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Depth Distribution of Yearling and Subyearling Chinook Salmon and Juvenile Steelhead

ZD DENG, X LI, T FU, RS BROWN, JJ MARTINEZ, PS TITZLER, JS HUGHES, GA MCMICHAEL, MA WEILAND, AH COLOTELO

Pacific Northwest National Laboratory

JR SKALSKI, RL TOWNSEND

University of Washington

BA TRUMBO, ML AHMANN, JF RENHOLDS

US Army Corps of Engineers, Walla Walla District

Background

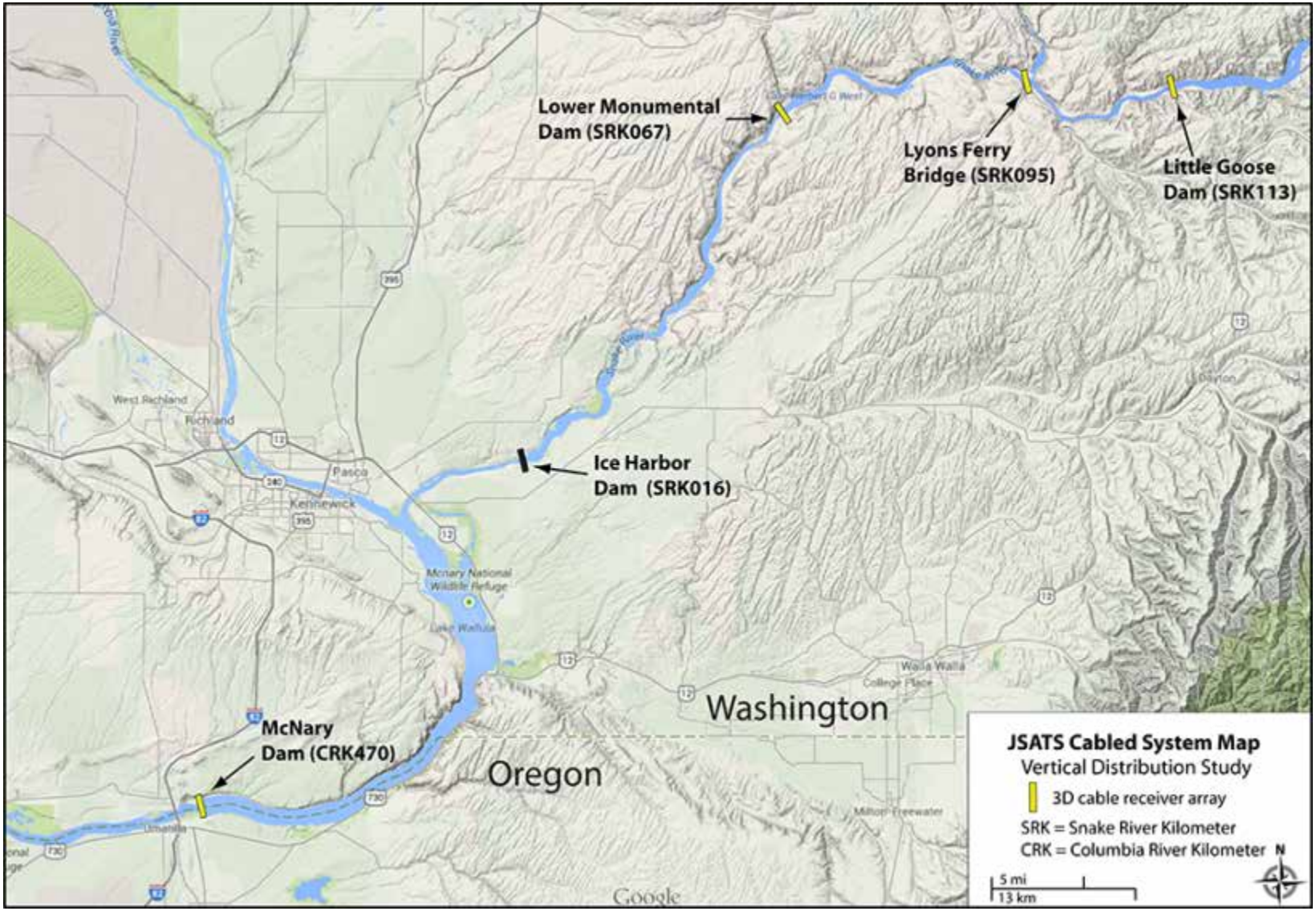
- Fish passing through hydro turbines can be exposed to rapid decompression.
- Rapid decompression may lead to pressure-related injury, or barotrauma, such as swim bladder rupture, hemorrhaging, and exopthalmia.
- The ratio of pressure change is the best predictor of the likelihood of barotrauma for juvenile salmonids (ratio = acclimation depth / lowest pressure during turbine passage).
  - Fish acclimated in shallower water column require less gas in the swim bladder to achieve neutral buoyancy when compared to fish that are acclimated in deeper water column and will be less susceptible to barotrauma.
- Acclimation depth (i.e., the depth at which fish are assumed to be neutrally buoyant) of juvenile salmonids as they approach hydro structures is critical for better understanding and evaluation of turbine passage.

Objectives

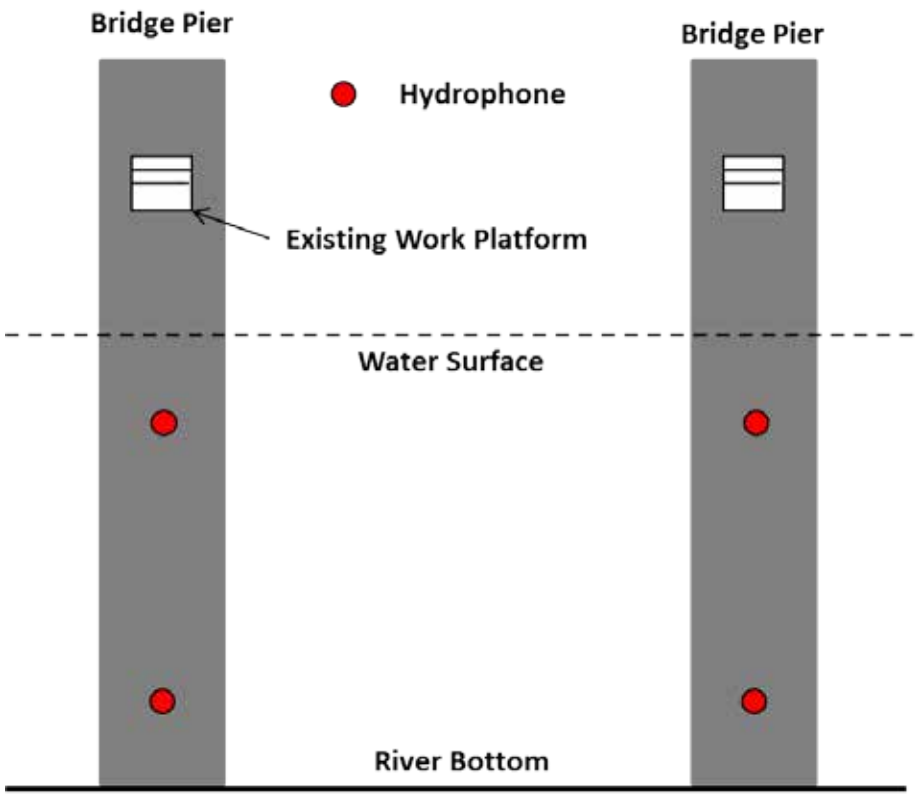
- Estimate the vertical depth distribution and acclimation depth of fish implanted with JSATS transmitters immediately prior to entering turbine units and the juvenile bypass system. Two years of data were available for this analysis.

- Estimate the vertical depth distribution and acclimation depth of subyearling Chinook salmon at a central location within the reach between dams, and determine if a significant difference exists in acclimation depth between the mid-reach and near-dam locations.

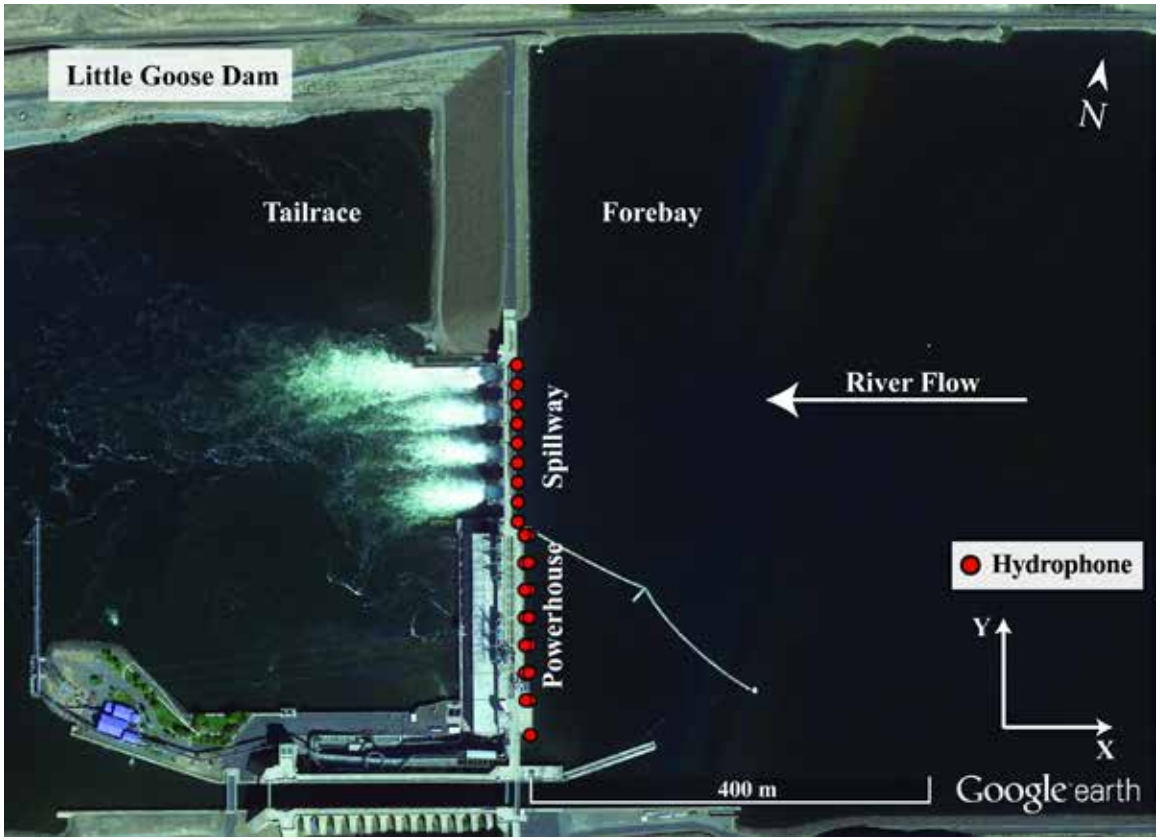
Study Sites

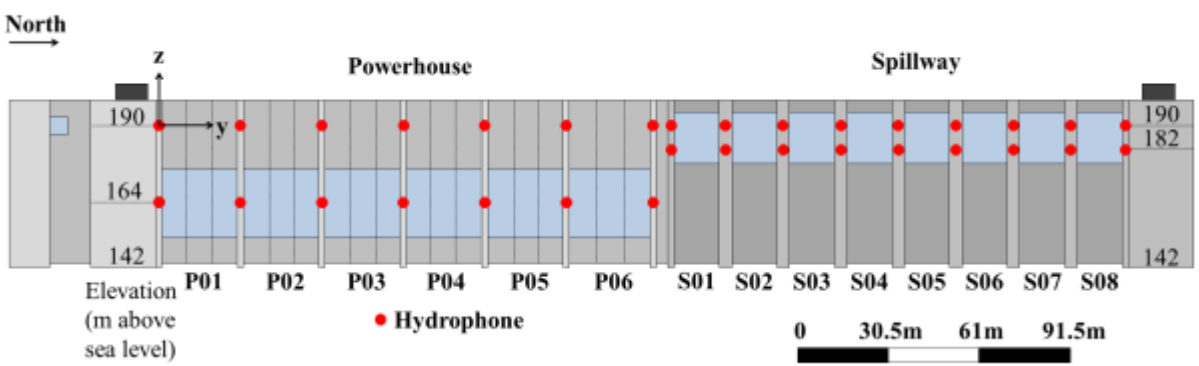

Lower Monumental Dam (SRK067)
Lyons Ferry Bridge (SRK095)
Little Goose Dam (SRK113)
Ice Harbor Dam (SRK016)
McNary Dam (CRK470)
Washington
Oregon
JSATS Cabled System Map
Vertical Distribution Study
3D cable receiver array
SRK = Snake River Kilometer
CRK = Columbia River Kilometer
N
5 mi
13 km
Google

Mid-reach Deployment at Lyons Ferry Bridge (LFB)

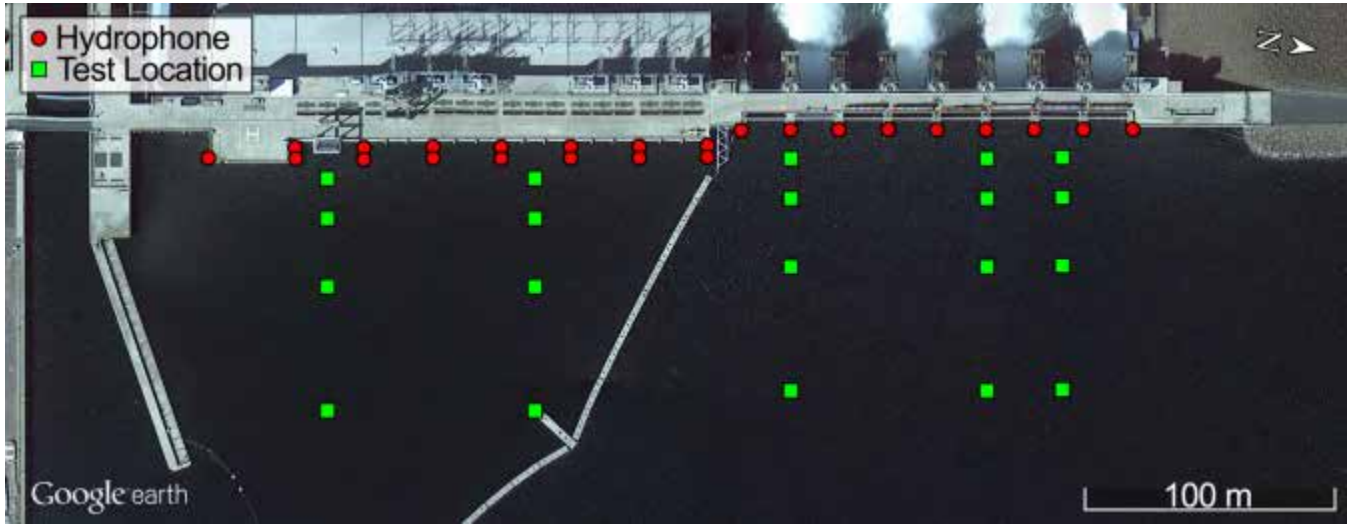


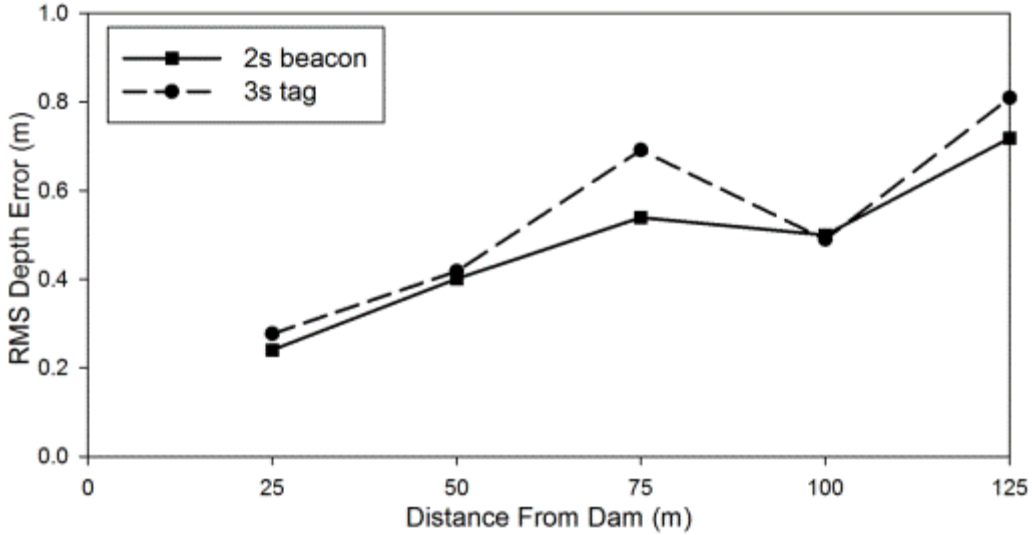
Deployment at Little Goose Dam (LGS)



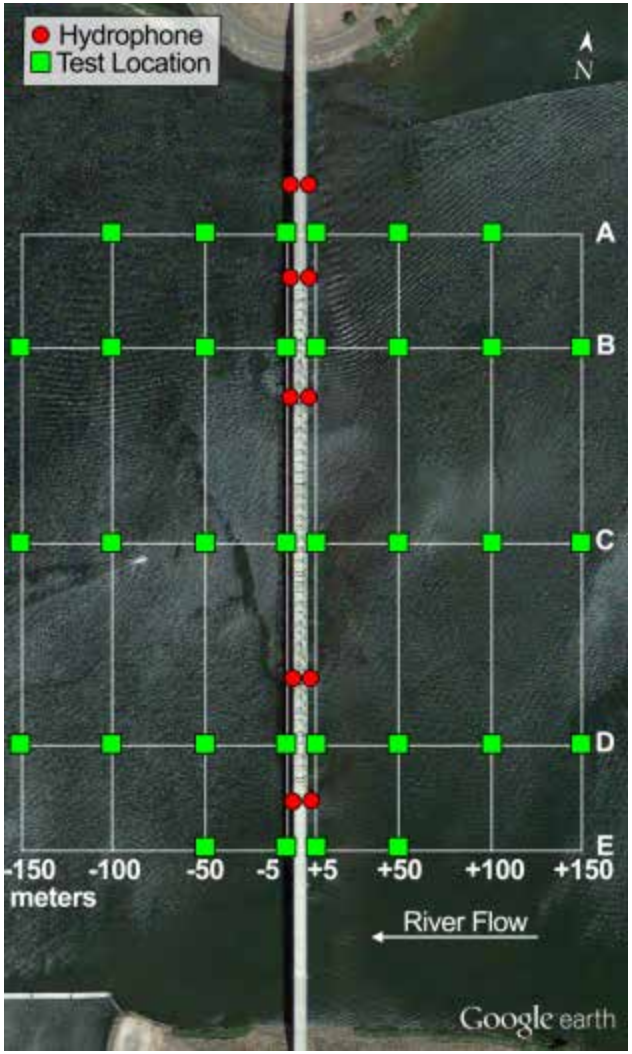


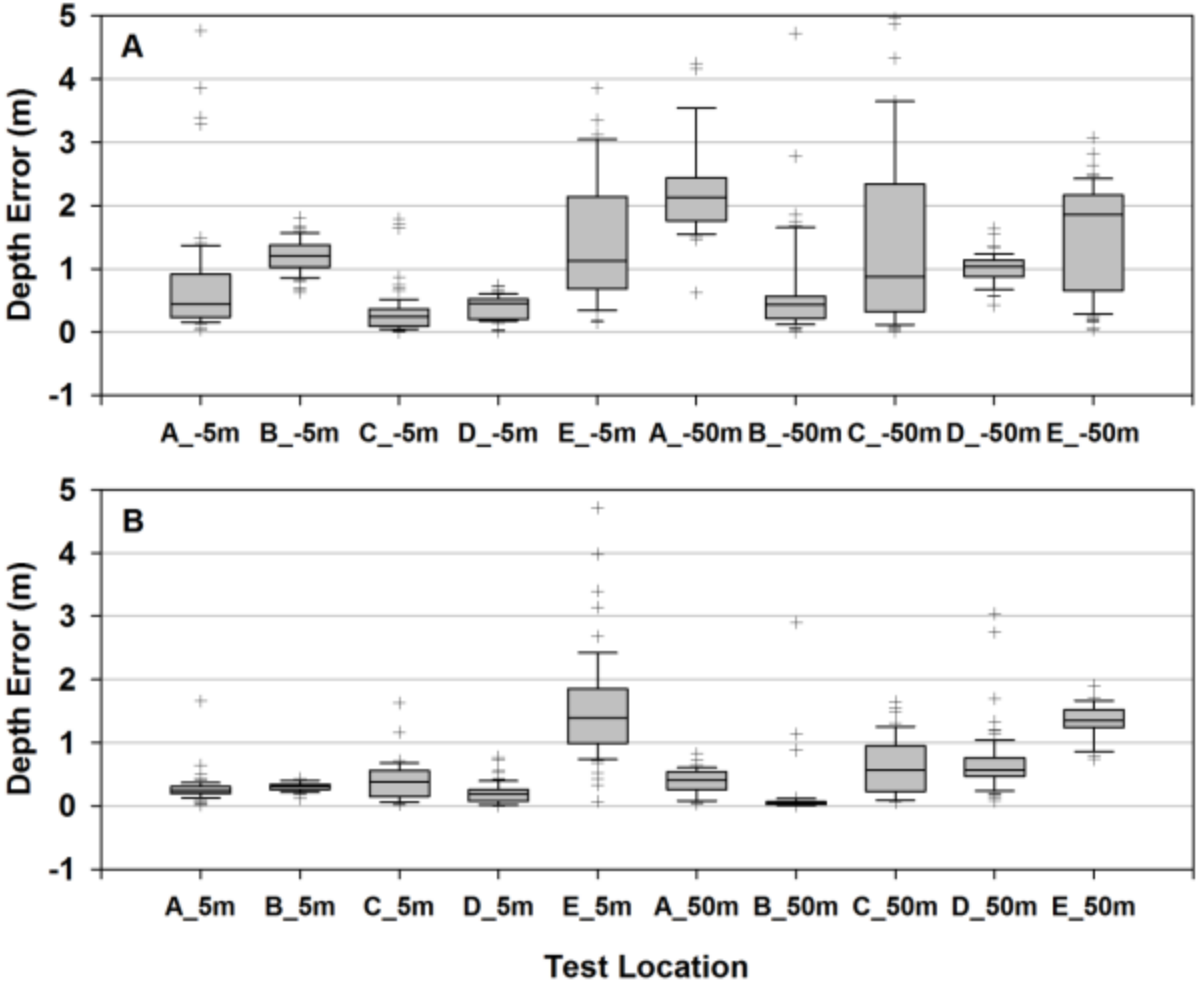
Controlled Error Analysis Testing - Forebay





Controlled Error Analysis Testing – Mid-reach





Data Collected in 2012 and 2013 under PSE Studies

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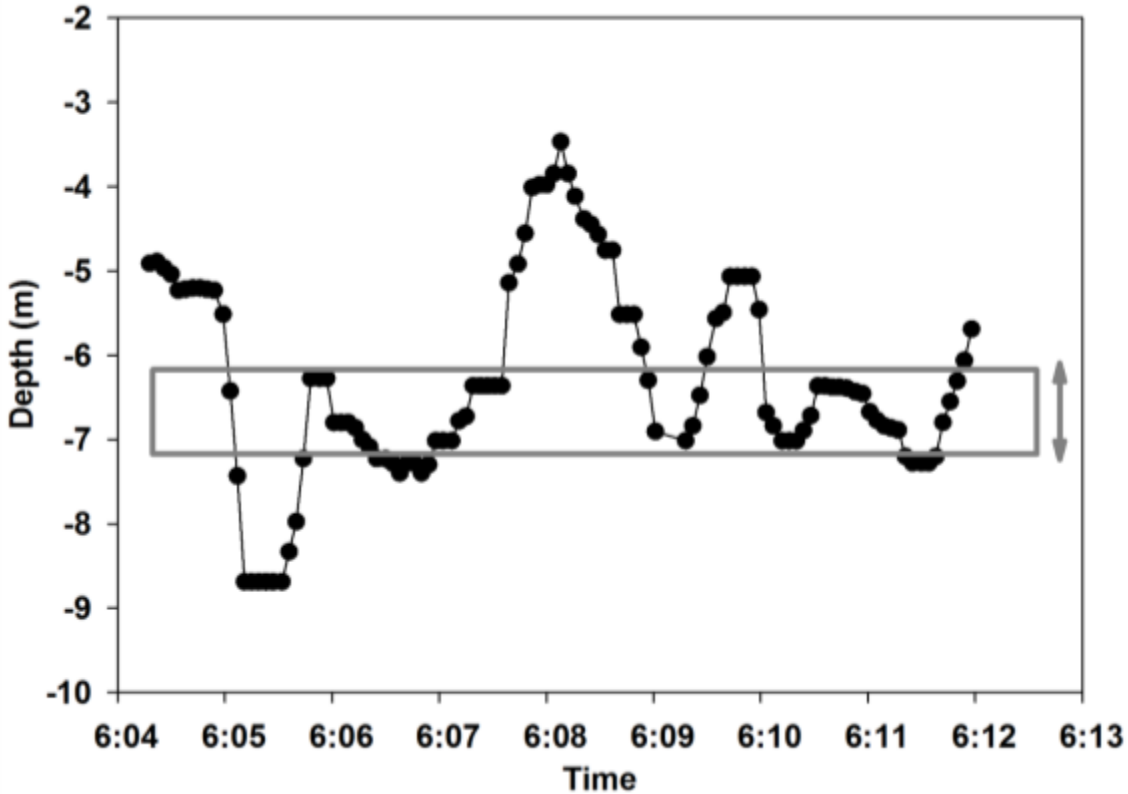
Year	Season	Location	Fish Species	Tag PRI (s)
2012	Spring	LGS and LMN	Steelhead (ST) Yearling Chinook (CH1)	3
	Summer	LGS and LMN	Subyearling Chinook (CH0)	4.2
2013	Summer	LGS, LFB, and LMN	Subyearling Chinook (CH0)	4.2

Acclimation Depth

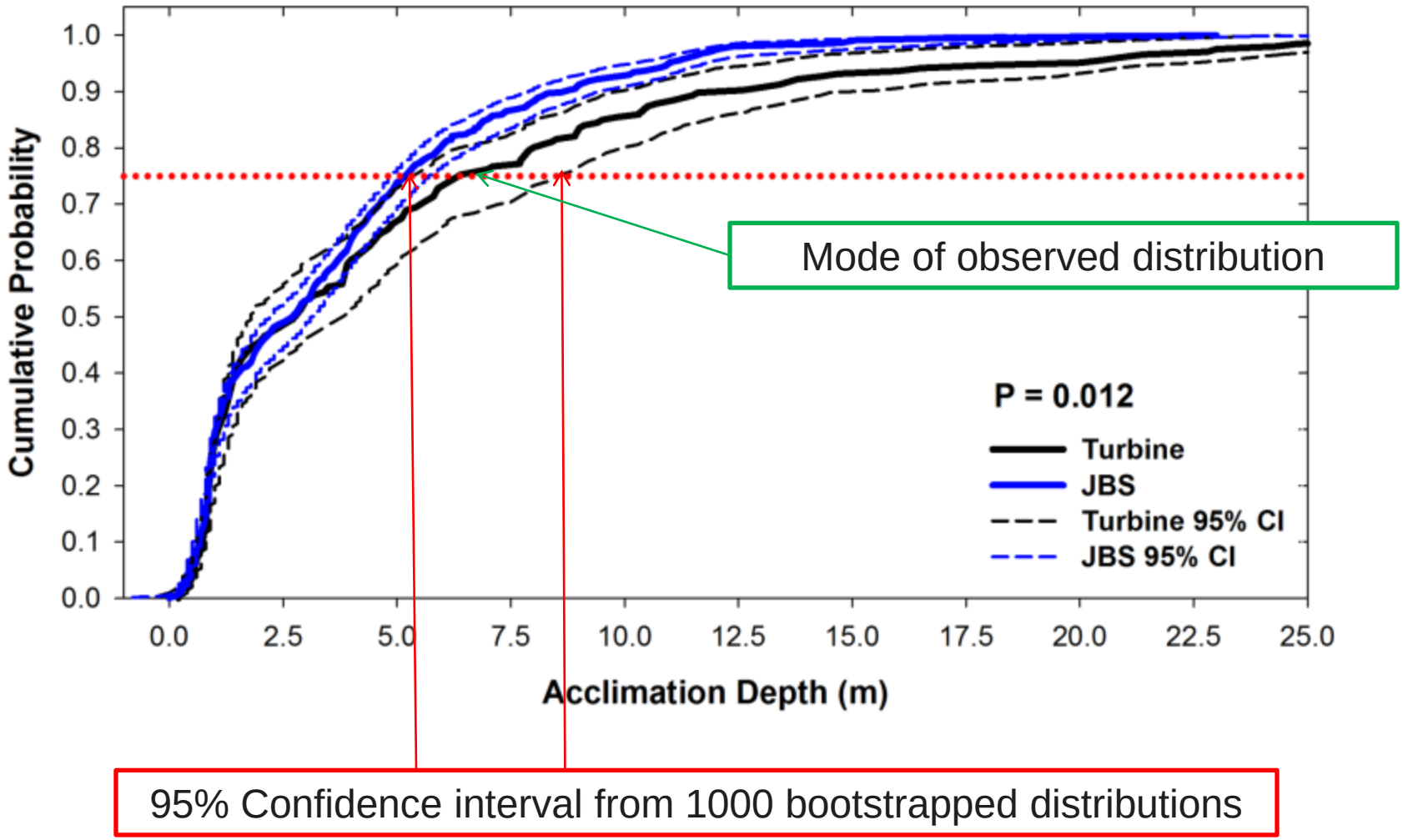
- Investigated five methods for estimating acclimation depth.
- Best method: the depth at which an individual fish swam for the longest time, with the assumption that fish were most likely to be neutrally buoyant at this depth. A 25-m horizontal distance limit was used to exclude the high flow influence of the powerhouse.



Statistical Methods

- Fish with similar characteristics (e.g., species, passage route, locations, etc.) were defined as a sample group in analysis.
- Comparison between two sample groups:
  - The primary analysis was based on the cumulative distribution function (cdf). A two-stage bootstrapping procedure was used to construct a 95% confidence interval for the cdf from 1000 bootstrapped simulations.
  - A modified *Kolmogorov-Smirnov* (K-S) test of equal distributions is performed if the observations are measured with error by bootstrapping the pooled data from two alternative sample distributions.

Example: Comparison of cdfs



Results: Mid-reach vs. Forebay

Year	Fish Species	S1	S2	P-value	S1		S2	
					N	Median Depth (m)	N	Median Depth (m)
2013	CH0	LGS	LMN	<0.001	2428	7	5388	6.2
2013	CH0	LGS	LFB	<0.001	2428	7	4224	5
2013	CH0	LFB	LMN	<0.001	4224	5	5388	6.2

N = sample size

- Subyearling Chinook salmon were consistently detected in shallower depths (the median acclimation depths were 1.2 to 2.0 m shallower) in the mid-reach location (LFB) than when in the dam forebays.

- The bathymetry of the Snake River may have contributed to these observations. In general, the mid-reach section of the river is shallower (up to 25 m deep) than at the forebays (~ 30 m deep).

Results: Turbine vs. JBS

Year	Fish Species	Location	P-value	Turbine-passed fish		JBS-passed fish	
				N	Median Depth (m)	N	Median Depth (m)
2012	CH1	LGS	0.132	66	4.6	545	3
2012	ST	LGS	0.016	34	7.5	730	4.9
2012	CH0	LGS	<0.001	139	8	632	3.9
2012	CH1	LMN	0.012	206	2.8	631	2.8
2012	ST	LMN	<0.001	137	7	1,220	6.1
2012	CH0	LMN	<0.001	470	7.1	549	4.7
2013	CH0	LGS	<0.001	129	12.2	470	9.5
2013	CH0	LMN	<0.001	256	11	319	8.9

- Turbine-passed fish were detected **deeper** in the water column than JBS-passed fish. This results was consistent across years, dams and species.

Turbine-Passed Fish: Year Effect

Fish Species	Location	P-value	2012 N	2012 Median Depth (m)	2013 N	2013 Median Depth (m)
CH0	LGS	<0.001	139	8	129	12.2
CH0	LMN	<0.001	470	7.1	256	11

- The depth distributions of turbine-passed subyearling Chinook salmon were considerably **deeper** (~4 m) at Snake River dams during 2013 than during 2012.
- Water temperature was higher in 2013 than 2012: the average daily water temperature during June and July was 2.4°C higher in 2013 than 2012.
- Water discharge was lower in 2013 than in 2012: the mean total spill rate of spillway was 11.3 kcfs lower, while the mean total spill rate of powerhouse was 11.2 kcfs lower in 2013 than in 2012.

Turbine-Passed Fish: Species Effect

Year	Location	S1	S2	P-value	S1		S2	
					N	Median Depth (m)	N	Median Depth (m)
2012	LGS	CH1	ST	0.044	66	4.6	34	7.5
2012	LGS	CH1	CH0	<0.001	66	4.6	139	8
2012	LGS	ST	CH0	0.436	34	7.5	139	8
2012	LMN	CH1	ST	<0.001	206	2.8	137	7
2012	LMN	CH1	CH0	<0.001	206	2.8	470	7.1
2012	LMN	ST	CH0	0.25	137	7	470	7.1

- At Snake River dams, yearling Chinook salmon tended to be detected at 2.9 to 4.3 m shallower depths than steelhead and subyearling Chinook salmon.
- The depth distributions between steelhead and subyearling Chinook salmon were similar for turbine-passed fish.

Turbine-Passed Fish: Location Effect

Year	Fish Species	P-value	LGS		LMN	
			N	Median Depth (m)	N	Median Depth (m)
2012	CH1	0.026	66	4.6	206	2.8
2012	ST	0.706	34	7.5	137	7
2012	CH0	0.694	139	8	470	7.1
2013	CH0	0.012	129	12.2	256	11

- The median acclimation depths of turbine-passed fish at LGS were slightly deeper than those at LMN, with differences of median acclimation depth ranging from 0.5 to 1.8 m.
- Overall, location did not influence the acclimation depths and depth distributions of juvenile salmon examined in this study as much as other factors (location effects showed the lowest significance level).

Powerhouse-Passed Fish: Influence of Diel Period

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Year	Fish Species	Location	P-value	Passed during day		Passed during night	
				N	Median Depth (m)	N	Median Depth (m)
2012	CH1	LGS	<0.001	371	3.1	240	4.3
2012	ST	LGS	<0.001	440	3.3	324	7.1
2012	CH0	LGS	<0.001	423	3.7	348	8.5
2012	CH1	LMN	<0.001	503	3	334	2.1
2012	ST	LMN	<0.001	647	3.8	709	8
2012	CH0	LMN	<0.001	466	4.6	553	10.1
2013	CH0	LGS	<0.001	291	9.2	308	11.4
2013	CH0	LMN	<0.001	366	8	208	14.4

- Both juvenile steelhead and subyearling Chinook salmon that passed at night were observed significantly deeper (the difference ranging from 2.2 to 6.4 m for subyearling Chinook salmon in 2012 and 2013, and 3.8 to 4.4 m for juvenile steelhead in 2012) in the water column than fish that passed powerhouse during the day.
- In comparison, yearling Chinook salmon did not respond strongly to the diel period at the Snake River dams.

Injectable Tag vs. PSE Tag

Year	Fish Species	Location	P-value	Fish Implanted with INJ Tags		Fish Implanted with PSE Tags	
				N	Median Depth (m)	N	Median Depth (m)
2013	CH0	LGS	<0.001	531	9.1	2428	7
2013	CH0	LMN	0.02	428	7	5388	6.2
2013	CH0	LFB	0.004	501	5.8	4224	5

- Subyearling Chinook salmon implanted with the smaller injectable transmitter tended to have acclimation depths that were **deeper** in the water column than those implanted with larger PSE tags.

Summary

- Most juvenile salmonids typically resided in the top 15 m of the water column in the Snake River as they approached the dams, while they were acclimated shallower, typically within the top 12 m at the mid-reach location.
- Subyearling Chinook salmon were consistently detected in shallower depths in the mid-reach location than in the dam forebays, possibly due to different bathymetry at these locations.
- Turbine-passed fish were observed consistently deeper in the water column than JBS-passed fish.
- Year and species strongly influenced the acclimation depths and depth distributions of juvenile salmon.
- Depth distribution varied between day and night for powerhouse-passed fish.

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All-Passed Fish: Year Effect

Fish Species	Location	P-value	2012 N	2012 Median Depth (m)	2013 N	2013 Median Depth (m)
CH0	LGS	<0.001	2653	3.9	2428	7
CH0	LMN	<0.001	6204	4	5388	6.2

- Similar to results of turbine-passed fish, the depth distributions of all the fish observed in 2013 were significantly **deeper** than those observed in 2012.

All-Passed Fish: Location Effect

Year	Fish Species	P-value	LGS N	LGS Median Depth (m)	LMN N	LMN Median Depth (m)
2012	CH1	<0.001	1661	1.7	3898	1.2
2012	ST	<0.001	1686	1.6	3970	1.5
2012	CH0	<0.001	2653	3.9	6204	4
2013	CH0	<0.001	2428	7	5388	6.2

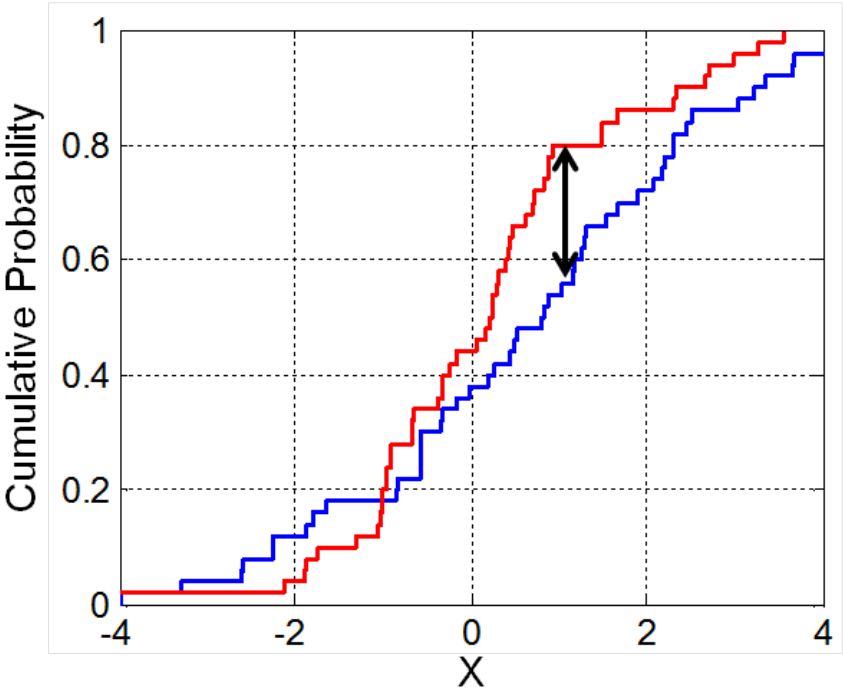
- Location effects were still weak with the differences in median depths ranging from 0.1 to 0.8 m, even though the comparisons were all significant when comparing LGS and LMN. Each sample group has large numbers of fish and the percentile values between the two locations were similar.

All-Passed Fish: Species Effect

Year	Location	S1	S2	P-value	S1		S2	
					N	Median Depth (m)	N	Median Depth (m)
2012	LGS	CH1	ST	<0.001	1661	1.7	1686	1.6
2012	LGS	CH1	CH0	<0.001	1661	1.7	2653	3.9
2012	LGS	ST	CH0	<0.001	1686	1.6	2653	3.9
2012	LMN	CH1	ST	<0.001	3898	1.2	3970	1.5
2012	LMN	CH1	CH0	<0.001	3898	1.2	6204	4
2012	LMN	ST	CH0	<0.001	3970	1.5	6204	4

- Overall, subyearling Chinook salmon tended to reside deepest in the water column compared to yearling Chinook salmon and juvenile steelhead.
- At LGS and LMN, the median acclimation depths of subyearling Chinook salmon were 2.2 to 2.8 m deeper than yearling Chinook salmon or steelhead for all passed fish in 2012.
- The median acclimation depths of steelhead were similar to that to yearling Chinook salmon with their difference ranging from 0.1 to 0.3 m.

Kolmogorov-Smirnov Test



CDF: cumulative distribution function, it gives the area under the probability density function from minus infinity to x.

The K-S statistic (black arrow): the max vertical distance between the two cdf's being compared (T value). The null hypothesis is that two samples are from the same unknown continuous distribution.

- The null hypothesis is rejected at level α if

$$T > c(\alpha)\sqrt{\frac{n_1 + n_2}{n_1 n_2}} \qquad c(\alpha = 0.05) = 1.36$$

This test is sensitive to differences in both location and shape of the empirical cumulative distribution functions of the two samples.