Factors affecting migratory success within the Wenatchee River in a population of reintroduced coho salmon

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Table of Contents

List of Tables

List of Figures

Introduction

Since 2008, Yakama Nation (YN) coho reintroduction has been operating under Broodstock Development Phase 2 (BDP2) as described in the Mid-Columbia Coho Restoration Master Plan (YN 2011). BDP2 shifts the focus of broodstock collection from Dryden Dam to Tumwater Dam, located farther upstream, to select for coho which are able to navigate Tumwater Canyon. BDP2 will be considered completed when 50% of the female broodstock is collected from Tumwater Dam over a three-year period.

All juvenile coho acclimated and released in areas upstream of Tumwater Dam are uniquely marked as juveniles with a blank-wire tag in the adipose fin. This tag makes it possible to recognize adult coho returning to the upper Wenatchee when sampled at downstream locations. In previous years a mark-recapture study was used to determine the proportion of adult coho that successfully ascend Tumwater Canyon. Upon initial capture and sampling at Dryden Dam (RK 28.0), we marked upper basin-destined fish with a Passive Integrated Transponder (PIT) tag. PIT tagged coho were released back into the Wenatchee River just above Dryden Dam. The tagged fish were then either recaptured at Tumwater Dam (RK 49.7) to be collected into broodstock or were detected on one of two PIT tag antenna arrays located in the fish ladder at Tumwater Dam.

Tumwater Canyon is a high-gradient confined reach of the Wenatchee River, extending for 15 river kilometers. Data from the previous mark-recapture study suggest that Tumwater Canyon may act as a kind of barrier, as evidenced by the low migratory success rate for Tumwater Dam. Even though the two capture locations are only 21.7 RK apart, only 31.7% of body tagged fish sampled at Dryden Dam successfully ascended Tumwater Canyon to Tumwater Dam (n=1,014; 2009-2012). These data also suggest that females have an especially hard time ascending Tumwater Canyon. Between 2009 and 2012 an average of 14.2% (range 3-24%) of females marked at Dryden Dam successfully ascended Tumwater Canyon (n=460), compared to a male success rate of 46.1% (n=554).

One M&E objective described in the Master Plan is to determine whether there are any measureable differences in phenotypic traits between coho salmon that are able to ascend Tumwater Canyon and those that cannot. Knowledge of any phenotypic differences will allow managers to adaptively manage the program should we fail to achieve BDP2 goals (YN 2011). The Master Plan identified a contingency plan, which included alternative methods of broodstock collection if BDP2 goals are not achieved.

The objective of the evaluation discussed in this report is to determine if there are environmental or phenotypic characteristics that determine which coho which are successful migrants.

We address this objective by answering several questions.

1. Which metrics are important in determining successful migration to Tumwater Dam?

2. Is there a difference in run timing, fish size, fish body shape, state of maturation, somatic lipid levels, or fish condition between successful and unsuccessful migrants?

If measurable differences exist between successful and unsuccessful migrants, the answer to these questions could help managers make decisions on broodstock collection efforts in the future.

Methods

The study discussed in this report was conducted in 2012 and 2014 at Dryden and Tumwater dams, located on the Wenatchee River in central Washington State. The Wenatchee River flows eastward from Lake Wenatchee to its confluence with the Columbia River at the town of Wenatchee. The Wenatchee River flows for 87 km and has 2 dams with fish traps: Dryden Dam, located at RK 28 and Tumwater Dam, located at RK 44. Both dams are owned by Chelan County Public Utility District (PUD) and provide year-round fish passage.

Returning coho trapped at Dryden Dam were determined to be of either Icicle Creek or upper basin origin by scanning the adipose fin with a CWT wand. Fish that were not body tagged were acclimated and released from Icicle Creek. Fish returning to Icicle Creek were not included in the study and were either collected into broodstock or released into the forebay of Dryden Dam. Fish marked with a blank wire tag in the adipose fin were acclimated and released as juveniles from the upper Wenatchee Basin (upstream of Tumwater Dam) and were the subject of this study. Study fish were placed into a 1,000 liter sampling tank located at Dryden Dam and anesthetized with 15mL of Tricaine-S (MS-222).

From study fish sampled at Dryden Dam, we measured a suite of morphological metrics:

Post orbital-hypural length (POH): a measure of body length from the posterior edge of the eye-orbit to the hypural plate was measured to the nearest millimeter. Unlike fork length POH is not influenced by kype development in males or fin erosion.

Kype length: Mature male coho (except jack coho) develop a hooked kype. The length of the kype will vary with state of maturation. Kype length was measured to the nearest millimeter from the anterior edge of the eye orbit to the end of the snout.

A/B ratio: A/B ratio is a body-shape metric used to gauge state of maturation in female coho salmon. The A/B ratio is the girth from lateral line to lateral line over the dorsal side of the fish, just anterior to the insertion of the dorsal fin, divided by the body girth from lateral line to lateral line on the ventral side of the fish (Figure 1). A large A/B ratio approaching 1.0 indicates a green or un-ripe female; as eggs mature, A/B ratios diminish when the ventral (belly) side increases in size relative to the dorsal side.

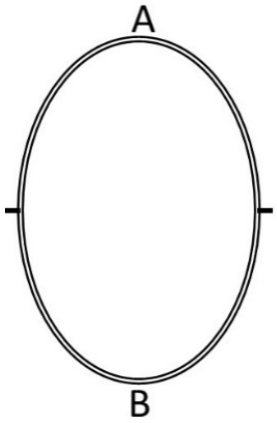

Figure 1. Diagram of girth measurements above and below the lateral line used in the calculation of the A/B ratio.

O-index is width of the body relative to the depth (body width / body depth; Figure 2). The O-index is a measured with calipers. Body depth measurements were taken as a vertical cross section from the anterior insertion of the dorsal fin to the belly. Width measurements were taken as a horizontal cross section directly below the anterior insertion of the dorsal fin on the lateral line (Figure 2). The O-index was measured on both male and female coho salmon.

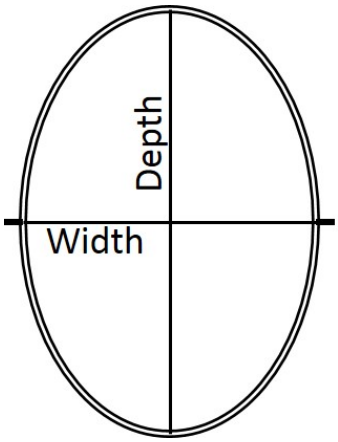

Figure 2. Diagram of body width and depth measurements used to calculate the O-index.

Descaling is a visual assessment of the amount of descaling and is assessed as either less than or greater than 20% missing scales. The descaling metric was collected from both male and female coho.

Fish condition was determined visually. Every fish was given a fish condition rating code between 1 and 5 (Table 1). The fish condition rating was collected from both male and female coho.

Table 1. Fish condition rating code and description

Code	Fish Condition
5	No marks or broken skin
4	Mark or injury which breaks skin
3	Injury which penetrates muscle
2	Injury which penetrates body cavity
1	Missing a portion of body

Somatic lipid level: The percentage of somatic fat content in each fish was measured non-lethally using a field portable fish Fatmeter (Distell Fish Fatmeter model 692, Distell Inc., West Lothian, Scotland, U.K.). Based on the strong proportional relationships between water, lipids and energy in migratory salmon, the handheld device uses a low powered microwave sensor to measure water content in somatic cells which it then converts to an estimate of the percentage of fat (lipids) found in the muscle tissue. The fat content was measured from two positions on each side of the fish. The mean fat content from the measurements was used as the final field estimate.

River Discharge: The daily mean river discharge in the Wenatchee River was recorded on each date of sampling from the USGS Wenatchee River gauge station at Peshastin (USGS 1245900).

Julian Date: The Julian date each fish was captured and sampled at Dryden Dam was recorded for all fish in the study.

Every fish sampled was marked with a unique floy and PIT tag for identification at Tumwater Dam and on the spawning grounds. Any injuries or abnormalities to the fish were noted on the data before the fish were taken to recovery. The fish were allowed to fully recover in the 1,000 liter recovery tank at Dryden Dam before being released back into the river in the forebay of Dryden Dam.

Coho were determined to be successful migrants if the unique PIT tag placed in them at Dryden Dam was detected on one of two (or both) antenna arrays in the fish ladder at Tumwater Dam.

Data for males and females was analyzed separately because morphological measurements will differ between genders, and factors affecting males may be different than factors affecting females.

A logistic regression was used to evaluate which variables are significant in determining whether a fish is able to ascend Tumwater Canyon to the dam. The Akaike Information

Criterion (AIC) was used to determine the best metric or combination of metrics to develop a model to predict successful migration to Tumwater Dam.

ANOVA was used to test for differences and interactions between variables for successful and unsuccessful migrants.

Results were graphically expressed (scatter plots) to look for trends in conditions under which coho are able to successfully ascend Tumwater Canyon and to highlight any condition under which coho appear unable to ascend Tumwater Canyon (e.g., river discharge, Julian date, low lipid levels, etc.).

Results

Successful Migration in Female and Male Coho

In 2012, the study included 128 female and 62 male coho collected from throughout the run. In 2014, 194 female and 89 male coho were included in the study. In both years, male coho had a higher migratory success rate than female coho (Table 2). A chi-square test of independence was performed to examine the relationship between gender and migratory success to Tumwater Dam (Table 2). Results of the chi-square confirmed that a significantly greater proportion of males are detected at Tumwater Dam than females (X^2=113.8, p=0.00, N=473).

Table 2. Percent successful female and male coho migrants in 2012 and 2014.

	2012			*2014*		
Gender	*Successful*	*Not Successful*	*% Successful*	*Successful*	*Not Successful*	
Females	*31*	*97*	*24.2%*	*17*	*177*	*8.7%*
Males	*34*	*28*	*54.8%*	*40*	*49*	*44.9%*

Because of the disparity in female and male success rates, and because some metrics measured (e.g., kype length, A/B ratio) are specific to one gender, male and female coho were treated separately in all further analyses.

Correlation of Metrics

A correlation matrix was calculated for metrics collected from males and females. The matrices for each gender were calculated separately. Both correlation matrices indicated that most variables were significantly correlated with Julian date. For females, Julian date was significantly correlated with CFS, condition, POH, A/B ratio, O-ratio, and somatic lipid levels (Table 3). For males, Julian date was correlated with CFS at tagging, fish condition, kype length and O-ratio (Table 4). Auto-correlated variables could not be used in the development of a predictive model to determine migratory success to Tumwater Dam.

Table 3. Correlation between metrics from female coho salmon sampled at Dryden Dam in the Wenatchee River, 2012 and 2014. Red font indicates a significant correlation (p<0.05).

	Date	River Discharge (cfs)	Condition	Color	POH	A/B Ratio	O Ratio	Somatic Lipid %	Descaling >20%
Date	1.00	0.66	-0.32	0.57	0.10	-0.53	0.24	-0.47	-0.11
CFS	0.66	1.00	-0.24	0.35	-0.20	-0.28	0.11	-0.32	-0.14
Condition	-0.32	-0.24	1.00	-0.54	-0.06	0.34	-0.28	0.34	-0.07
Color	0.57	0.35	-0.54	1.00	-0.01	-0.43	0.21	-0.44	0.03
POH	0.10	-0.20	-0.06	-0.01	1.00	-0.31	0.27	-0.02	-0.02
A/B Ratio	-0.53	-0.28	0.34	-0.43	-0.31	1.00	-0.44	0.45	-0.01
O Ratio	0.24	0.11	-0.28	0.21	0.27	-0.44	1.00	-0.26	-0.10
Somatic Lipid %	-0.47	-0.32	0.34	-0.44	-0.02	0.45	-0.26	1.00	-0.03
Descaling >20%	-0.11	-0.14	-0.07	0.03	-0.02	-0.01	-0.10	-0.03	1.00

Table 4. Correlation between metrics from male coho salmon sampled at Dryden Dam in the Wenatchee River, 2012 and 2014. Red font indicates a significant correlation (p<0.05).

	Date	River Discharge (cfs)	Condition	Color	POH	Kype	O Ratio	Somatic Lipid %	Descaling >20%
Date	1.00	0.67	-0.31	0.71	0.13	0.35	-0.49	0.10	-0.04
CFS	0.67	1.00	-0.23	0.37	-0.12	0.11	-0.26	0.10	-0.06
Condition	-0.31	-0.23	1.00	-0.35	-0.22	-0.18	0.27	0.08	-0.11
Color	0.71	0.37	-0.35	1.00	0.18	0.35	-0.42	0.06	0.04
POH	0.13	-0.12	-0.22	0.18	1.00	0.79	-0.07	-0.01	0.05
Kype	0.35	0.11	-0.18	0.35	0.79	1.00	-0.22	-0.01	0.01
O Ratio	-0.49	-0.26	0.27	-0.42	-0.07	-0.22	1.00	0.03	0.03
Somatic Lipid %	0.10	0.10	0.08	0.06	-0.01	-0.01	0.03	1.00	-0.01
Descaling >20%	-0.04	-0.06	-0.11	0.04	0.05	0.01	0.03	-0.01	1.00

Predictive Model Selection

Working only with uncorrelated metrics we used a logistic regression with the AIC score to determine the best metric or combination of metrics to develop a model to predict successful migration to Tumwater Dam. Results are ranked based upon the lowest AIC score. While the AIC score alone is meaningless, the lowest AIC score is considered the best predictive model of "success." When comparing models, if the difference between AIC scores (ΔAIC) is less than 2,

there is no functional difference in predictive power (Burnham and Anderson, 1998). In cases where AIC scores were similar we chose the simplest model (i.e., the model with the least number of parameters) since the additional metrics were not adding measurable predictive power.

Females

To develop a model that predicts which female coho sampled at Dryden will be successful ascending Tumwater Canyon, we excluded all metrics significantly correlated with Julian date (CFS, Condition, A/B ratio, O-ratio, and Somatic Lipid %). For female coho salmon we ran the logistic regression using Julian date, POH, and descaling. The model with the lowest AIC score included both date and descaling; however, a simpler model using only date had a Δ AIC score of 0.186. For reasons described above we chose date alone as the best predictive model of success (Table 5). Based on the Δ AIC, Julian date should be as effective at predicting successful recapture at Tumwater Dam as date and descaling together.

Table 5. Results of the logistic regression with AIC scores for female coho. The yellow highlighted cells represent the best predictive variables for successful migration.

	Var. 1	Var. 2	Var. 3	Degr. of Freedom	AIC	ΔAIC	L.Ratio Chi²	p
1	Date	Descaling >20%		2	196.8830	0	80.29866	0.000000
2	Date			1	197.0699	0.1869	78.11184	0.000000
3	Date	POH	Descaling >20%	3	198.1813	1.2983	81.00039	0.000000
4	Date	POH		2	198.3158	1.4328	78.86594	0.000000
5	POH			1	266.1432	69.2602	9.03853	0.002643
6	POH	Descaling >20%		2	267.5164	70.6334	9.66527	0.007965
7	Descaling >20%			1	274.5861	77.7031	0.59560	0.440261

Date and CFS

Of the females coho sampled at Dryden Dam, 100% of those arriving in mid-September 2012 were successful reaching Tumwater Dam (Figure 3). The proportion of successful migrants dropped dramatically as the season progressed. By mid-October less than 10% of the female migrants in both years were successful. Run timing in 2014 was later than in 2012, and the early to mid-September component of the return was absent (Figure 4). In both years, the proportion of successful female migrants dropped to less than 10% by mid-October, with no successful migrants once discharge began to increase. The proportion of successful migrants over time and river discharge (CFS) in 2012 and 2014 can be found in Figures 3 and 4.

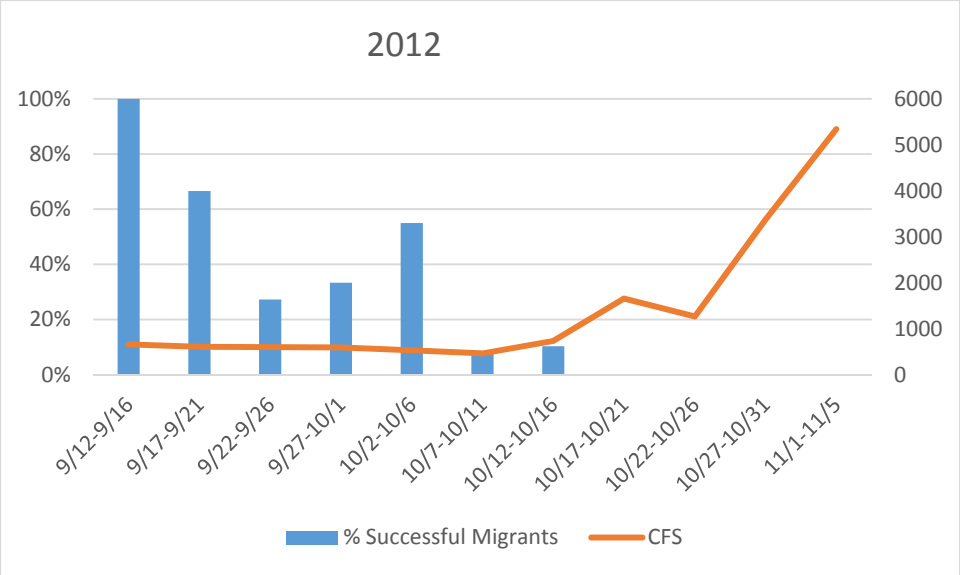

Figure 3. Percent of successful female coho migrants relative to date and CFS, 2012.

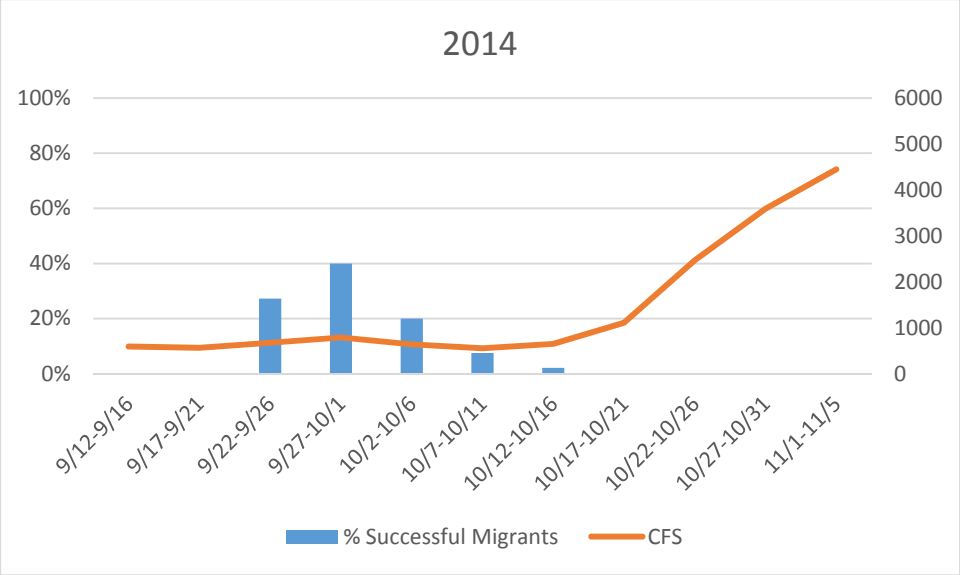

Figure 4. Percent of successful female coho migrants relative to date and CFS, 2014.

Because the proportion of successful female migrants declines prior to increasing river discharge (cfs), cfs does not appear to be the main factor influencing the success of coho returning in September and early October. However, high water events which typically occur in late October or early November seem to prevent late-arriving females from reaching Tumwater Dam.

Descaling

Though not a powerful predictive variable, A chi-square test of independence was used to examine the relationship between descaling (>20%) and migratory success to Tumwater Dam.

Successful females had significantly lower occurrence of descaling than unsuccessful females (X^2=227.33, p=0.00, N=322). Table 6 indicates the proportion of descaled fish among successful and unsuccessful migrants. Despite the significant results of the chi square, the overall incidence of descaling in both groups was low and therefore not likely a major factor in determining successful migration.

Table 6. Proportions of descaled fish among successful and unsuccessful female coho migrants.

	Unsuccessful	**Successful**
>20% Descaling	33	4
< 20% Descaling	241	44
% Descaled	12.0%	8.3%

Additional Analysis of Metrics

Because several of the measured variables were auto-correlated with date it is difficult to distinguish the importance of one correlated variable over another correlated variable. Each correlated variable may contribute to the success of each migrant. We evaluated each variable independently to look for factors which may explain why successful migration to Tumwater Dam declines with date.

Somatic Lipid Level

Somatic lipid level (%) was significantly and negatively correlated with date for female coho and therefore was excluded from the predictive model.

Results of an ANOVA indicate successful migrants to Tumwater Dam had a significantly higher somatic lipid level than unsuccessful migrants (p=0.000); however, there was no difference in lipid levels between years (Table 7; Figure 5). All but one successful female coho had somatic lipid levels equal or greater than 1% (Figure 6). Declining somatic lipid levels are one variable that may explain why date is an important predictor of successful migration.

Table 7. Results of a factorial ANOVA comparing somatic lipid level (%) and migratory success (successful and unsuccessful migrants), 2012 and 2014.

	SS	Degr. of Freedom	MS	F	p
Intercept	220.4621	1	220.4621	2450.969	0.000000
Year	0.0021	1	0.0021	0.023	0.879032
Success	5.2253	1	5.2253	58.092	0.000000
Year*Success	0.1098	1	0.1098	1.220	0.270139
Error	28.6038	318	0.0899		

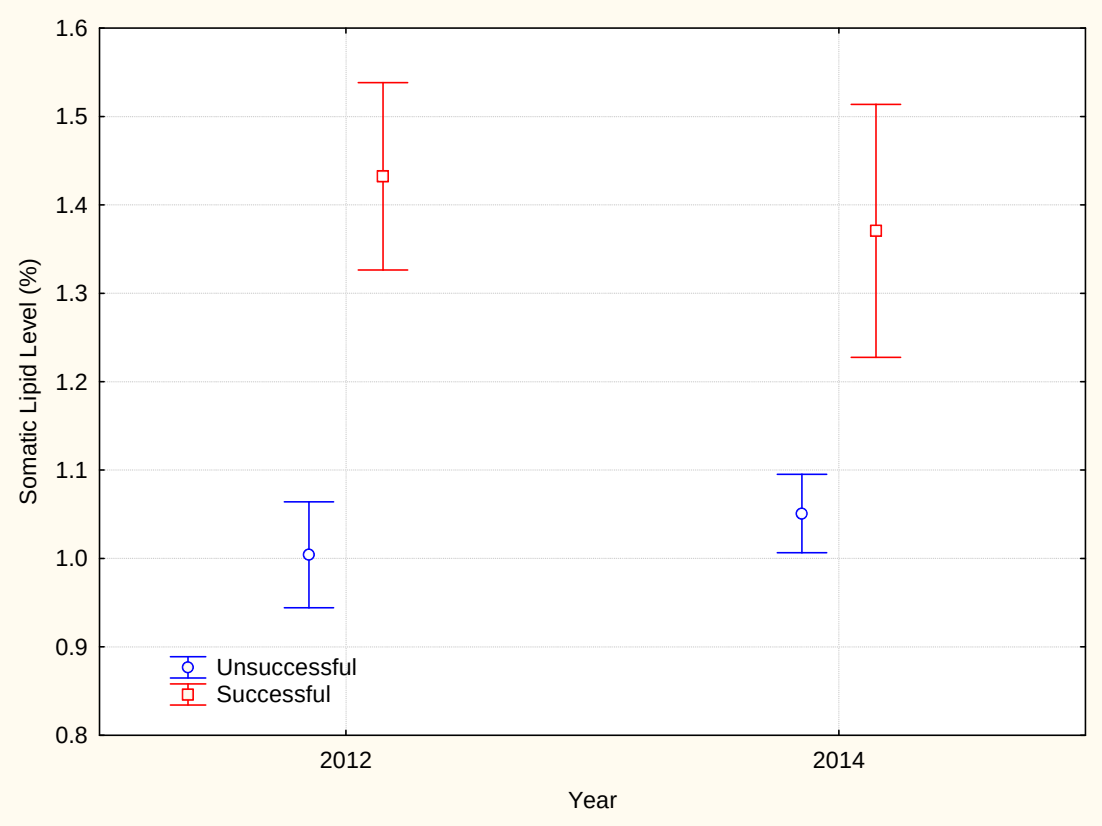

Figure 5. Somatic lipid levels (%) in successful and unsuccessful female coho. Error bars represent 95% confidence intervals around the mean.

Lipid level was negatively correlated with date (r^2=0.22; Figure 6). Early migrating coho had higher success rates to Tumwater Dam and had higher lipid levels (Figures 3, 4, and 6).

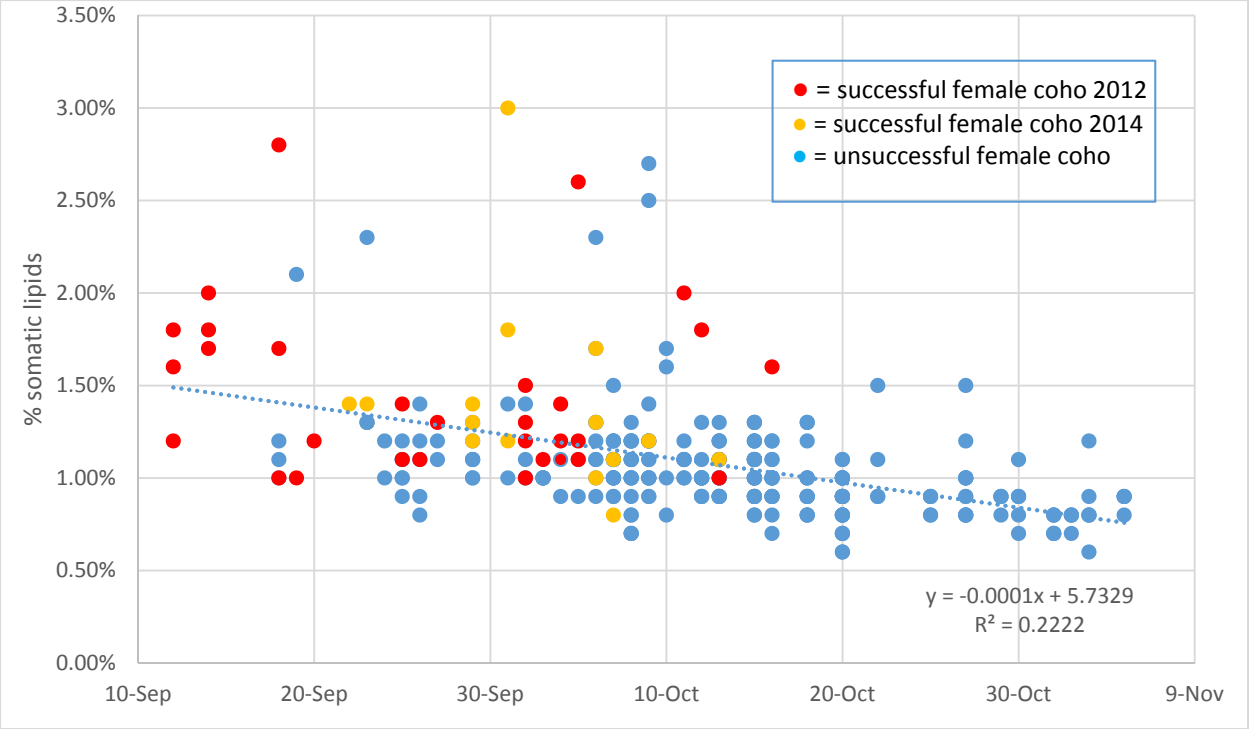

Figure 6. Linear regression between somatic lipid level and date in female coho sampled at Dryden Dam in 2012 and 2014.

Post-Orbital Hypural Length (POH)

The length of females was not significantly correlated with date. While size did not stand out as a reliable predictor of whether or not a female would be successfully detected at Tumwater Dam, successful females were significantly smaller than unsuccessful females (Table 8; Figure 7) however post-hoc analysis (Tukey HSD) revealed that the difference in size between successful and unsuccessful female coho existed only in 2014. It is possible that in some years it may be advantageous to be smaller in size (Figure 7).

Table 8. ANOVA comparing length of successful and unsuccessful female coho sampled in 2012 and 2014.

	SS	Degr. of Freedom	MS	F	p
Intercept	39060779	1	39060779	25026.24	0.000000
Year	3228	1	3228	2.07	0.151374
Success	10687	1	10687	6.85	0.009302
Year*Success	4721	1	4721	3.02	0.082984
Error	496332	318	1561		

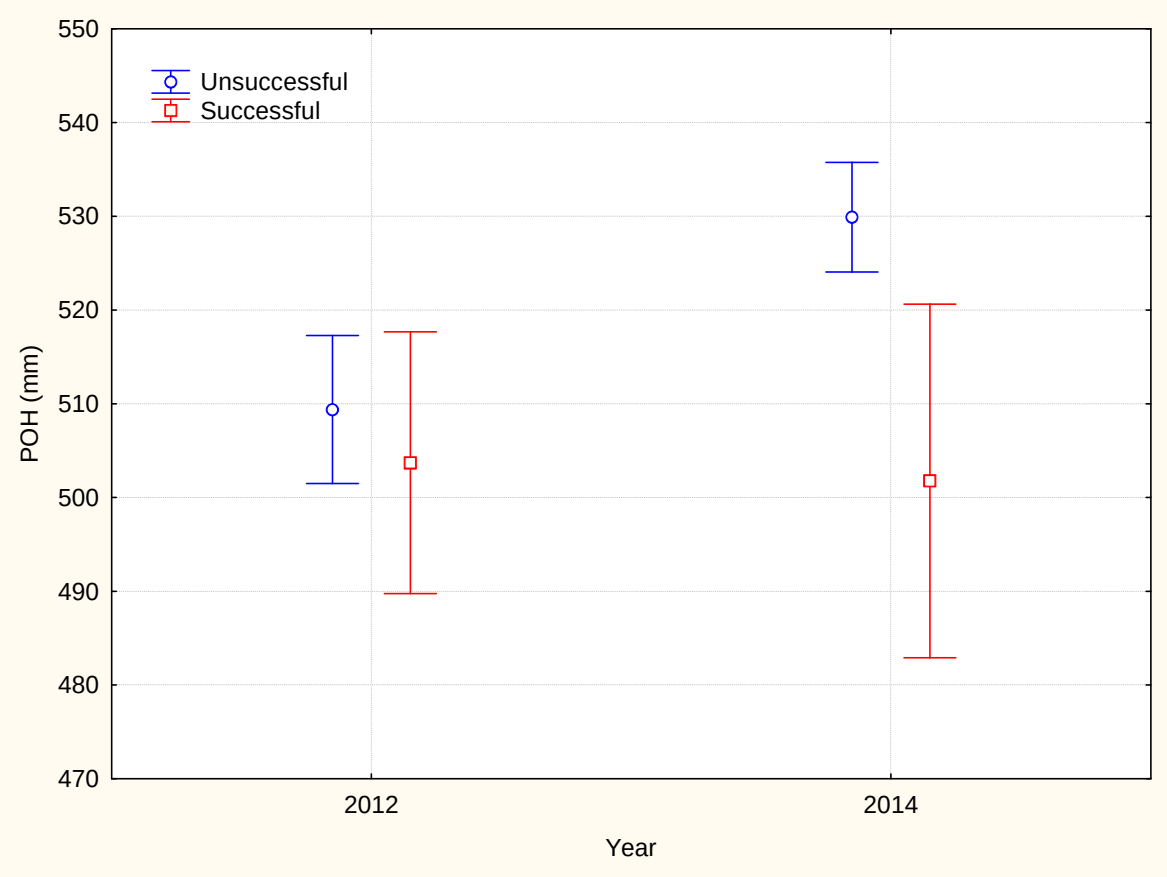

Figure 7. Comparison of fish length (mm) and migratory success for female coho in 2012 and 2014. Error bars represent 95% confidence intervals.

A/B ratio

A/B-ratio is a metric which measures the change in body shape as a female salmon matures. The A/B-ratio was significantly negatively correlated with date. A fish with an A/B ratio approaching 1.0 would be a green fish showing little maturation; as the eggs mature and the fish belly grows larger and hangs lower, the A/B-ratio decreases.

Results of an ANOVA indicated that in all years successful fish had a significantly higher A/B ratio than unsuccessful female coho (Table 9; Figure 8).

Table 9. ANOVA comparing the difference in A/B ratio and migratory success for female coho sampled at Dryden Dam in 2012 and 2013.

	SS	Degr. of Freedom	MS	F	p
Intercept	65.22685	1	65.22685	28210.89	0.000000
Year	0.00607	1	0.00607	2.62	0.106241
Success	0.19207	1	0.19207	83.07	0.000000
Year*Success	0.00358	1	0.00358	1.55	0.214227
Error	0.73525	318	0.00231		

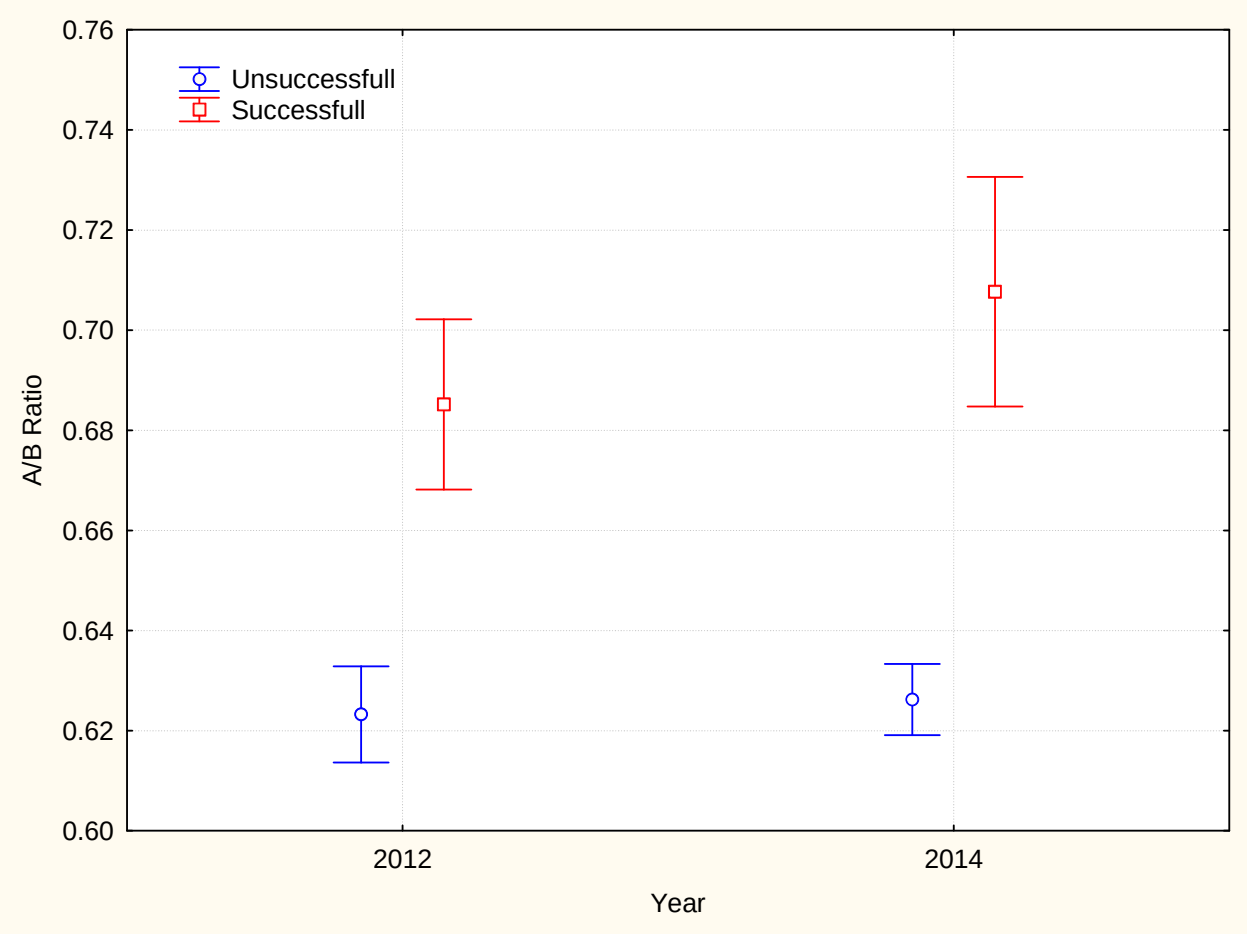

Figure 8. Differences in A/B-ratio between successful and unsuccessful female coho sampled at Dryden Dam in 2012 and 2014. Error bars represent 95% confidence intervals around the mean.

There was a significant negative relationship between A/B ratio and Julian date (Figure 9). Because of this relationship, earlier returning fish in general had a higher A/B ratio then later returning female coho. We observed no successful migrants with an A/B ratio less than 0.6.

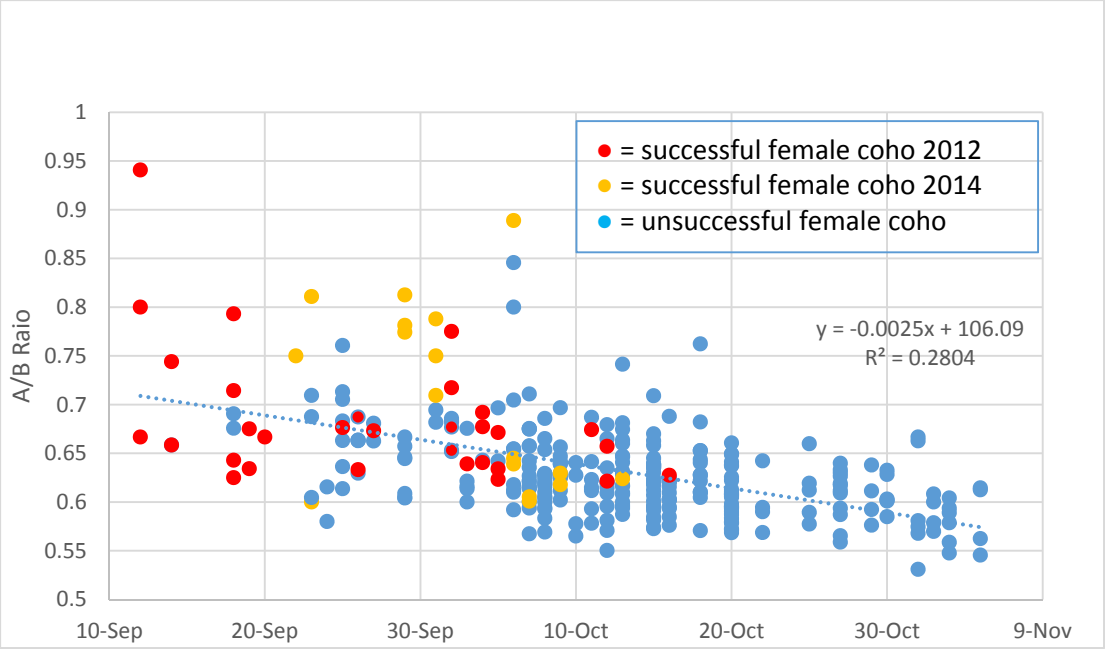

Figure 9. Relationship between date and A/B ratio in female coho salmon.

O-Index

O-index, similar to A/B ratio, is another metric used to measure body shape (see methods for a description). While O-index was also significantly correlated with date, the correlation was weak (r^2=0.0594; Figure 10). There did not appear to be any trends in O-index associated with successful or unsuccessful female coho. The A/B ratio may be a better metric from which to measure body shape as a female fish matures.

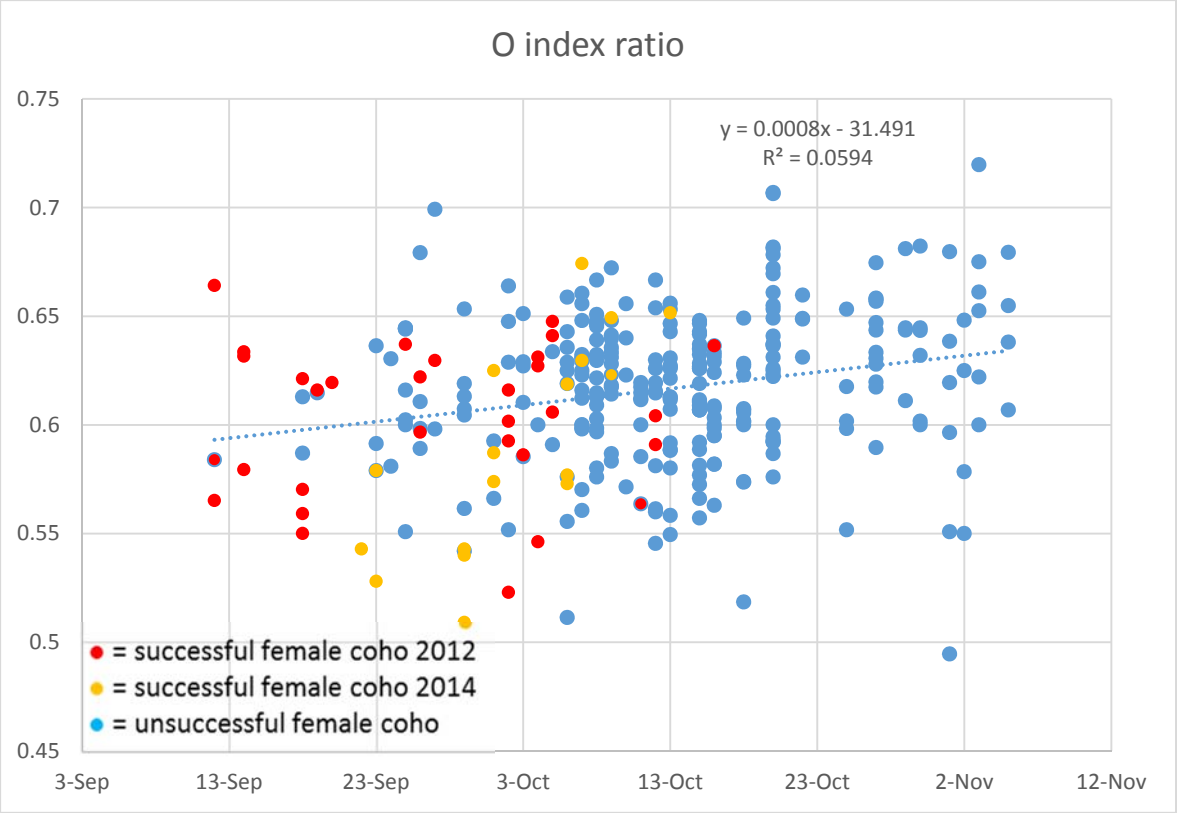

Figure 10. The relationship between O-index and date in female coho salmon sampled at Dryden Dam.

Fish Condition

A rating of overall fish condition (see methods for a description of the ratings) was also significantly correlated with date; more injuries were documented on later arriving fish than earlier arriving fish (Figure 11). No fish with a condition rating of 1 or 2 were successful in reaching Tumwater Dam. Only 2 fish with a condition rating of 3 were successful. Successful migrants typically had a fish condition rating of either 5 (no injuries) or 4 (skin injury) (Figure 11). In both years, successful fish had a higher average condition rating then unsuccessful fish (Table 10).

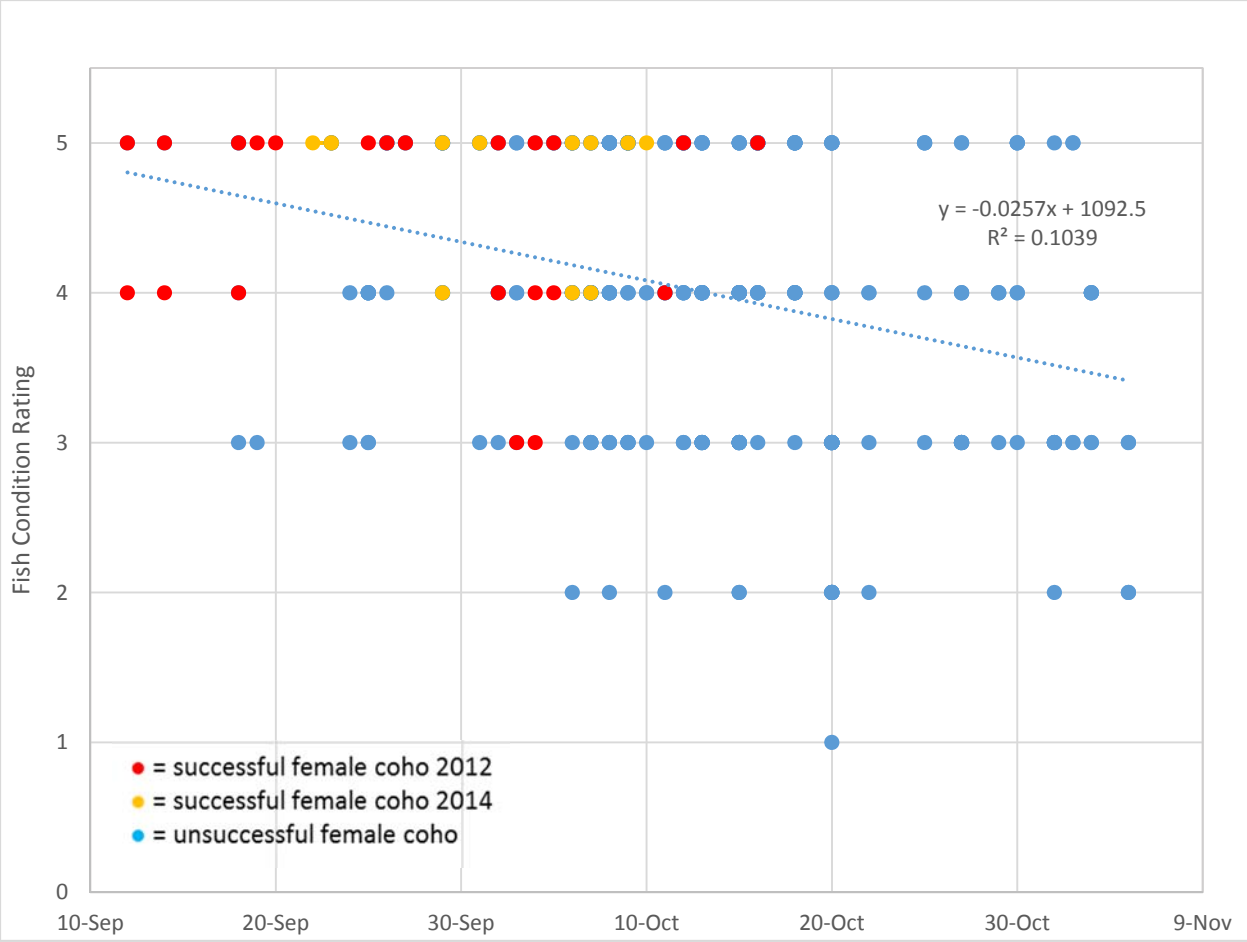

Figure 11. Linear regression between fish condition rating and date.

Table 10. Analysis of variance examining differences in fish condition ratings between successful and unsuccessful female coho in 2012 and 2014.

	SS	Degr. of Freedom	MS	F	p
Intercept	2830.082	1	2830.082	3879.336	0.000000
Year	0.412	1	0.412	0.564	0.453109
Success	18.399	1	18.399	25.220	0.000001
Year*Success	4.521	1	4.521	6.198	0.013303
Error	231.990	318	0.730		

Males

To develop a model that predicts which male coho sampled at Dryden will successfully ascend Tumwater Canyon, all metrics significantly correlated with the Julian date were excluded (river discharge, condition, kype length and O-ratio). The logistic regression included Julian date, POH, somatic lipid level, and descaling. The predictive model with the lowest AIC score

included only descaling (AIC = 208.39; Table 11). However, looking closer at the data, we observe that very little descaling was documented among male coho and that descaling really provides no predictive value. In fact, only two of the 151 male coho sampled at Dryden over two years were classified as having descaling over 20% or more of their body, and both these coho were successful.

Table 11. Predictive model building result for male coho sampled at Dryden Dam.

	Var. 1	Var. 2	Var. 3	Var. 4	DF	AIC	ΔAIC	L.Ratio Chi²	p
1	Descaling >20%				0	208.3900	0	2.880798	3.000E+30
2	Date	Descaling >20%			1	208.5067	0.1167	4.764132	2.906E-02
3	Date	POH	Descaling >20%		2	209.0103	0.6203	6.260553	4.371E-02
4	Date	Fat %	Descaling >20%		2	209.6031	1.2131	5.667715	5.879E-02
5	POH	Descaling >20%			1	209.6290	1.2390	3.641827	5.635E-02
6	Fat %	Descaling >20%			1	209.7293	1.3393	3.541588	5.985E-02
7	Date	POH	Fat %	Descaling >20%	3	210.0774	1.6874	7.193435	6.598E-02
8	POH	Fat %	Descaling >20%		2	210.9844	2.5944	4.286432	1.173E-01
9	Date				1	211.3252	2.9352	1.945674	1.631E-01
10	Date	POH			2	211.5932	3.2032	3.677614	1.590E-01
11	Date	Fat %			2	212.3829	3.9929	2.887975	2.360E-01
12	POH				1	212.3838	212.3838	0.887066	3.463E-01
13	Fat %				1	212.5796	4.1896	0.691275	4.057E-01
14	Date	POH	Fat %		3	212.6188	4.2288	4.652045	1.991E-01
15	POH	Fat %			2	213.7117	5.3217	1.559186	4.586E-01

Descaling.

Results of a chi square showed no significant difference in the proportion of successful and unsuccessful male migrants that were descaled >20% (X^2=2.05, p=0.15, N=153; Table 12).

Table 12. Proportions of descaled male coho grouped by migratory success.

	Unsuccessful	Successful
>20% Descaling	0	2
< 20% Descaling	77	72
% Descaled	0%	2.7%

Julian Date

Both years combined, the percent of males sampled at Dryden Dam that successfully migrated (49%) was significantly greater than the percent of successful females (15%; Table 2).

Like the females, later arriving males had a lower success rate; however, the decrease in the proportion of successful male migrants was not as clear nor as drastic as the decrease in success rate for female migrants (Figures 12 and 13). Like females, increasing river flow appears to eventually mark the end of male coho migration at Tumwater Dam (Figures 12 and 13).

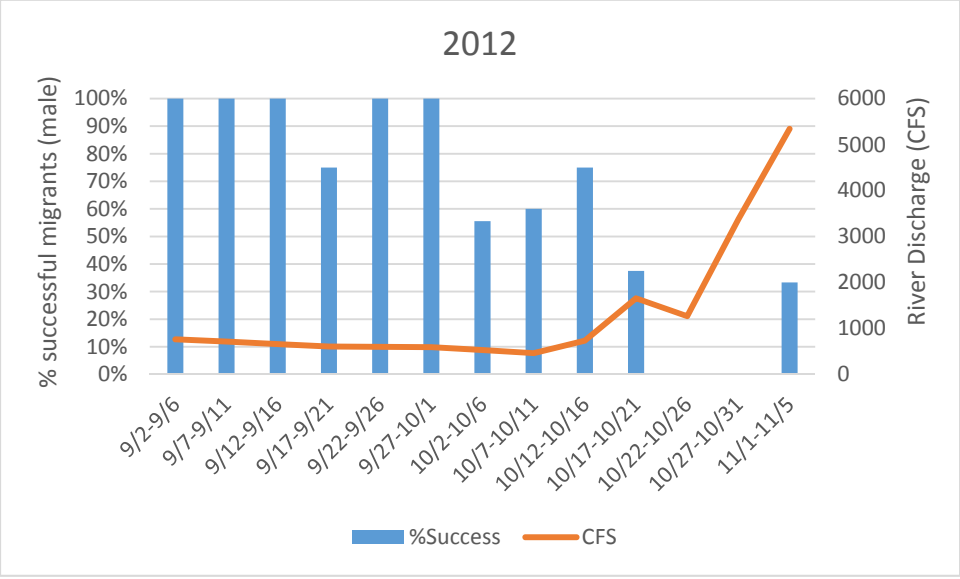

Figure 12. The percent of male coho sampled at Dryden Dam that successfully migrated and were detected at Tumwater Dam in 2012.

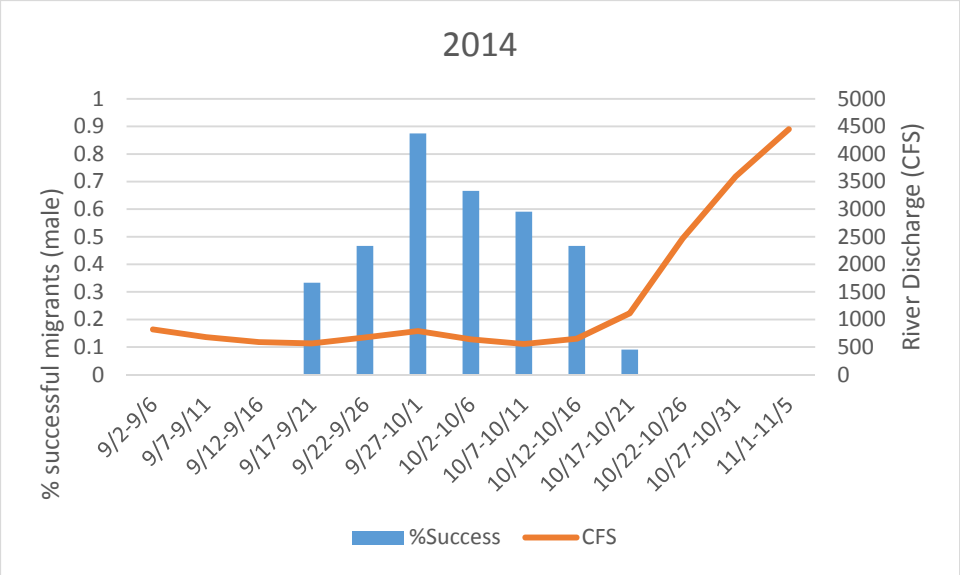

Figure 13. The percent of male coho sampled at Dryden Dam that successfully migrated and were detected at Tumwater Dam in 2014.

No single metric stood out as a predictor of successful migration to Tumwater Dam for male coho salmon. ANOVA results indicated no significant difference in somatic lipid levels, fish size (POH), kype length, or O-index for successful and unsuccessful male migrants. Fish condition was the only metric in which differences were found between successful and unsuccessful male migrants.

Table 13. Summary of ANOVA results between successful and unsuccessful male coho.

Metric	Significant difference between successful and unsuccessful male migrants	P value
Somatic Lipid Level	No	0.264
POH (fish size)	No	0.203
Kype Length	No	0.376
Fish Condition	Yes	0.005
O-Index	No	0.221

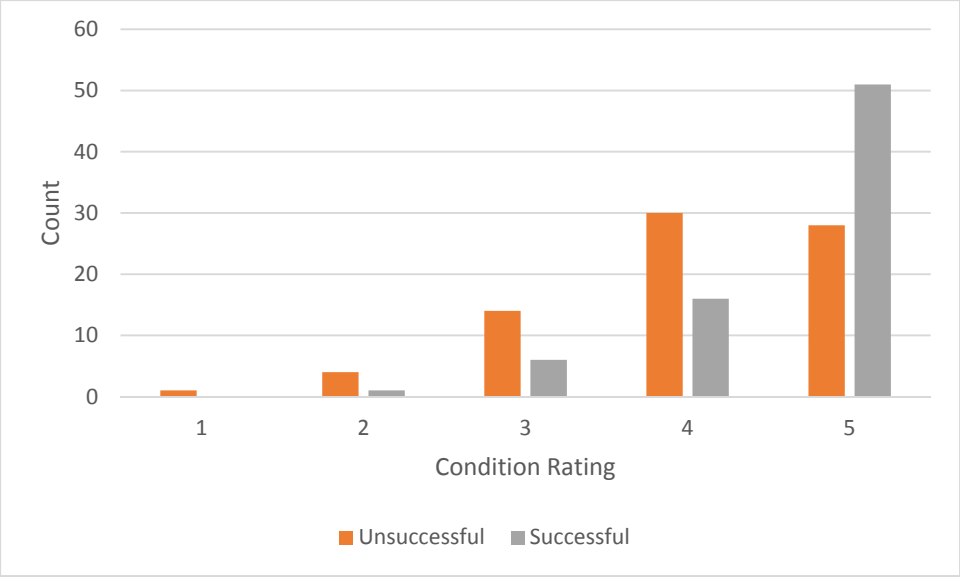

Figure 14. Fish condition ratings in successful and unsuccessful male coho.

Discussion and Conclusions

The difference in success rates for male and female coho was not unexpected. We currently collect much of our male broodstock at Tumwater Dam; however, the numbers of females that successfully arrive at Tumwater Dam limit our abilities to expand the program into the upper Wenatchee Basin where suitable spawning and rearing habitat likely exists (as proposed for the Natural Production Phases of the Coho Restoration Program).

The results of this study indicate that date, or the time of year coho return to the Wenatchee River has a strong influence on the ability of returning fish, particularly the female coho salmon, to navigate Tumwater Canyon and return successfully to the upper reaches of the basin. There are multiple reasons why date is such an important factor; however, because so many of the phenotypic variables collected from female coho salmon are auto-correlated with date, determining the importance of a single variable is difficult.

Energy reserves, measured in the form of somatic lipid content, were significantly higher in earlier returning female coho. It is possible that later returning coho do not have sufficient energy stores to navigate Tumwater Canyon.

State of maturation also progresses with date. State of maturation was indirectly assessed through the change that occurs in body shape (A/B ratio). Early returning fish have significantly higher A/B ratios than later returning fish. A mature female coho may not have the fusiform shape needed to navigate a high-gradient river reach.

In addition to lipid levels and state of maturation, date was also correlated with decreased fish condition (i.e., increased occurrence of injury), which may hinder passage through Tumwater Canyon.

Likely no single metric determines successful migration; rather, the cumulative changes that occur—decreasing lipid levels, maturation, and declining fish condition—all contribute to decreasing success rates for later returning fish.

For coho reintroduction to be successful in the upper reaches of the Wenatchee River, continued broodstock collection which emphasizes collection from Tumwater Dam is crucially important. Incorporating female coho which have the correct run timing, spawn timing or energetics to be able to return to the upper reaches of the Wenatchee River is important to the development of a local broodstock. In addition to collecting fish at Tumwater Dam, in large return years, selection of broodstock with higher lipid levels, earlier run timing, and later maturation may allow us to collect additional fish from Dryden Dam expressing phenotypic characteristics required to navigate Tumwater Canyon.

While male coho were overall more successful at reaching Tumwater Dam than female coho, the male success rate is still lower than desired. Unlike female coho, we did not find a phenotypic or environmental characteristic which suggested why some male coho are not successful. For male coho there was no significant difference in any phenotypic metrics between successful and unsuccessful fish. The coho reintroduction program currently collects sufficient numbers of male broodstock from Tumwater Dam. We will continue to collect male coho from Tumwater Dam up to full broodstock collection needs.

Literature Cited

Burnham, K., and D. Anderson. 1998. Model selection and multimodel inference: A practical information theoretical approach, second edition. Springer, New York.