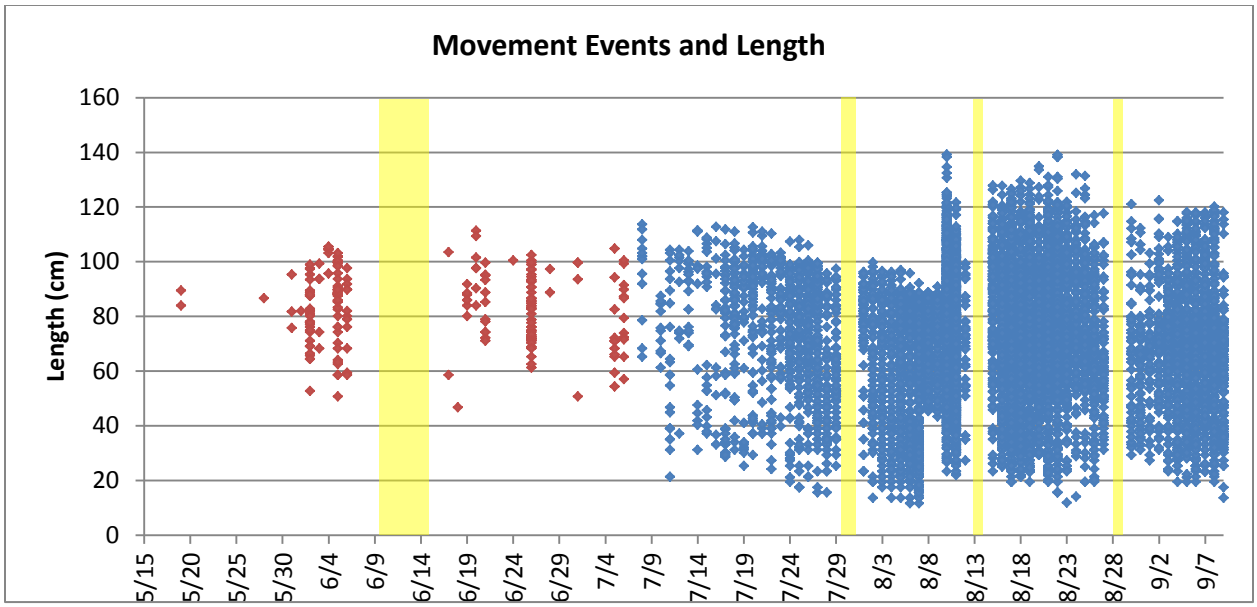

Figure 12. Plot of "movement events" and their corresponding length over the entire 2011 monitoring season, with red indication events during the BCP, and area in yellow indicating period of no monitoring.

Discussion

Broodstock Collection Period Totals

During the BCP, nearly equal upstream and downstream “movement events” occurred through S2, often in the same day, with a net of 16 upstream “events”. In May and early June, adult steelhead could account for some of these events.

The timing of movement appears correlated with Icicle discharge, with movement occurring during periods of lower discharge (Figure 13). A similar pattern of movement at lower discharges occurs with respect to timing of unique PIT-tagged spring Chinook salmon entering the LNFH adult ladder in 2011 (Figure 14).

Keefer et al. (2004) suggests that other factors, such as metabolic activity and reproductive maturation may have greater explanatory power on migration behavior than river discharge in Columbia River Chinook salmon. The BCP occurs more than 2 months before the peak spawning time for Icicle Creek spring Chinook salmon, and fish using Icicle Creek for pre-spawn staging have very few movement options (Miller 2009). The “movement events” occurring during the BCP likely represent a small number of fish “nosing around” before other possible inductive factors such as photoperiod and/or temperature incite final spawning behavior.

The year 2011 was an unusual hydrographic year, with periods of high discharge protracted through much of the summer. More years of monitoring are needed to encompass the range of hydrologic conditions possible in Icicle Creek.

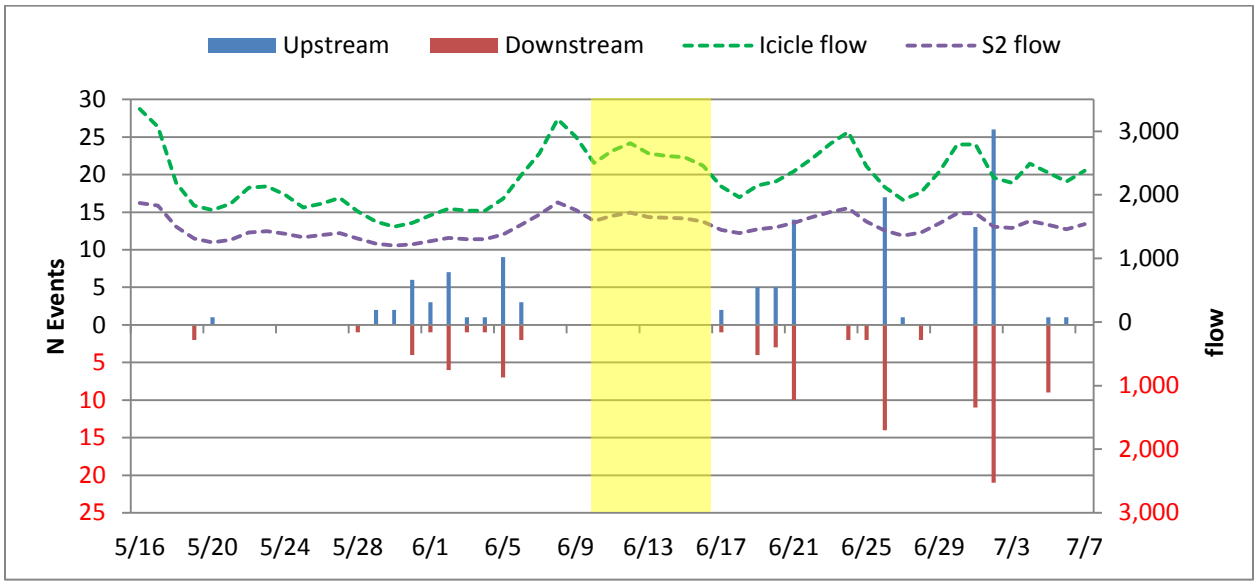

Figure 13. "Movement events" and discharge during the BCP, 2011, with area in yellow indicating period of no monitoring.

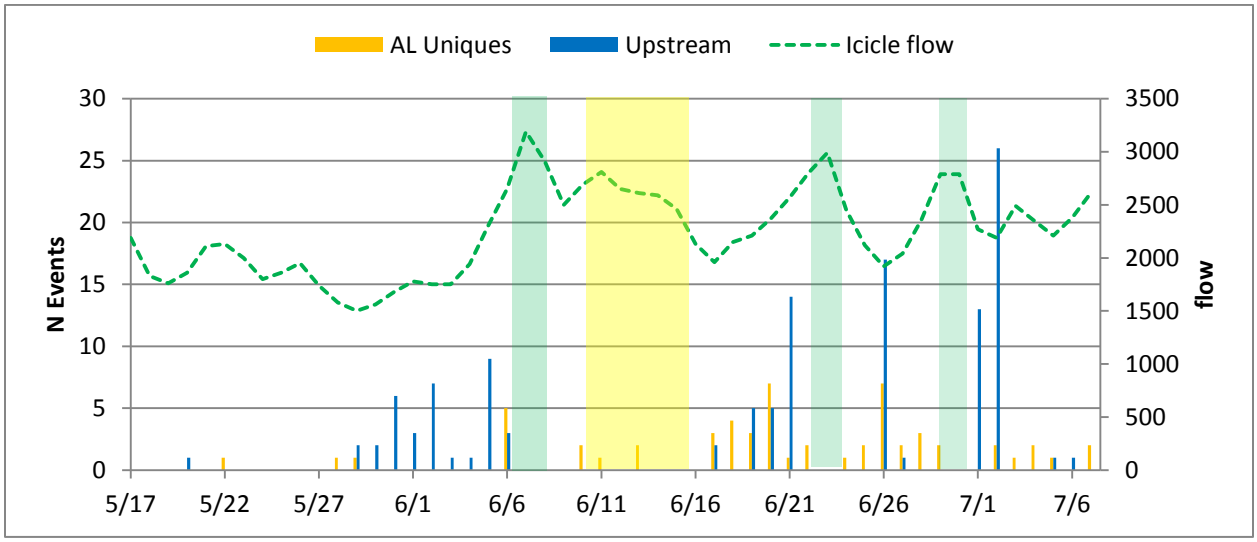

Figure 14. Upstream "movement events" and LNFH adult ladder (AL) unique PIT tags (first detection), with Icicle Creek discharge, during the BCP, 2011. Area in yellow indicates period of no monitoring, and area in green indicates high flow events.

Season Totals

Beginning in mid-July, the number of "movement events" increased significantly in both directions (Figure 10). Of the 689 net upstream "movement events" during the entire 2011 season, 99% of these occurred after the BCP ended. The increase in "movement events" also corresponds with a decrease in discharge, with Icicle Creek reaching its summer "base flow" during this period (Figure 15). However, as with the discharge/movement correlation during the BCP, other factors must be considered. Movement in late July and early August also corresponds to the initiation of spawning behavior, with the first redds being created in early August (Miller 2009). During this time, spring Chinook salmon emerge from "staging" habitat and move onto the shallow riffle spawning grounds. With competition for space and mates, as well as predator avoidance, it can be expected that movement would increase during this time.

There are a few possible explanations for the apparent "equality" of upstream and downstream "movement events" across the monitoring season (Figure 10). The fish may not be finding what they are looking for (habitat, abiotic conditions, etc.) after moving upstream, resulting in an immediate corresponding downstream movement. There also may be a few fish that are attracted to the area around the monitoring site, and are actively "milling" in this area. The gradual cumulative increase in upstream "movement events" may reflect an upstream counting bias over a season of thousands of events.

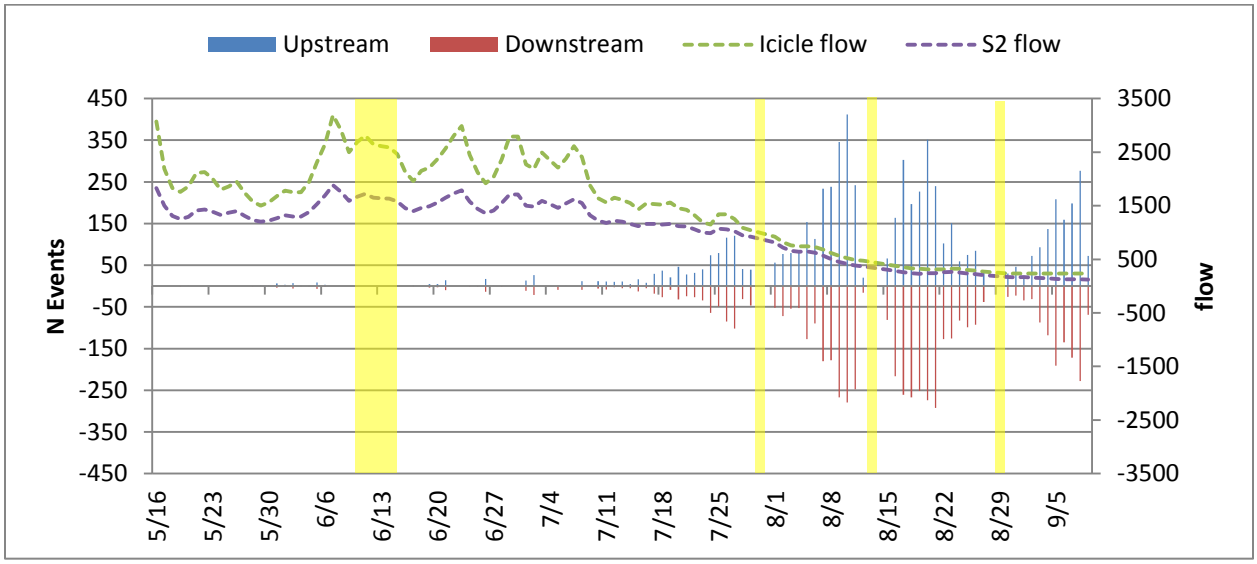

Figure 15. "Movement events" and discharge during the entire monitoring season, 2011, with area in yellow indicating period of no monitoring.

DIDSON Validation

Based solely on the number of "movement events", it would appear that hundreds of spring Chinook salmon passed S2 during late July and early August. However with the addition of LNFH return information and Icicle Creek survey data, we suggested that the numerous "movement events" actually reflects a (relatively) small number of fish actively passing upstream and downstream through S2.

Multiple methods can be used to estimate the total number of spring Chinook salmon using the limited habitats of Icicle Creek. Using Passive Integrated Transponder (PIT) tag data, we can calculate that the 69 PIT-tagged LNFH origin spring Chinook that passed Rock Island Dam is estimated to represent 6,543 fish (does not include 2YO "minijacks", Columbia River DART). Nearly all of these fish are destined for Icicle Creek, with no harvest in the Columbia or Wenatchee River. Another model, using Bonneville Dam counts, historic adult returns, and harvest rates, predicted 8,082 adult spring Chinook salmon would enter Icicle Creek (Cooper pers. com.)

From the estimated 6,000 to 8,000 spring Chinook salmon using Icicle Creek in 2011, an estimated 825 were harvested in the Icicle Creek sport harvest, an estimated 778 were harvested in the Icicle Creek Tribal harvest, and 4,970 were collected at the LNFH adult ladder trap (Maitland pers. com., Dick pers. com., Rayton pers. com., respectively, Table 3).

Table 3. Estimates of accounting metrics for Icicle Creek adult spring Chinook salmon returns.

Year	Estimated Icicle Return Based on Rock Island PIT's	Estimated Icicle Return Based on Dam Counts, Historic Returns, and Harvest Rates	Average Icicle Creek Sport Harvest	Estimated Icicle Creek Tribal Harvest	LNFH Adult Ladder Trap	Estimated Total Accounted For
2011	6,543	8,082	825	778	4,970	6,573

To estimate how many spring Chinook salmon remained in Icicle Creek after the BCP, two independent surveys can be examined. First, the CCPUD conducts spawning ground surveys for spring Chinook salmon in Icicle Creek in August and September each year. In 2011, 19 redds were surveyed and 7 carcasses were sampled above S2 (Keller pers. com., Table 4). Additionally, 2 of these redds were excavated <10m upstream of the DIDSON insonified area. Fish associated with these redds likely moved through the insonified area many times during the spawning season.

Table 4. Spring Chinook salmon redds in Icicle Creek above S2.

Year	River	Redds Above S2
2006	Icicle	0
2007	Icicle	2
2008	Icicle	34
2009	Icicle	9
2010	Icicle	27
2011	Icicle	19

Second, the MCRFRO annually conducts a thorough snorkel survey of the entirety of Icicle Creek. In 2011, this survey occurred on 10-Aug, and 77 adult spring Chinook salmon were encountered in the entire Icicle Creek, with 17 of these occurring above S2 (Hall internal memo 2011, Table 5).

Table 5. Spring Chinook salmon in Icicle Creek above S2. Includes live fish and carcasses.

Year	River	SCS Above S2
2006	Icicle	36
2007	Icicle	24
2008	Icicle	202
2009	Icicle	135
2010	Icicle	146
2011	Icicle	17

While the DIDSON monitoring program counted hundreds of "movement events" in July and August of 2011, accounting for the adult spring Chinook salmon using hatchery return, harvest, spawning ground, and snorkel data suggests that these "movement events" represent a small number of fish actively passing upstream and downstream of S2. There is no evidence that hundreds if individual spring Chinook salmon remained in Icicle Creek after the 2011 BCP.

Lengths

The movement of fish with lengths <40cm increased greatly in July and August (Figure 12). Fish of this size are not likely adult spring Chinook salmon. The most common fish of this size in Icicle Creek are rainbow trout and suckers (*Catostomus spp*.).

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.

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