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MEMORANDUM

TO: FPAC

Michele DeHart

FROM: Michele DeHart

DATE: July 6, 2017

SUBJECT: McNary Dam Spring Chinook Ladder Re-ascension Analysis

A special FPAC meeting was held on Wednesday May 18, 2017 to discuss concerns that were expressed regarding spring Chinook adult fallback issues at McNary Dam that were presented by NOAA at the previous day's Technical Management Team (TMT) conference call. NOAA expressed concern that during the period of May 9-12, high fallback rates were observed at McNary Dam that may have been related to spill levels and/or spill percentages. The high fallback rates that NOAA presented were generated by a query on the Data Access Real Time (DART) webpage, titled the PIT Tag Adult Fallback Adjustment Rate (AFAR) (http://www.cbr.washington.edu/fallback/). The special FPAC meeting was called to discuss the relationship between spill and fallback and to discuss if a recommendation regarding operations should be made.

At the FPAC meeting NOAA presented their analysis and stated that they believe there is an increase in fallback rate when spill is above 60% or total spill is above 270 Kcfs. Based on previous discussions in FPAC, NOAA asked FPAC members if there was a spill volume or percentage above which managers would support changing MCN turbine operations to above the 1% efficiency curve in order to reduce spill. At the FPAC meeting, the Fish Passage Center (FPC) staff pointed out that it was unable to recreate the re-ascension rates (i.e., fallback) that the DART analysis was reporting. Furthermore, it was pointed out that a number of fish that were detected at the first group of coils near the entrance can go undetected for more than six hours before being detected at the detection system near the counting windows. The concern was that the DART methodology described the use of a 6-hour time gap to identify re-ascensions, therefore considering these separate ascensions and, likely overestimating re-ascension rates. FPC presented a preliminary analysis using the re-ascension data from DART, which highlighted that even with the DART methodology there is high variability in fallback rates, even in years where Biological Opinion (BiOp) spill levels were provided (e.g., 2009, 2010, 2015, and 2016). Consequently, FPAC members were concerned about recommending an operational change at that time. It was pointed out that the flow at McNary was not expected to increase in the next few weeks, giving time to complete an evaluation of the DART methodology and the re-ascension rates.

The FPC agreed to conduct a more thorough evaluation of the DART methodology and an analysis of the past ten years of PIT-tag data for adult detections at McNary Dam. This FPC analysis will focus on two primary questions: 1) can the DART methodology be used to evaluate adult fallback and guide operational changes in the FCRPS and 2) what affects re-ascension of spring Chinook adults at McNary Dam. Subsequent discussions in FPAC led to additional questions, including an assessment of whether there is an alternative methodology that can be used to provide a web-accessible query that accurately depicts PIT-tag re-ascension rates for each FCRPS project.

Hydroelectric projects at mainstem FCRPS projects present several obstacles to upstream passage of adult salmonids. Fishway water temperatures, facility operations, tailrace hydraulics, powerhouse unit operation patterns, spillbay operation patterns, combinations of operational patterns, water quality, and juvenile downstream passage histories can all effect upstream passage timing and fallback and re-ascension. The following analyses only addresses the specific question of reducing spill at McNary Dam by operating turbine units above the 1% efficiency range to reduce fallback. Below is a summary of our findings from this analysis, followed by a more detailed explanation of the methods and results.

- We do not recommend using the DART Daily PIT tag Adult Fallback Adjustment Rate (i.e., DART) methodology for either adjusting adult counts or as an estimate of total daily fallbacks of PIT-tagged fish. The DART methodology overestimates re-ascension rates.
- The DART methodology does not appear to correctly estimate the number of unique ladder ascensions of PIT-tagged fish and is not an appropriate tool to use to gauge the effects of dam operations on fallback rates.
- We believe the FPC methodology for estimating re-ascension is more realistic than the DART methodology, as it is not based on some set time-gap for assessing separate ladder ascensions but, instead, relies on PIT-tag detections at the ladder exit coils followed by detections at a ladder entrance. However, we would not recommend using the FPC methodology in a real-time manner, as several days may occur between subsequent ladder ascensions and, therefore, the identification of a re-ascending PIT-tagged adult may change from day to day.
- Based on logistic regression modeling, spill volume, exit date, and exit ladder were all found to significantly affect re-ascension rates.

- In general, Snake River Chinook that were transported as juveniles had higher probabilities of re-ascension than Snake River Chinook that migrated in-river. This is true at all levels of spill. The difference between Snake River (in-river) fish versus Upper Columbia fish was relatively small and only present at higher spill volumes
- In general, as spill volume increased re-ascension rates also increased.
    - The predicted re-ascension probabilities ranged from 0.056 at lower spill volumes (~63 Kcfs) to 0.161 at higher spill volumes (~328 Kcfs) at the Oregon shore ladder (MC1) and 0.063 to 0.182 at the Washington shore ladder (MC2).
    - The proposed operation of allowing the Action Agencies to operate the powerhouse above the 1% efficiency curve when spill exceeds 270 Kcfs would result in relatively low reductions in the probability of re-ascension.
- The coefficient estimate for exit date was negative, indicating that, at a set spill volume and exit ladder date, the probability of re-ascension decreases as the season progresses. This conclusion should be considered with caution as it may be the result of our use of exit date in the analytical structure used.
- Logistic regression model results also indicated that, at a set spill volume and exit date, fish exiting the Washington shore ladder (MC2) had higher probabilities of re-ascension than those exiting the Oregon shore ladder (MC1).
- The small reductions in re-ascension rates associated with the proposed operational change of increasing powerhouse flow when spill volumes exceed 270 Kcfs will result in increased powerhouse passage of juvenile fish, Powerhouse passage has been shown to decrease smolt-to-adult return rate.(Tuomikoski et al. 2010, McCann et al. 2016). Based on our analysis, the small changes in re-ascension rates at extremely high spill levels should not warrant operational changes that increase the number of juvenile fish experiencing powerhouse passage.

Review and Evaluation of the DART Daily PIT Tag Adult Fallback Adjustment Rates and Development of an Alternative Methodology

There is a desire by the fishery managers to have an automated method that accurately depicts fallback rates for each FCRPS project. Estimates of fallbacks are usually provided by visual counts or by radiotelemetry studies. Over the years, there has been a desire to expand the use of PIT-tags to the estimation of fallback due to their widespread use and the expansion and installation of adult fishway PIT-tag detectors. This would allow in-season response to adult passage issues on a real-time basis.

One tool that managers use to assess fallback rates is the DART Daily PIT tag Adult Fallback Adjustment Rates (herein referred to DART), which is available via a query on the DART webpage (http://www.cbr.washington.edu/fallback/). According to the DART website, "These adult fallback adjustment rates are designed as modifiers of the US Army Corps' visual count in order to provide an estimate of total adult passage abundance". The tool was developed to adjust window counts by reducing the total count by the proportion of PIT-tag fallbacks. It is worth noting that the DART estimates are essentially daily estimates of the proportion of PIT-tagged adults that are unique. Therefore, the proportion of PIT-tagged adults that are fallbacks (i.e., re-ascensions) is simply 1 minus the proportion of unique tags. Estimating adult fallback with PIT-tags is currently not possible, as PIT-tagged adults can only be detected if they fall back through the juvenile bypass system. Therefore, any PIT-tagged adults that fall back through the spillway or turbines will not be detected. Instead, when relying on PIT-tags, re-ascension rates are often used as surrogates for fallbacks.

The DART estimates are based on the algorithm developed by Burke et al. (2004), which presented an interpretive model that was developed for estimating re-ascension rates from PIT-tag detections of migrating adult salmonids as a surrogate for fallback rates. This interpretive model was based on studies from 2003 and 2004 when comparisons were made between actual fallback rates associated with radio tags and estimated re-ascension rates from PIT-tagged fish. The question is whether the re-ascension data provided by DART can be used real-time, without further analyses, for making in-season management and operational changes.

As requested by FPAC, the FPC staff reviewed the methodology utilized by the DART Daily PIT tag Adult Fallback Adjustment Rate web query. For our evaluation, the FPC staff focused on spring Chinook adults at McNary Dam (MCN). The DART methodology includes all PIT-tagged fish detected of a particular species at the particular site of interest, regardless of where they originated. For example, when evaluating adult fallbacks at MCN, the DART methodology includes PIT-tagged adults that originated below MCN, which overshoot their natal rivers, fall back, and re-ascend at much higher rates than upriver migrants. The fallback and re-ascension behavior of fish originating below MCN is not likely related to conditions at the dam, but more likely due to those fish seeking cues to their natal streams. The inclusion of these fish would be appropriate for adjusting window counts, but would bias analyses trying to relate fallbacks to dam operations. Overshoots from the John Day, Klickitat, and Umatilla rivers all show a propensity to fallback at a higher rate than salmon that were released in areas above MCN, such as the Snake or Upper Columbia rivers.

As mentioned above, the DART methodology was developed based on a paper that compared radio telemetry results to PIT-tag re-ascension data from 2003 and 2003 (Burke et al, 2004). However, in 2006, the PIT-tag antenna configuration changed at MCN, with the inclusion of counting window antennae at the Washington shore ladder (MC2). It is unclear from the DART website metadata how that change was taken into account in their estimates for years after 2006. Based on our review, it also appears that the methods described on the DART website do not reflect the actual methods outlined in Burke et al. (2004), as the interpretive model presented in Burke et al. (2004) uses a 12-hour gap to identify unique ladder passage events but the DART methodology uses a 6-hour gap. It is unclear why DART uses a 6-hour gap to determine separate ladder ascensions. DART uses unique ladder ascensions divided by total ladder ascensions for each date to determine a unique proportion. By reducing the gap from 12-hours to 6-hours, the DART methodology likely inflates separate ascension events, thus leading to overestimates of daily re-ascension rates (i.e., fallback rates). Furthermore, the DART methodology appears to inflate fallback rates by counting fish that began their ascension on one day but finished the next (i.e., overnight ascension) as separate passage events on two days. Therefore, the PIT-tag detection on the second day would be considered as a non-unique tag and, thus, a re-ascension.

FPC Method of Identifying PIT-tag Re-ascension Compared to DART

In order to accurately assign each passage event, the FPC staff developed an algorithm that tracked the direction and location of ladder detections at MCN. For each fish, a "map" of passage was generated that identified passage through entry coils, exit coils, and direction of movement (or lack of movement) between entry and exit coils as well as identifying gaps between detections of greater than six hours. A ladder passage was considered completed when the fish was last observed at the exit coils. Subsequent re-entry at entrance coils indicated a new ascension event, regardless of the amount of time or whether a day or more passed between exit and re-entry. Ladder passages that did not include detections at exit coils were considered truncated or incomplete.

Table 1 is provided below to illustrate a few examples of the passage "maps" that were generated by the FPC algorithm. These "maps" were generated for each individual adult PIT-tagged Chinook detected in the MCN adult ladders between April 25th and June 15th for the years 2006 through 2017 (2017 detections ran through May 26th). For this portion of our analysis, which compares the FPC methodology of identifying a re-ascension to that of DART, we included PIT-tagged Chinook that originated (i.e., tag site) both above and below MCN and were detected, as adults, at MCN. However, we did not include adults that were captured and PIT-tagged at the Bonneville Adult Fish Facility (AFF). The exclusion of AFF fish is similar to what the DART methodology does when selecting a single species.

Passage Map 1 shows a typical ladder passage with detections at entry coils (denoted by a series of 'E' symbols); progress up the ladder (denoted by '+'); a single "|" indicating no movement between detections mid-ladder; and finally detections at the exit coils (denoted by a series of 'X' symbols) which are the coils at the counting stations at McNary Dam. This first map would be assigned by both the FPC and DART as a single unique event. In some cases, as illustrated by Map 2, a fish moves up the ladder, then back down the ladder (denoted by '-'), and then re-ascends to exit. Based on the FPC methodology, the fish in Map 2 contains a single ascension event. However, Map 2 would be considered two ascension events by the DART methodology because the time spent in the ladder spanned two calendar days (in this case May 9 to May 10, 2017). Map 3 shows an example of a fish that exited the ladder and subsequently re-entered and ascended the ladder a second time. Map 3 would be considered a re-ascension under both the FPC and DART methodologies. Map 4 shows an example of a fish that entered the ladder, progressed upstream but delayed for 6+ hours in the middle of the ladder (denoted by a 'G' symbol) before successfully exiting. Under the FPC methodology, Map 4 would be considered a single ascension. However, under the DART methodology, this would be considered two separate ascensions because of the 6+ hour gap. Map 5 is an example of a fish that was seen entering the ladder but never had a clear exit detection. Map 6 shows a fish that fell back within the ladder multiple times, and had a gap below the count station window. It then fell back through the ladder and exited out to the tailrace. It re-entered the tailrace 15 days later. Based on the multiple entry dates, DART would assign two separate ladder passage events to this fish, but in reality the fish never exited into the forebay, based on the detection history mapped below. Therefore, based on the FPC methodology, it should not be considered as a fallback as a fallback can only occur after a successful exit. Furthermore, a passage of this type should not be used to readjust window counts since it passed into and back down through the count window and, thus, should have been added and subtracted from the window counts.

Table 1. Examples of Adult PIT-tagged Chinook Passage “Maps” based on PIT-tag detections at McNary Dam.

Map Number	**Passage Map**	**Description**
1	**EEEEE++|+++XXXXXX**	Single passage event without re-ascent. Fish was within PIT-tag array for less than 2 hrs.
2	**E|+|++|+|||||-||--|-|-EEEEEEEEE+|+|+|++X…(50X)**	Single passage event with up (+) and down (-) movement in ladder, and 51 exit coil detects.
3	**EEEE+|+||+|+|+XXXXEEEE++|+|++XXXX**	Two passage events. First ascent with exit coil detections followed by entry coil detect (in red) and re-ascent to exit.
4	**EEEEE|+|+|+|+|GXXXXXXX**	Single passage event with 6h+ gap (**G**) just below exit coils.
5	**ET**	Truncated ladder event that was removed from analysis.
6	**EEEE|+|++|+||----- EEEEEEEE|++|+|+|GXXXXXXXXXXX-|---|- EEEEEEEEE++|++||-|---|-EEE**	Three fallbacks within ladder and a gap below count station. Fifteen day gap between entry detects at red EE.

We attempted to compare the FPC method to the DART estimates in order to determine how well the two methods agreed. While it was difficult to recreate the daily counts generated by DART, we were able to match quite closely the seasonal estimates that DART developed using the gaps in ladder passage to adjust the number of re-ascensions we identified. Our daily counts differed by 0 to 30 or more fish due to their methods of determining a unique ladder passage event versus ours. Based on our analysis, the DART methodology overestimated re-ascension rates by between 5% to 7% on a seasonal basis (Table 2).

Table 2. Summary of seasonal comparisons between DART estimates of unique adult passage proportions and those derived by FPC. The comparisons used DART summary data from a web query of spring Chinook adults compared to PIT-tag query of spring Chinook from PTAGIS database. The data spanned the dates April 25 to June 15 each year.

Return Year	Proportion Unique Passage Events		Annual Differences
	FPC	DART	FPC - DART
2006	0.93	0.89	0.05
2007	0.93	0.86	0.07
2008	0.96	0.90	0.06
2009	0.96	0.90	0.06
2010	0.97	0.91	0.06
2011	0.93	0.87	0.06
2012	0.94	0.89	0.05
2013	0.97	0.91	0.06
2014	0.98	0.92	0.06
2015	0.96	0.91	0.05
2016	0.96	0.89	0.07
Average	**0.95**	**0.90**	**0.06**

To further explore why there were differences between FPC total ladder ascents and DART (as well as non-unique events which we interpreted as fallbacks originally), we looked closely at a four day period in 2017 (May 9 to May 12). We used only fish detected in the Oregon shore ladder (MC1) in order to make the comparison as simple as possible. In this four day period, DART estimated a total of 47 ladder passage events, with 33 estimated unique for an estimated proportion unique of 0.70 (Table 3). By comparison FPC estimated 35 total ascents, with 31 unique, with 4 fish identified to have re-ascended (Table 3). Based on our detailed comparison it appears that the DART method counts the number of tags in the ladder on any given day, and determines what proportion had been previously detected. Although the metadata stated that gaps were used to identify unique events, this did not appear to explain the patterns in results reported in the DART data. We found 13 fish during this four day period that delayed passage in the ladder overnight. This overnight delay would lead DART to assign these 13 fish as non-unique detections. One fish also re-ascended ladder MC1 after previously ascending MC2. This may account for the 14 non-unique detections from DART. The FPC method identified four fish that exited the top of the ladder (detected at the counting station coils and were later detected re-entering the ladder and exiting again. Two of those salmon that re-ascended did so within a single calendar day. It is not clear that the DART method identified those as separate passage events.

Table 3. Comparison of FPC methods and DART proportion unique ladder passage events in 2017.

Fist Detection Date at MC1	Total Ladder Passages		Unique Ladder Passages		Proportion Unique	
	FPC	DART	FPC	DART	FPC	DART
May 9	3	4	3	3	1.00	0.75
May 10	11	13	10	10	0.91	0.77
May 11	11	15	8	11	0.73	0.73
May 12	10	15	10	9	1.00	0.60
Overall	**35**	**47**	**31**	**33**	**0.89**	**0.70**

In summary, the DART method appears to rely on daily tallies of PIT-tagged adults detected in the ladder and then determines if those fish were seen on a previous date to determine unique and total ladder ascension events. This method does not represent actual ladder passage events, resulting in an overestimation of total ladder passage events as well as unique passage events. Most importantly, the DART method appears to incorrectly identify fish that holdover in the ladder overnight as separate ladder passage events. That flawed method leads to a misidentification of true re-ascension rates. Furthermore, use of this method to adjust adult counts is ill-suited at best. Any predictive capability of this method may be due to the possible relationship between the proportion of adult fish that delay in the ladder and the proportion of fish that re-ascend. We would not recommend this method be used for either adjusting adult counts or as an estimate of total daily fallbacks of PIT-tagged fish.

Factors Affecting Re-ascension

For this portion of our analysis, we focus on the second question that was posed by FPAC: what affects re-ascension rates at McNary Dam (MCN)? To answer this question, we constructed a logistic regression model using re-ascension (0 or 1) as the response variable. We relied on the same re-ascension methodology as the above analyses (FPC methodology), with two major modifications: 1) we did not include any fish that originated (i.e., tag site) below MCN and 2) we included both known and unknown spring Chinook (i.e., run types = 1 or 5). As mentioned above, the fallback and re-ascension behavior of fish originating below MCN is not likely related to conditions at the dam (i.e., flow, spill, powerhouse flow, etc.) but more likely due to those fish seeking cues to their natal streams. Therefore, it would not be appropriate to include these fish in an analysis investigating the effects of project operations on re-ascension rates. Similar to the above analyses, our logistic regression analysis did not include adults that were captured and PIT-tagged at the Bonneville Adult Fish Facility (AFF). This is different from a preliminary NOAA analysis that was presented at the May 30, 2017 FPAC meeting. Similar to our reasoning for not including fish that were tagged and released as juveniles below MCN, including fish tagged as adults at the AFF would not be appropriate, as many of these fish may be overshoots and, therefore, their fallback and re-ascension behavior may not be related to conditions at MCN but, instead, may be due to them seeking cues to their natal streams. Furthermore, the juvenile history (transported vs. in-river migrant) is unknown for fish that are tagged as adults at the AFF.

For our logistic regression model, we explored a suite of operational parameters as explanatory variables, including: river flow (Kcfs), spill volume (Kcfs), proportion spill, and powerhouse flow (Kcfs). However, due to the high correlation between these operational parameters, we chose to focus primarily on spill volume and powerhouse flow as the operation parameters in our logistic regression model (Figure 1). To account for a seasonal effect and the effect of ladder, we also included exit date (Julian day) and ladder exit (MC1 or MC2) into the logistical regression model. Because we suspected correlations within individual years, and correlations among multiple ascensions by the same fish, we included years and repeat ascensions [1] as random effects in our model.

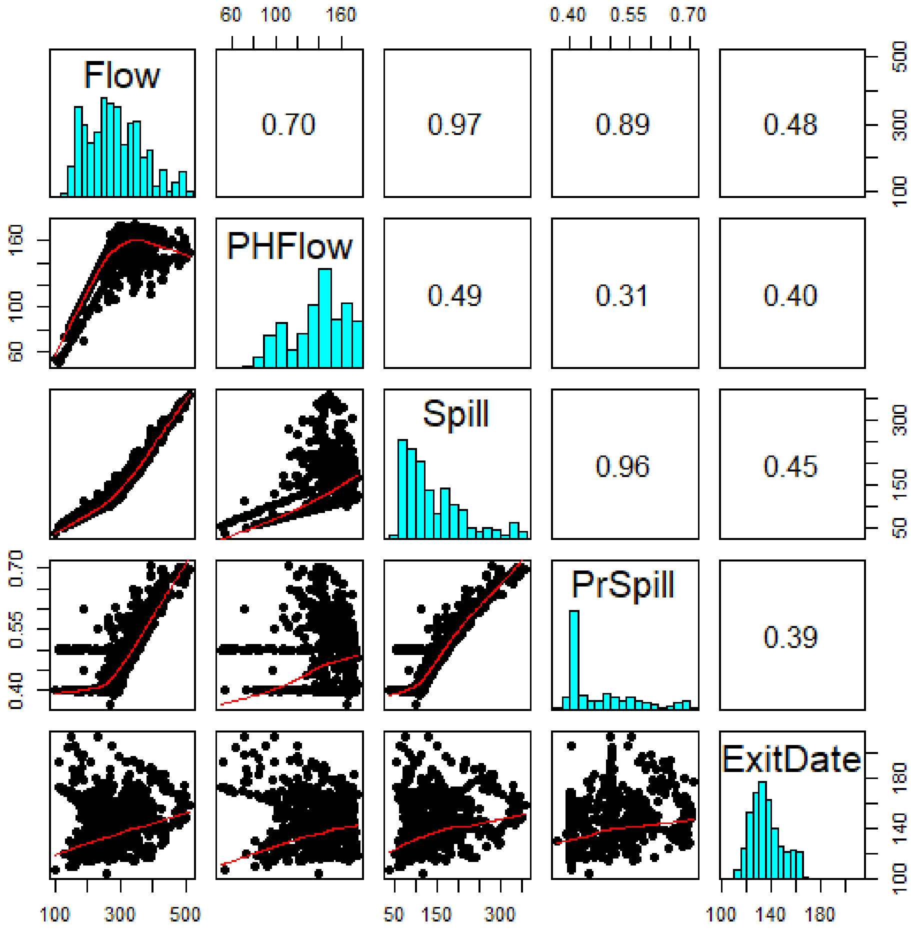

Figure 1. Correlation matrix of operational parameters considered for logistic regression analysis of re-ascension rates at MCN.

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[1] We assigned an indicator of "1" to all repeat ascensions, otherwise "0".

The global model was written as:

$$y_i = \begin{cases} 1 & if\ subsequently\ re - ascended \\ 0 & if\ no\ subsequent\ re - ascension \end{cases}$$

$$logit(y_i) = \beta_0 + \beta_{spill} \cdot Spill_i + \beta_{exitday} \cdot ExitDay_i + \beta_{PHFlow} \cdot TotalPHFlow + \beta_{exitMC2} \cdot ExitMC2_i + \alpha_{year[i]} + \gamma_{repeat[i]}, \qquad [1]$$

where $\alpha_{year[i]} \sim N(0, \sigma_\alpha^2)$, year= 2006 to 2017,
and $\gamma_{repeat[i]} \sim N(0, \sigma_\gamma^2)$, repeat= 1 or 0.

To better facilitate model conversion, we standardized the spill volume, exit date, and powerhouse flow variables by subtracting the mean from each observed value (centering) and dividing it by standard deviation (scaling). We then fitted the mixed effects model in R (R Core Team, 2016) using package lme4 (Bates et al. 2015), and used bootstrap procedures with 1,000 iterations to obtain standard errors and 95% confidence intervals (CI's) for our estimates. Based on results of the global model, we developed simplified versions by eliminating any variables that were not significant (i.e., $p > 0.05$) until settling on a final model.

As constructed, the model coefficient of spill volume represents the change in re-ascension rate in relation to a standard deviation change in spill volume (for fish ascended ladder MC1). However, the coefficient estimate was in the scale of logit probability, and one way to make it interpretable was to transform the value to probability scale using an inverse-logistic function. Keep in mind that the inverse-logistic function was curved, so the expected difference in re-ascension rate in relation to a fixed difference in spill volume would not be a constant.

One additional question that we investigated was, what effects do origin (i.e., Evolutionary Significant Unit) and juvenile passage history (i.e., transportation) have on the re-ascension rates of spring Chinook adults at MCN. To answer this question, we added a variable for Evolutionarily Significant Units/juvenile transport history (ESU/transport) for each fish to the final model. We categorized the fish in our data into three ESU/transport groups: 1) Snake River fish that migrated in-river as juveniles ($Snake_R$, 2) Snake River fish that were transported as juveniles ($Snake_{Tr}$), and 3) Upper Columbia River fish (UppCol), which all migrated in-river. The new model was written as follows:

$$y_i = \begin{cases} 1 & if\ subsequently\ re - ascended \\ 0 & if\ no\ subsequent\ re - ascension \end{cases}$$

$$logit(y_i) = \beta_0 + \beta_{spill} \cdot Spill_i + \beta_{snakeTr} \cdot SnakeTr_i + \beta_{UppCol} \cdot UppCol_i + \beta_{exitday} \cdot ExitDay_i + \beta_{exitMC2} \cdot ExitMC2_i + \alpha_{year[i]} + \gamma_{repeat[i]}, \qquad [2]$$

where $\alpha_{year[i]} \sim N(0, \sigma_\alpha^2)$, year= 2006 to 2017,
and $\gamma_{repeat[i]} \sim N(0, \sigma_\gamma^2)$, repeat= 1 or 0.

In this model, the model coefficient for Snake_{Tr} represents the difference in re-ascension rates between the Snake in-river group and the Snake River transport group for fish ascending ladder MC1, at a set spill volume and exit date. Similarly, the model coefficient for UppCol represents the difference in re-ascension rates between the Snake in-river group and the Upper Columbia group for fish ascending ladder MC1, at a set spill volume and exit date.

Results

The results from our global model are presented below in Table 4. The coefficient for powerhouse flow had a large *p*-value (p = 0.356). Therefore, we dropped this variable since we gained little benefit by keeping it in the model. We subsequently re-fitted the model and the results for the final model are shown in Table 5.

Table 4: Estimates for the fixed effects from the global model (equation 1).

Fixed Effects	**Estimate**	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept)	-2.496	0.7602	-3.283	0.001
Spill Volume	0.3297	0.05106	6.457	<0.001
Exit Date	-0.1177	0.03792	-3.105	0.002
Powerhouse Flow	-0.0497	0.05382	-0.9234	0.356
Exit MC2	0.1469	0.07304	2.011	0.044

Table 5: Estimates for the fixed and random effects after removing the powerhouse flow variable from the global model.

Random Effects:	**Variance**	**Std. Dev**
Year	0.2311	0.4808
Repeat Ascension	1.116	1.057

Fixed Effects:	**Estimate**	**Std. Error**	***z* value**	**Pr(>|z|)**
(Intercept)	-2.5	0.743	-3.364	0.001
Spill Volume	0.3165	0.04877	6.49	<0.001
Exit Date	-0.1254	0.03727	-3.365	0.001
Ladder Exit (MC2)	0.1492	0.073	2.043	0.041

Spill volume, exit date, and ladder exit all had a significant effect on re-ascension rates. In general, as spill volumes increase, the probability of re-ascension increases. In addition, at a set spill volume, fish that exit the Washington shore ladder (MC2) have a higher probability of re-ascension. Finally, the model indicates that, at a set spill volume and ladder exit, the probability of re-ascension decreases as the season progresses (Table 5).

Overall, the predicted re-ascension probabilities ranged from 0.055 (SE= 0.004, 95% CI= 0.046 to 0.063) at lower spill volumes (~63 Kcfs) to 0.161 (SE= 0.017, 95% CI= 0.130 to 0.197) at higher spill volumes (~328 Kcfs) at the Oregon shore ladder (MC1) and 0.063 (SE= 0.005, 95% CI= 0.053 to 0.073) to 0.182 (SE= 0.021, 95% CI= 0.145 to 0.226) at the Washington shore ladder (MC2) (Figure 2, dashed line). To illustrate the impact of the proposed operation of allowing the Action Agencies to operate the powerhouse at MCN above the 1% efficiency curve when spill volumes exceed 270 Kcfs, we provide the following hypothetical scenario. Based on discussions at TMT, allowing the Action Agencies to operate above the 1% efficiency curve would allow for up to 40 Kcfs additional flow to pass through the powerhouse, which would equate to a reduction in spill of 40 Kcfs. In our scenario, we assessed the change in re-ascension rate by reducing spill from 270 to 230 Kcfs, as:

For Exit MC1:

$$logit^{-1}(\beta_0 + \beta_{spill} \cdot scale(270)) - logit^{-1}(\beta_0 + \beta_{spill} \cdot scale(230)), \qquad [3]$$

for Exit MC2:

$$logit^{-1}(\beta_0 + \beta_{spill} \cdot scale(270) + \beta_{exitMC2}) - logit^{-1}(\beta_0 + \beta_{spill} \cdot scale(230) + \beta_{exitMC2}), \qquad [4]$$

where $scale(x) = (x - \overline{x})/s$.

At a spill volume of 270 Kcfs, the estimated probability of re-ascension at the Oregon shore ladder (MC1) is 0.129 (SE= 0.010, 95% CI= 0.108 to 0.149), while that at the Washington shore ladder (MC2) is 0.147 (SE= 0.014, 95% CI= 0.122 to 0.174). Reducing spill to 230 Kcfs resulted in a probability of re-ascension of 0.110 (SE= 0.007, 95% CI= 0.095 to 0.123) at MC1 and 0.125 (SE= 0.010, 95% CI= 0.106 to 0.145) at MC2. This equated to a change of 0.019 (SE= 0.004, 95% CI= 0.012 to 0.027) in re-ascension rate for MC1 and 0.021 (SE= 0.004, 95% CI= 0.014 to 0.030) for MC2 by reducing spill from 270 to 230 Kcfs.

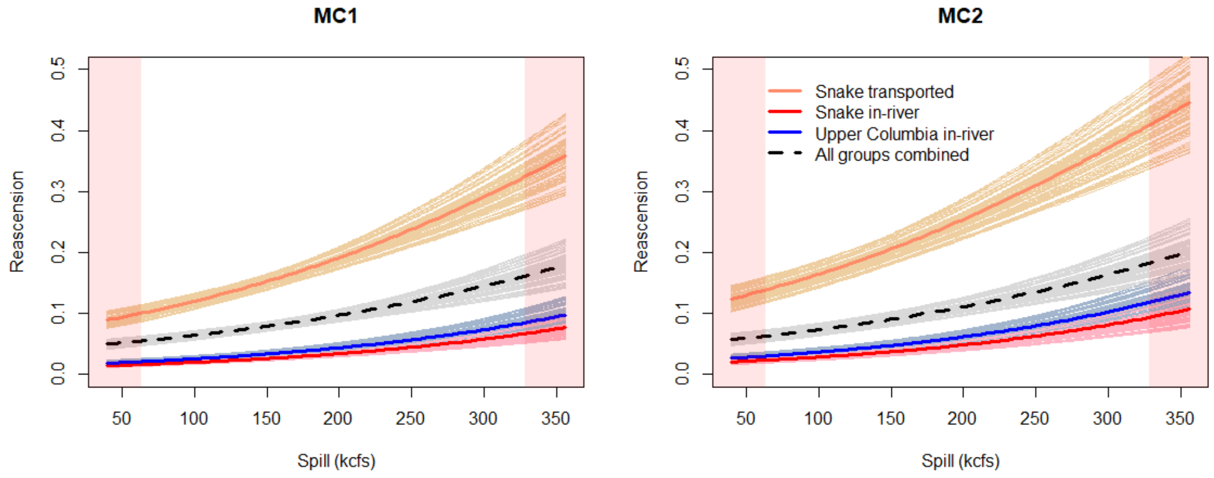

Figure 2: Estimated relationship between spill volume and probability of re-ascension using mixed effects logistic regression models. The thicker lines represent the probability of re-ascension over a range of spill volumes and the thin lines show the 95% CI for the model fit. All available data are used for the fitted relationship, but our discussion of results focuses on the 2.5th to 97.5th percentiles (non-shaded area).

After adding the ESU/Transport variable to the final model, the coefficient estimates for both Snake transport (Snake_{TR}) and Upper Columbia (UppCol) were significant ($p < 0.05$) (Table 6). In general, Snake River spring Chinook that were transported as juveniles (Snake_{TR}) had higher probabilities of re-ascension than Snake River spring Chinook that migrated in-river as juveniles (Snake_{IR}) (Figure 2). This is true at all levels of spill (Figure 2). Although statistically significant, the difference between Snake River (in-river) fish versus Upper Columbia fish (all in-river migrants) was relatively small but most prevalent at higher spill volumes (Figure 2).

Table 6: Estimates for the fixed and random effects after adding the variable for ESU/Transport to the final model.

Random Effects:	**Variance**	**Std. Dev**
Year	0.143	0.3781
Repeat Ascension	0.5818	0.7628

Fixed Effects:	**Estimate**	**Std. Error**	***z* value**	**Pr(>|*z*|)**
(Intercept)	-3.671	0.556	-6.602	<0.001
Spill Volume	0.3853	0.04908	7.851	<0.001
Snake Transport (Snake_{TR})	1.901	0.08248	23.05	<0.001
Upper Columbia (UppCol)	0.2563	0.1109	2.31	0.021
Exit Day	-0.2111	0.03886	-5.432	<0.001
Ladder Exit (MC2)	0.3645	0.07629	4.778	<0.001

To illustrate the effect of transportation on re-ascension rates, we modeled a hypothetical scenario where the spill volume was set at the mean spill volume for our dataset (140 Kcfs) and the probability of re-ascension was estimated for Snake (in-river) and Snake (transported) fish. At the mean spill volume of 140 Kcfs, the probability of re-ascension for Snake (in-river) fish was 0.025 (SE= 0.002, 95% CI= 0.021 to 0.029) at MC1 and 0.035 (SE= 0.003, 95% CI= 0.028 to 0.042) at MC2, whereas that for Snake (transported) fish was 0.146 (SE= 0.007, 95% CI= 0.131 to 0.158) at MC1 and 0.197 (SE= 0.013, 95% CI= 0.171 to 0.220) at MC2. This equates to a difference of 0.121 (SE= 0.006, 95% CI= 0.108 to 0.132) in re-ascension rate for fish exiting MC1 and 0.162 (SE= 0.011, 95% CI= 0.140 to 0.182) for fish exiting MC2 at this level of spill.

Discussion

Based on our review of the DART methodology, we do not think it appropriate to use the DART Daily PIT tag Adult Fallback Adjustment Rate tool to assess fallback rates (i.e., re-ascension) at McNary Dam. Furthermore, it is not appropriate to use this DART tool to assess the degree to which project operations affect re-ascension rates. This assessment agrees with one of the conclusions drawn in Burke et al. (2004). In their summary and conclusions section, Burke et al. (2004) stated that, although the PIT-tag model performed well when determining the magnitude and timing of passage events, it had varying degrees of success with determining post-fallback re-ascensions. If the PIT-tag model presented in Burke et al. (2004) had varying levels of success at predicting post-fallback re-ascensions, one could expect that the DART methodology would have even less success, as the potential for over-estimating re-ascension rates is inflated with the DART methodology of using a 6-hour gap instead of the 12-hour gap that the Burke et al. (2004) model was based on.

The FPC methodology for identifying re-ascension is more reliable than DART, as it is not based on a set time-gap for assessing separate ladder ascensions but, instead, relies on detections at the ladder exit followed by detections at a ladder entrance. However, it does not allow for estimating daily probabilities of re-ascension, as several days may occur between subsequent ladder ascensions and, therefore, the identification of a re-ascending PIT-tagged adult may change from day to day. Therefore, we would not recommend using the FPC methodology in a real-time manner. At this point, we have only applied the FPC methodology to PIT-tag data from MCN. Whether this methodology could be applied at other FCRPS projects would need to be explored. Finally, if the FPC methodology were to be used to quantify re-ascension at any given FCRPS project, we would argue that this should only be done for fish that were tagged as juveniles from sites originating above the project of interest.

Based on our logistic regression model, spill volume was found to affect re-ascension rates. As spill volume increased, re-ascension rates also increased. Based on our model, the maximum predicted probability of re-ascension was ~0.161 at the Oregon shore ladder (MC1) and ~0.182 at the Washington shore ladder (MC2) at spill volumes of ~328 Kcfs (Figure 2). The proposal to increasing powerhouse at spill volumes at or above 270 Kcfs would only result in a reduction in the probability of re-ascension of 0.019 to 0.021, depending on the exit ladder. This small reduction in fallbacks (i.e., re-ascension) comes at the cost of increased powerhouse passage for juveniles passing McNary Dam. The increase in powerhouse passage may be relatively low at these higher spill proportions but the impacts of powerhouse passage may also increase, as the 1% efficiency range is supposed to create the best conditions for fish. Any operations above the 1% efficiency range is likely to result more turbulent conditions that could harm juveniles passing MCN during this time. These are all factors that managers will need to weigh when considering modifying operations at MCN.

Our logistic regression model indicates that the probability of re-ascension does not increase as the season progresses in the same manner as spill increases. This result is contrart to what we might expect. This may be the result of our application of ladder exit date in the analytical structure utilized. This will be explored in future analyses of fallback and re-ascension.

Our logistic regression model also indicated an effect of ESU/Transportation group such that Snake River (transported) spring Chinook adults had much higher probabilities of re-ascension than did Snake River (in-river) spring Chinook adults (Figure 1). This is similar to some of the results presented in a 2016 NOAA report entitled: Refining our understanding of early and late migration of adult Upper Columbia and Snake River spring/summer Chinook salmon: passage timing, travel time, fallback and survival (Crozier et al. 2016). In their report, Crozier et al. (2016) found that Snake River adult spring Chinook that were transported as juveniles had higher mean fallback rates and probability of fallback compared to those who migrated in-river as juveniles.

Finally, although we included total powerhouse flow in our global logistic regression model, we could not analyze the effects of individual powerhouse unit operations (i.e., which units are operating and how much from each unit). In addition, our spill variable (i.e., spill volume (Kcfs) did not account the operation of individual spill bays (i.e., which spill bays were operating and how much from each bay). Our logistic regression analyses suggest that fish exiting the Washington shore ladder (MC2) have higher probabilities of re-ascension (Tables 5 and 6). Currently, powerhouse unit operation data are not available to the FPC. Both of these (powerhouse unit and spill bay operation) should be investigated in the future, since the specific unit operations and spill bay operations affect tailrace hydraulics which affect which ladder fish enter. If the operation of particular unit and/or spill bays affects which ladder a fish enters than this, in turn, could affect fallback (i.e., re-ascension) rates.

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