ANALYSES OF JUVENILE CHINOOK SALMON AND STEELHEAD TRANSPORT FROM LOWER GRANITE AND LITTLE GOOSE DAMS, 1998-2008

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Executive Summary

- The report provides analyses of patterns of smolt-to-adult return rates (SARs) relative to in-season migration timing of smolts. SARs of juvenile fish that were transported from either Lower Granite Dam (LGR) or Little Goose Dam (LGO) were compared to SARs of non-transport fish that migrated through the lower Snake and Columbia Rivers in the years 1998 – 2008.

- The measure used to assess the benefit of transport relative to downstream migration was the transport to migrant ratio (T:M), defined as the ratio of SAR for transported fish to that of non-transport migrants for corresponding groups. Statistical models produced estimated values for the SARs of the two groups and the T:M for each day was estimated from those estimates.

- To study seasonal SAR patterns required known dates of juvenile passage. Therefore, migrant groups were formed from PIT-tagged fish that were bypassed (i.e., detected) at the collector dams. The value of information from bypassed migrants has been discounted by some scientists in the region because bypassed fish generally have lower SARs than fish that pass the collector projects undetected via non-bypass routes (mostly over the spillway, with a small proportion through turbines). During periods of transport, migrants among the non-tagged run-at-large mostly pass via non-bypass routes (bypassed non-tagged fish are mostly transported), so extrapolation of results for bypassed migrants to the run at large could be biased (estimated T:M ratios greater than would have occurred for the run at large). The report addresses this potential bias by carefully considering standards for comparison of SARs and T:M (detailed below).

- Over the years, fish have been PIT tagged both upstream from LGR and at LGR. Tagging location was included as a potential factor in the models of SAR. In some cases where data were available from both tagging locations, SARs were not statistically different between tagging locations. In other cases, SARs differed significantly but relative SARs between transport and migrant fish (i.e., T:M ratio) were the same. In still others, both SARs and T:M differed depending on tagging location.

- The basic unit of data on which the analyses were based was the estimated SAR for a daily group of fish. Each LGR analysis included as many of the following four categories as were available: fish tagged upstream of LGR and transported from LGR; fish tagged upstream of LGR and detected and returned to river at LGR; fish tagged at LGR and transported from LGR; fish tagged at LGR and released in the tailrace of LGR. Each LGO analysis included only two groups, transported and in-river, as all fish were tagged upstream of LGO. Although analyses were based on SARs for daily groups, there was too much sampling variability in the daily points for effective visual display. Instead, our figures included estimated SARs for daily groups pooled into weekly periods. Weekly points, with relatively less "noise," effectively summarized the daily data and provided a clearer picture.

- A statistical regression method (Poisson log-linear regression) was used to fit a curve or a straight line to the daily SAR data points, and to assess the fit statistically. Potential factors to explain SARs were migration group (transported or in-river migrant), tagging location, and date of passage (day of year). Two- and three-way interactions among these factors were also considered. Information-theoretic (AIC-based) methods were used to identify a best-fitting model for each species and rearing-type combination in each year. As from any regression method, the resulting lines and curves represent a "smoothing" of the data points, in this case the estimated daily SARs, and the data points themselves were "scattered" around the smoothed line.

- Details of river environment (e.g., flow, spill, water temperature, number of fish migrating through dams, etc.) were not considered explicitly in this analysis (i.e., measures of these characteristics were not included as factors potentially affecting SAR or T:M).

- Daily T:M ratios estimated from the fitted SAR curves were assessed relative to two different "standards." T:M greater than 1.0 indicated that among fish in the bypass system, those that were transported returned at a higher rate than those that were returned to the river. The second standard, designed for inference to the run at large, was based on a correction factor calculated to compensate for the bypass effect. These correction factors "raised the bar" to a standard higher than a T:M of 1.0. The estimated bypass effect varied by year and species, and the resulting alternative standards ranged from 1.02 – 1.04 for wild Chinook and 1.03 – 1.11 for wild steelhead at LGR and 1.08 – 1.22 for wild Chinook and 1.08 – 1.31 for wild steelhead at LGO. T:M greater than this alternative standard indicated that transported fish in the run at large returned at a higher rate than migrants in the run at large.

- Regression results for each species/rearing-type/year were illustrated with a set of figures: one small figure for each tagging location showing point estimates of SAR for weekly pooled groups, with standard errors, and the best-fit curves or lines from the regression for transport and migrant fish; and one large figure showing the curves for T:M through the season derived from best-fit SAR curves, along with 95% confidence "envelopes" around the curves. Appendix A includes 42 such sets of figures for transport from LGR. Appendix B includes 42 sets for transport from LGO.

- The best-fit curves for T:M ratios were summarized, relative to the 1.0 standard and the alternative standard, in a series of color-coded figures (Figures 2-5 for transport from LGR and Figures 6-9 for transport from LGO). Each horizontal line in the figures represents one migration season for a species/rearing-type/tagging location combination, with a series of color-coded boxes representing days in the migration season. The color coding indicates on which days the estimated T:M was less than the standard, which days the estimated T:M was greater than the standard, and whether the difference between estimated T:M and standard was significant.

- In most cases, estimated T:M remained constant or increased throughout the migration season. For both species and both rearing types in all migration years before 2006, the estimated T:M ratio exceeded the alternative standard (i.e., exceeded the "higher bar" and so therefore also exceeded the 1.0 standard) for fish that arrived at LGR on May 1 or later, and the difference was usually statistically significant.

- In migration years 2006-2008 there have been some exceptions to the post-May 1 pattern: estimated T:M still usually increased through the season, but there were instances when the estimate did not exceed the standards until later in May, and for hatchery Chinook in 2006 the estimated T:M was less than 1.0 throughout the season. It is difficult to determine at this point whether altered spill operations and returning all bypassed smolts to the river during the early part of the migrations in 2006-2008 have resulted in changed T:M ratios compared to earlier years. Estimated T:M ratios for some groups at LGR were apparently lower, at least early in the season (e.g., hatchery steelhead and hatchery Chinook 2006, wild Chinook 2006, and hatchery Chinook in 2008). Adult returns are incomplete for some of these migration years, and final results cannot be evaluated for another year or two.

- The analyses presented in this report are intended to assist managers with the decision of when to transport during the spring migrant period. As noted by the Independent Scientific Advisory Board (ISAB 2008-5), besides T:M ratios for spring-summer Chinook and steelhead, managers should also consider other factors, including maintaining the ability to learn how populations respond to current dam configurations under a range of operations and conditions, the effect of transport on straying rates, and the response to transport of ESUs other than spring/summer Chinook and steelhead. Additional years of adult returns from ongoing and future studies are needed to fully elucidate these issues.

Background

This paper provides analyses of smolt-to-adult return rates (*SAR*s) of wild and hatchery juvenile Snake River yearling Chinook salmon and Snake River steelhead that were either collected and transported from the Snake River or migrated through the federal hydropower dams of the lower Snake and Columbia Rivers. Analyses were conducted separately for smolts transported from Lower Granite Dam (LGR) and Little Goose Dam (LGO). Returning adults were counted at LGR. We have not conducted analyses for smolts transported from Lower Monumental Dam (LMO). The analyses cover smolt migration years 1998 through 2008 for Chinook salmon and 1998 through 2007 for steelhead.

Transport operations differed somewhat in 2006 from previous years and were substantially different in 2007 and 2008, with transport initiated later in the season and more water spilled to benefit migrant fish. The new operations were intended not only to improve juvenile migration speed and survival, but also to increase adult returns of migrant fish. Under the new management strategy smaller proportions of the non-PIT tagged populations of smolts were transported (Table 1). This resulted from a combination of migration timing, delayed start to transport at Snake River dams, voluntary spill program, and surface-passage structures added in recent years -- LGR (2002), LMO (2008), Ice Harbor (2005), and McNary dams (2007). Flow conditions varied among 2006 (very high flow), 2007 (low flow), and 2008 (intermediate). Flow indices (daily flow weighted by fish passage index) calculated for the 2006 migration were 130.5 kcfs for yearling Chinook salmon and 135.4 kcfs for steelhead. For 2007, flow indices were 85.9 kcfs for yearling Chinook salmon and 81.4 kcfs for steelhead. For 2008, flow indices were 125.4 kcfs for yearling Chinook salmon and 110.2 kcfs for steelhead, respectively. To begin to address the efficacy of the new strategy, this memo re-analyzes *SARs* of transported and migrant PIT-tagged Chinook and steelhead juveniles from migration years 1998 through 2005 and compares the results from these years to *SARs* of transported and migrant PIT-tagged juveniles from migration years 2006 through 2008 (adult returns to date).

Table 1. Estimated percentage of non-PIT tagged wild and hatchery yearling Chinook salmon and steelhead smolts transported from Snake River dams from 2006 through 2008.

Year	Percent transported	
	Wild	Hatchery
	Yearling Chinook salmon	
2006	59.9	62.3
2007	24.8	25.4
2008	54.3	45.3
	Steelhead	
2006	74.6	76.0
2007	41.1	41.1
2008	50.5	46.6

For yearling wild and hatchery Chinook salmon, we have complete returns for the 1998-2006 outmigration years, returns of 1-and 2-ocean adults from the 2007 outmigration, and of 1-ocean adults from the 2008 outmigration. For hatchery and wild steelhead, we have complete returns for the 1998-2006 outmigration years, and 1-ocean adults from the 2007 outmigration. Most (if not all) of the 1-ocean (A-run) from the 2008 steelhead outmigration and 2-ocean (B-run) from the 2007 steelhead outmigration year have already passed Bonneville Dam. However, in each return year 5-15% of the transported steelhead do not migrate over LGR during their year of return to the river. Instead, they remain in the river between Bonneville and Lower Granite Dams, not passing LGR until the following spring. Thus, steelhead returns to LGR in 2009 (except for 1-ocean fish from migration year 2007 that passed in spring 2009) were too incomplete to include in these analyses.

The implementation of transport at Snake River dams changed in 2006 from strategies used in previous years. Rather than transporting from the beginning of the migration season, dam operators bypassed collected fish back to the river at LGR, LGO, and LMO dams early in the season. Further, when transport was initiated, it was implemented sequentially at successive downstream dams, so that fish bypassed at upriver dams were mostly not collected and transported at lower river dams. In 2006, transport began at LGR on 20 April, at LGO on 24 April, and at LMO on 28 April. In 2007 transport began at LGR on 1 May, at LGO on 8 May, and at LMO on 11 May. In 2008 transport began at LGR on 1 May, at LGO on 10 May, and at LMO on 13 May.

Study Designs and Migrant (“Control”) Fish

Transport studies are typically designed such that one group of fish is transported (“T” group), and a comparison group of “migrants” migrates through the hydropower system in the river (“M” group). Historically, the annual *SARs* of these two groups were compared using ratios (“T:M ratios”) that determined the relative performance of transport to migrant fish. The choice of fish to use for the migrant group has varied. In recent years, many in the region have favored using non-detected PIT-tagged fish because these fish migrate past all transport collector dams (LGR, LGO, and LMO) without going through a bypass system; the same passage history as migrant fish in the unmarked population during times of transportation. Historically, all unmarked fish collected at those dams were routed for transport, while migrant fish were those that passed via spillways, surface collectors, or turbines. Further, previous research has demonstrated that non-detected PIT-tagged fish returned as adults at greater rates than those PIT-tagged smolts that were detected going through 1-3 bypass systems (Sandford and Smith 2002; Williams et al. 2005).

Here, we conducted analyses differently from those conducted previously. As detailed below, rather than estimating annual T:M values, we analyzed within-season temporal trends in T:M ratios. By definition, we do not know the timing of dam passage for non-detected fish. Thus, non-detected fish cannot be used to investigate within-season trends. Instead, to assess transport from a particular collector dam, we used PIT-tagged fish detected and bypassed at that dam, recognizing they likely returned at rates lower than non-detected PIT-tagged fish (below we explain how we took into account this difference in SARs in interpreting our results).

We used detected fish in our migrant group for three reasons. First, under the new management strategy (2006 and beyond), unmarked fish in the population collected at LGR in the earlier part of the season are routed back to the river to continue their migration. Thus, PIT-tagged fish returned to the river after detection during the parts of the season when no transport occurred actually do represent a segment of the unmarked population. Secondly, migrant fish detected at collector dams provided us the ability to determine temporal trends in the T:M ratio. Thirdly, to address the management question, “Should we transport fish collected today or return them to the river?” our analyses provided the data needed to evaluate which strategy worked best, given that fish had already been collected. Our analyses do not address management strategies related to provision of spill, even though the proportion of fish collected at a dam obviously relates to the duration and proportion of spill. In the last 10 years, the proportion of the unmarked migrant population migrating to below McNary Dam that was not collected at LGR, LGO, and LMO dams (those fish represented by the non-detected PIT-tagged fish) ranged from near zero when spill did not occur to as high as 60% for hatchery Chinook salmon under low flow/high spill conditions and operation of removable spillway weirs (Figure 1).

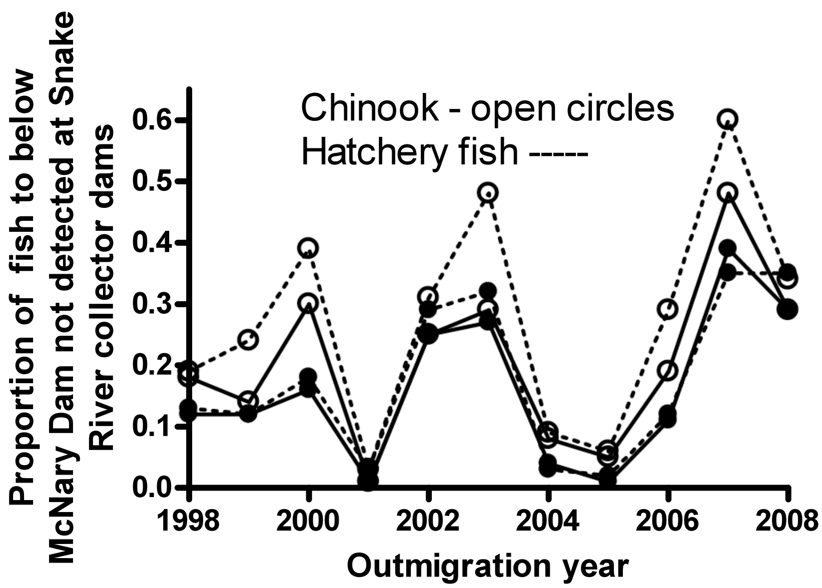

Figure 1. Estimated annual proportion of PIT-tagged fish arriving at Lower Granite Dam and surviving to McNary Dam tailrace that were not detected at Lower Granite, Little Goose, or Lower Monumental Dams (includes detected and not-detected fish at McNary Dam). Chinook -- open circles, steelhead solid dots, hatchery fish------, and wild fish solid lines. (Analyses based on Sandford and Smith 2002).

Past analyses of management strategies have concluded that when the annual T:M ratio exceeded 1:1, a transport strategy would provide the highest overall adult returns. The data used in these earlier analyses did not take into account the within-year temporal changes in the T:M, nor did they generally account for the higher SAR for PIT-tagged fish never detected in the system. Here, we interpreted our results relative to two different standards for T:M ratios. The first used the old methods where a ratio exceeding 1.0 indicates that transported fish returned at a rate greater than bypassed fish (vice versa, if < 1.0, migrant fish returned at rates greater than transported fish). The second standard was set higher such that transported fish had to return at a greater rate than the population as a whole, this population included the proportion of fish that were never bypassed.

Mechanisms For Higher Return Rate of Non-Detected Fish

Various mechanisms (causes of mortality) have been suggested to explain the differential return rate between detected and non-detected fish. One hypothesis (first published in Budy et al. 2002), suggests that bypass systems at the dams stress fish, but the mortality suffered because of this stress does not occur until after the fish leave the hydropower system. An alternative hypothesis is that smaller fish tend to pass through bypass systems while larger fish tend to pass the dams (undetected) through other routes (Zabel et al. 2005). Smaller fish subsequently return at lower rates than larger ones (Zabel and Williams 2002), and this leads to the observed differential return rates. Another possible mechanism is that the majority of non-detected fish pass through spillways, and spilled fish pass dams more quickly than fish that pass through bypass systems. Thus, non-detected fish arrive to the estuary up to several days earlier than multiply-bypassed ones and return at greater rates based on the relationships described in Scheuerell et al. (2009).

In fact, all three mechanisms may operate to a certain degree. Understanding the contributing mechanisms has implications beyond transport studies. If bypass systems do, in fact, impart latent effects on juveniles, managers will need to consider this when deciding when to return collected fish to the river, determining levels of spill to use, and proposing actions to improve bypass systems.

Methods

The analyses detailed here investigated in-season temporal trends in absolute and relative *SARs* of PIT-tagged salmonids with various passage histories through the dams on the Lower Snake River. We refer to the *SAR* of fish transported from a collector dam relative to the *SAR* for "migrants" (those that migrated within the river) generically as the "T:M ratio." Analyses were done separately for fish transported from LGR and LGO dams.

Data

Data are from PIT-tagged fish released for migration years 1998 through 2008. For fish passing LGR each year there were potentially 16 different data sets, resulting from the combinations of two species (spring/summer Chinook and steelhead), two rearing types (wild and hatchery), two release areas (all sites upstream from LGR and in the tailrace at LGR), and two passage histories (transported or migrant). In some years, some combinations of species and rearing type were not released at LGR; only upstream-released data are available from those years. For LGO, there were 8 possible data sets each year – fish were not tagged and released at the dam; all were released upstream of LGO. Adult returns are not complete for migration years 2007 and 2008. This limited some of the analyses.

For each data set, we obtained PIT-tag observation data from PTAGIS and compiled daily counts of fish transported from each dam and of fish detected and returned to the river (upstream-released fish) or released in the tailrace after tagging at the dam. We used PTAGIS records of PIT-tagged adults detected at LGR to estimate *SARs*. We tabulated all returning PIT-tagged adults according to their juvenile group (transport or migrant) and date of detection or release at LGR or LGO as juveniles.

Analysis

Analyses were done separately for each species and rearing-type combination (e.g., hatchery Chinook) in each year. Based on date of LGR or LGO juvenile passage, we estimated daily and weekly *SARs* for each group. We modeled daily *SAR* data simultaneously for the (up to) four groups using a generalized linear model for Poisson observations with a logarithmic link function for the linear predictor (see below).

For upstream-released fish, the migrant group was defined as all fish that were detected at LGR or LGO and directed to the tailrace. For fish tagged at LGR, the migrant group was defined as all fish released into the tailrace.

Weekly SAR estimates

Weekly estimates of *SAR* for a group were obtained by summing the daily estimates (or counts) of smolts passing LGR or LGO and the counts of returning adults to LGR from the group that had passed LGR or LGO as juveniles during the week. We calculated the weekly estimated *SAR* as:

$$S\hat{A}R_w = {}^{A_w}\!/_{J_w}$$

where J_w is the weekly smolt total and A_w is the adult total for the weekly group. The standard error of the estimated *SAR* was estimated under the assumption that the adult count was distributed as a binomial random variable with success probability equal to *SAR* and the number of trials equal to the number of juveniles:

$A_w \sim Binomial(J_w, SAR_w)$, so that $\hat{s}.e.(S\hat{A}R_w) = \sqrt{\dfrac{S\hat{A}R_w(1 - S\hat{A}R_w)}{J_w}}$.

We constructed approximate 95% confidence intervals as $S\hat{A}R_w \pm 1.96 \bullet \hat{s}.e.(S\hat{A}R_w)$.

When a week had zero adult returns, we used the "Rule of Three" to construct an approximate 95% confidence interval as [0, $3/J_w$) (Hanley and Lippman-Hand 1983).

Regression Analysis of Daily SAR estimates

We viewed daily data in the way described above for weekly counts; the adult count for juvenile day (A_i) at LGR or LGO was a binomial count with success probability SAR_i and number of trials equal to the number of juveniles (J_i) in the group on day *i*. We modeled daily *SARs* for a given species and rearing type as a function of the day of year, release location (for LGR analyses), and passage experience (transported or migrant).

Regression models for binomial data— We considered using logistic regression of the binomial data (see, for example, Scheuerell et al. 2009), as it handles zero-count data well (many days had no adult returns for a particular group). For our purposes, a practical drawback of logistic regression is that the logit (log(P/(1-P)) of the success probability is modeled as a linear function of predictors, and it is not straightforward to extract estimates of T:M ratios and associated standard errors from logistic-regression model coefficients.

A useful alternative, which closely approximates the binomial when success probabilities (i.e., adult return rates in these analyses) are small, is Poisson log-linear regression. The Poisson distribution is often used to describe integer counts of events over a fixed space, time, or sampling effort where the upper value of the counts is not bounded. Examples include the number of sea turtles counted along a 10-km transect, or number of adult steelhead passing a viewing window in a 30-min interval. In the PIT-tag *SAR* data, the number of returning adults for each LGR- or LGO-juvenile-passage day is the Poisson count, and the "sampling effort" is the number of juveniles that had passed LGR or LGO on that juvenile-passage day. This sampling effort is obviously not constant for each observation, but the Poisson model can still be used as long as the sampling effort for each observation is accounted for in the model.

In Poisson log-linear regression, the natural logarithm of the mean of the counts (λ) is modeled as a linear function of predictor variables. The model for the logarithm of the expected number of adults returning for a particular LGR juvenile-passage day *i*, given the number of outmigrating juveniles (J_i) and a set of *k* covariate values ($\boldsymbol{X}_i$) for the day is:

$$\log[\lambda_i \mid X_i, J_i] = \beta_0 + \sum_{j=1}^{k} \beta_j X_{ij} + \log(J_i)$$

This model specifies that the number of adults returning, given $\boldsymbol{X}_i$ and J_i, is Poisson-distributed with mean $\exp[\log(\lambda_i \mid X_i, J_i)]$. Note that the regression coefficient for $\log(J_i)$ is not estimated; it is fixed at a value of 1.0. This is equivalent to expressing the logarithm of the mean *SAR* as:

$$\log[\frac{\lambda_i}{J_i} \mid X_i, J_i] = \beta_0 + \sum_{j=1}^{k} \beta_j X_{ij}$$

The covariates included in the model can be random or fixed, continuous or categorical. The Poisson log-linear regression model is a generalized linear model and can be fit using maximum likelihood methods with most standard statistical packages. Extra-Poisson variation ("overdispersion") can be accounted for using quasi-likelihood methods. Standard likelihood-based model selection can used criteria such as Akaike Information Criterion adjusted for extra-Poisson variation (overdispersion) and where necessary ($QAIC_c$) (Burnham and Anderson 2002).

In LGR analyses, for the four groups of fish for each species/rearing type combination we modeled the daily *SARs* as a function of one continuous covariate (day of year) and two categorical variables (an indicator variable for transport and an indicator for release at LGR). We also tested for two-way and three-way interactions among predictors. Thus, the linear equation for the full model of the log of the number of returning adults for group *g* from juvenile-passage day *i* was:

$$\log[\frac{A_{g,i}}{J_{g,i}} \mid J_{g,i}] = \beta_0 + \beta_1 D_i + \beta_2 L_g + \beta_3 T_g + \beta_4 (D_i L_g) + \beta_5 (D_i T_g) + \beta_6 (D_i L_g) + \beta_7 (D_i L_g T_g)$$

where D_i is the day of year for juvenile-passage day i (e.g., May 1 = 121 in non-leap years);

L_g is 0 for groups released upstream of LGR and 1 for groups released at LGR or LGO;

T_g is 0 for migrant groups and 1 for transported groups.

To see how the T:M ratio is extracted from the parameters of this regression model, consider the transported and migrant groups of fish released upstream from LGR, for which L_g is 0. The *SAR* for the transported and migrant groups on juvenile-passage day *i* are, respectively:

$$SAR_{T,i} = \frac{A_{T,i}}{J_{T,i}} \mid J_{T,i} = \exp(\beta_0 + \beta_1 D_i + \beta_3 T_g + \beta_5 (D_i T_g))$$, and

$$SAR_{M,i} = \frac{A_{M,i}}{J_{M,i}} \mid J_{M,i} = \exp(\beta_0 + \beta_1 D_i).$$

The T:M ratio is, then:

$$T:M = \frac{SAR_{T,i}}{SAR_{M,i}} = \frac{\exp(\beta_0 + \beta_1 D_i + \beta_3 T_g + \beta_5 (D_i T_g))}{\exp(\beta_0 + \beta_1 D_i)} = \exp(\beta_3 T_g + \beta_5 (D_i T_g)).$$

In LGO analyses, there are only two groups of fish for each species/rearing type combination (no fish tagged at the dam), and we modeled the daily *SARs* as a function of one continuous covariate (day of year) and one categorical variable (an indicator variable for transport). Thus, the linear equation for the full model of the log of the number of returning adults for group *g* from juvenile-passage day *i* was:

$$\log[\frac{A_{g,i}}{J_{g,i}} \mid J_{g,i}] = \beta_0 + \beta_1 D_i + \beta_3 T_g + \beta_5 (D_i T_g)\,.$$

Model selection--- As described above, in LGR analyses, for each year our data potentially included four combinations of species and rearing type, and for each combination there were potentially four groups of PIT-tagged fish (transported and migrant groups released upstream from LGR and transported and migrant groups released at LGR). In the previous section, we gave the full model for a species/rearing type combination when all four groups were available. Denoting the main effects of that model as "D" for day of year, "L" for release area, and "T" for transported, and considering all admissible subsets of that full model (interactions do not appear without main effects), there are 19 possible models of *SAR* to consider, including the null model with only intercept β_0:

Possible Models for LGR data	
#	**Model**
0	0
1	D
2	L
3	T
4	D + L
5	D + T
6	L + T
7	D + L + T
8	D + L + D*L
9	D + T + D*T
10	L + T + L*T
11	D + L + T + D*L
12	D + L + T + D*T
13	D + L + T + L*T
14	D + L + T + D*L + D*T
15	D + L + T + D*L + L*T
16	D + L + T + D*T + L*T
17	D + L + T + D*L + D*T + L*T
18	D + L + T + D*L + D*T + L*T + D*L*T

For LGO analyses, all fish had the same release area (i.e., upstream from dam), so that factor did not appear in the 5 possible models for LGO data:

Possible Models for LGO data	
#	**Model**
0	0
1	D
3	T
5	D + T
9	D + T + D*T

For each combination of species/rearing type in each year, we fit all of the possible models (depending on which groups of PIT-tagged fish were available) and ranked the models according to the small-sample-corrected AIC_c adjusted for extra-Poisson variation (overdispersion), and where necessary ($QAIC_c$) (Burnham and Anderson 2002).

We illustrated the data for each species/rearing type combination, along with the corresponding top $QAIC_c$-ranked model, in a three-panel figure, showing the weekly *SAR* estimates for all groups, along with fitted curves from the top-ranked model for the *SAR* for each group and for the T:M ratio. The fitted curves are plotted in the illustration for the period of the central 95% of cumulative passage index (i.e., the curves are not plotted in the tails of the passage index distribution – first and last 2.5%).

Standards for Comparison of SARs

As previously noted, the purposes of this analysis required the use of “migrant” fish that had known passage or tagging dates at LGR or LGO. Consequently, all T:M ratios reported here compare *SARs* for transported fish with migrant fish that were detected (bypassed) at least once. Thus, a T:M ratio greater than a standard of 1.0 for a given day indicated that fish transported from LGR or LGO on that day returned at a higher rate than fish that were in the bypass system on the same day, but were returned to the tailrace. T:M ratios based on this migrant group address the question “Once a fish is in the bypass system, is it better to transport it downstream or to return it to the river?” If the T:M ratio based on the bypassed migrant group exceeded 1.0 then transport led to a greater return rate than return to tailrace.

Also as previously discussed, to assess the efficacy of transport as an overall strategy, the *SAR* for transported fish is properly compared to the *SAR* expected for the entire migrant population under a no-transport scenario; this population includes both fish that are bypassed and fish that are never bypassed. Accordingly, we defined an additional standard for comparison to transport *SAR*s to properly represent the migrant group that includes both bypassed and never-bypassed fish. Because never-bypassed (i.e., never-detected PIT-tagged fish) generally have higher *SAR*s than bypassed (detected) fish, the second standard was higher than the 1.0 standard discussed above based on the bypassed migrant group. To determine exactly how much higher to set the standard, we considered two factors: (1) the *SAR* of PIT-tagged fish that best represented the non-transported unmarked fish (i.e., those not detected at any of the collector dams LGR, LGO, or LMO) relative to the *SAR* of the migrant group used in our analysis (i.e., detected and returned to the river at LGR or LGO); and (2) the proportion of fish in the migrant population as a whole that were never detected. For example, if never-detected fish have a *SAR* 50% higher than those detected, and 40% of the population is never detected, then the population as a whole will have a *SAR* 20% greater than the detected group, and the T:M ratio in our analyses would have to exceed the standard of 1.2 to conclude that a maximized transport strategy would lead to higher overall returns (1.2 = 40% x 1.50 + 60% x 1.00).

We refer to the higher standard as the “adjusted baseline.” The calculation of the actual adjusted baselines for each year for each species/rearing type at each dam proceeded as follows. (1) The ratio of estimated *SAR*s for never-detected and detected fish was quite variable, probably in large part due to sampling error (Tables 2 and 3). Therefore, in the calculation of every year’s standard we applied the long-term geometric means of the ratios (final entry of each column of Tables 2 and 3 – the shorter-term geometric mean for recent years is given for comparison). (2) Because the proportion of fish in the never-detected group is a function of the new management strategy in recent years, we used year-specific estimates of this proportion in the adjusted-baseline calculations for 2006-2008 (See Figure 1 and Tables 4 & 5). The resulting adjusted-baseline standard for 2006- 2008 ranged from 1.02 to 1.28 for LGR data sets and from 1.07 to 1.39 for LGO data sets (Tables 4 and 5). (3) Because one purpose of this analysis is to assess transport in the context of the new management strategy, not the context that existed previously, we applied the average of the adjusted baseline standards for recent years as the standard for migration years 1998-2005, rather than the (mostly lower) standards that would result from applying steps (1) and (2) to obtain year-specific values for those years.

When the estimated T:M ratio in our analyses exceeded the appropriate adjusted baseline standard (see Tables 4 and 5), we took it as evidence that transported fish returned at a higher rate than the migrant population as a whole. When the T:M ratio was lower than the adjusted baseline standard, transported fish returned at a lower rate than the migrant population as a whole.

Table 2. Ratios of estimated annual *SAR* of PIT-tagged fish not detected at Lower Granite, Little Goose, or Lower Monumental Dams (includes detected and not-detected fish at McNary Dam) to estimated annual *SAR* of PIT-tagged fish bypassed at Lower Granite Dam with any subsequent downstream detection history.

Migration Year	**Wild Chinook**	**Hatchery Chinook**	**Wild steelhead**	**Hatchery steelhead**
1998	1.25	1.55	3.32	3.49
1999	1.10	1.07	1.40	1.89
2000	0.84	0.96	0.90	0.90
2002	1.40	1.09	0.79	1.10
2003	1.42	1.15	0.83	2.01
2004	2.11	2.14	NA	3.29
2005	0.44	1.67	NA	2.40
2006	1.01	1.18	2.12	1.32
2007	1.11	1.28	0.92	1.51
2008	0.96	0.93		
Geometric means:				
2006-2008	1.03	1.12		
2006-2007			1.40	1.41
1998-2008 (excl. 2001)	**1.09**	**1.26**		
1998-2007 (excl. 2001)				**1.81**
1998-2007 (excl. 2001,4,5)			**1.27**	

Table 3. Ratios of estimated annual *SAR* of PIT-tagged fish not detected at Lower Granite, Little Goose, or Lower Monumental Dams (includes detected and not-detected fish at McNary Dam) to estimated annual *SAR* of PIT-tagged fish bypassed at Little Goose Dam with any subsequent downstream detection history.

Migration Year	**Wild Chinook**	**Hatchery Chinook**	**Wild steelhead**	**Hatchery steelhead**
1998	2.42	3.33	3.76	3.55
1999	1.14	1.30	2.00	1.98
2000	1.07	1.15	0.76	0.60
2002	1.61	1.06	1.06	1.02
2003	2.28	1.72	1.61	1.30
2004	2.47	2.00	NA	2.01
2005	0.45	1.96	NA	3.09
2006	1.27	1.52	2.05	1.24
2007	1.33	1.78	3.00	1.41
2008	2.07	1.51		
Geometric means:				
2006-2008	1.52	1.60		
2006-2007			2.48	1.32
1998-2008 (excl. 2001)	**1.45**	**1.65**		
1998-2007 (excl. 2001)				**1.58**
1998-2007 (excl. 2001,4,5)			**1.79**	

Table 4. Calculation of alternative baseline standard T:M for comparisons for fish transported from Lower Granite Dam. For migration years 2006-2008, components of calculation are the *SAR* of PIT-tagged fish not detected at any of the collector dams LGR, LGO, or LMO relative to the *SAR* of PIT-tagged fish bypassed at Lower Granite Dam with any subsequent downstream detection history, and the proportion of fish in the migrant population as a whole that were never detected. The average standard for years 2006-2008 was applied to migration years 1998-2005.

	Wild Chinook			**Hatchery Chinook**			**Wild Steelhead**			**Hatchery Steelhead**		
Migration Year	SAR Ratio[a]	Prop. Nondet[b]	**Alt. Std.**	SAR Ratio[a]	Prop. Nondet[b]	**Alt. Std.**	SAR Ratio[c]	Prop. Nondet[b]	**Alt. Std.**	SAR Ratio[d]	Prop. Nondet[b]	**Alt. Std.**
1998-2005	1.09	0.32[e]	**1.03**[e]	1.26	0.41[e]	**1.11**[e]	1.27	0.26[e]	**1.07**[e]	1.81	0.27[e]	**1.22**[e]
2006	1.09	0.19	**1.02**	1.26	0.29	**1.08**	1.27	0.11	**1.03**	1.81	0.12	**1.10**
2007	1.09	0.48	**1.04**	1.26	0.60	**1.16**	1.27	0.39	**1.11**	1.81	0.35	**1.28**
2008	1.09	0.29	**1.02**	1.26	0.34	**1.09**	1.27	0.29	**1.08**	1.81	0.35	**1.28**

a. Geometric mean of annual ratio of SAR of "never-detected" fish to SAR of fish detected at Lower Granite Dam, 1998-2008 (excl. 2001).

b. Proportion of fish migrating to downstream of McNary Dam not detected at Snake River collector dams.

c. Geometric mean of annual ratio of SAR of "never-detected" fish to SAR of fish detected at Lower Granite Dam, 1998-2007 (excl. 2001,2004,2005).

d. Geometric mean of annual ratio of SAR of "never-detected" fish to SAR of fish detected at Lower Granite Dam, 1998-2007 (excl. 2001).

e. Mean of 2006-2008 values.

Table 5. Calculation of alternative baseline standard T:M for comparisons for fish transported from Little Goose Dam. For migration years 2006-2008, components of calculation are the *SAR* of PIT-tagged fish not detected at any of the collector dams LGR, LGO, or LMO relative to the *SAR* of PIT-tagged fish bypassed at Little Goose Dam with any subsequent downstream detection history, and the proportion of fish in the migrant population as a whole that were never detected. The average standard for years 2006-2008 was applied to migration years 1998-2005.

	Wild Chinook			**Hatchery Chinook**			**Wild Steelhead**			**Hatchery Steelhead**		
Mig. Year	SAR Ratio[a]	Prop. Nondet[b]	**Alt. Std.**	SAR Ratio[a]	Prop. Nondet[b]	**Alt. Std.**	SAR Ratio[c]	Prop. Nondet[b]	**Alt. Std.**	SAR Ratio[d]	Prop. Nondet[b]	**Alt. Std.**
1998-2005	1.45	0.32[e]	**1.14**[e]	1.65	0.41[e]	**1.27**[e]	1.79	0.26[e]	**1.21**[e]	1.58	0.27[e]	**1.16**[e]
2006	1.45	0.19	**1.08**	1.65	0.29	**1.19**	1.79	0.11	**1.08**	1.58	0.12	**1.07**
2007	1.45	0.48	**1.22**	1.65	0.60	**1.39**	1.79	0.39	**1.31**	1.58	0.35	**1.20**
2008	1.45	0.29	**1.13**	1.65	0.34	**1.22**	1.79	0.29	**1.23**	1.58	0.35	**1.20**

a. Geometric mean of annual ratio of SAR of "never-detected" fish to SAR of fish detected at Lower Granite Dam, 1998-2008 (excl. 2001).

b. Proportion of fish migrating to downstream of McNary Dam not detected at Snake River collector dams.

c. Geometric mean of annual ratio of SAR of "never-detected" fish to SAR of fish detected at Lower Granite Dam, 1998-2007 (excl. 2001,2004,2005).

d. Geometric mean of annual ratio of SAR of "never-detected" fish to SAR of fish detected at Lower Granite Dam, 1998-2007 (excl. 2001).

e. Mean of 2006-2008 values.

Results

Lower Granite Dam

For each migration year (MY) and fish grouping (wild Chinook salmon, hatchery Chinook salmon, wild steelhead, hatchery steelhead), we tested a suite of 19 models to investigate the relation between *SAR* and factors 'day of year', 'release location' (at or above LGR), 'mode of migration' (Transported or Migrant), and the interactions of factors. The best fitting models based on $QAIC_c$ are listed and corresponding *SAR*s and estimated T:M ratios are illustrated in Appendix A (Table A2 and Figures A1-A42).

Each of three factors tested was important in a majority of the best fitting models, with date occurring in 39 of 42 cases, 'release location' occurring in 28 of 42 cases, and 'mode of migration' occurring in 37 of 42 cases (Table A2). Many of the best fitting models also contained interactions, meaning that the slope of the *SAR* relationships varied across values of the factors (e.g., estimated T:M ratio depended on date). In 2 of the 5 cases when 'mode of migration' was not included in the best fitting model (1998 wild steelhead and 2002 hatchery steelhead), there were no PIT-tagged transported fish, so no comparison was possible. In the other three cases, *SAR*s of transported fish and migrants were not statistically different. Accordingly, the estimated T:M ratio was equal to 1.0 across the entire season in these cases. It is likely that the estimated T:M ratio was also not significantly different from the adjusted-baseline standard, though we did not conduct formal statistical tests of this hypothesis. Similarly, in some cases when 'release location' was not included in the best fitting model, PIT-tagged fish were released at only one of the locations, so comparisons were not possible.

When the factors 'mode of migration' and 'release location' appeared in the model but their interaction did not, it indicated that *SAR*s differed according to release location, but the estimated T:M ratio was the same for both release locations. This occurred in 17 cases (Table A2 and Figures A1-A42). When the model included the interaction between 'mode of migration' and 'release location', both *SAR*s and estimated T:M ratios differed between 'release location'. This occurred seven times (Table A2 and Figures A1-A42).

Color-coded charts (Figures 2-5) provide visual means to assess temporally varying estimated T:M ratios from the best fitting models relative to the standards for comparison. Dates are color-coded on the charts to indicate when estimated T:M ratios were significantly lower than the standard (dark blue) (the estimated T:M ratio and the upper 95% confidence bound were below the line), estimated T:M ratios were lower than the standard, but not significantly so (light blue) (the estimated T:M ratio was below the line, but the upper 95% confidence bound was not), estimated T:M ratios were higher than the standard, but not significantly so (light green) (the estimated T:M ratio was above the line, but the lower 95% confidence bound was not), and estimated T:M ratios were significantly higher than the standard (dark green) (the estimated T:M ratio and the lower 95% confidence bound were above the line).

Little Goose Dam

For each migration year (MY) and fish grouping (wild Chinook salmon, hatchery Chinook salmon, wild steelhead, hatchery steelhead), we tested a suite of 5 models to investigate the relation between *SAR* and factors 'day of year' and 'mode of migration' (Transported or Migrant), and the interaction of factors. The best fitting models based on $QAIC_c$ are listed and corresponding *SAR*s and estimated T:M ratios are illustrated in Appendix B (Table B2 and Figures B1-B42).

Each of the two factors tested was important in a majority of the best fitting models, with 'day of year' (D) occurring in 37 of 42 cases, and 'mode of migration' (T) occurring in 38 of 42 cases (Table B2). In the 4 models that did not include mode of migration, *SAR*s of transported fish and migrants were not statistically different. Accordingly, the estimated T:M ratio was equal to 1.0 across the entire season in these cases. It is likely that the estimated T:M ratio was also not significantly different from the adjusted-baseline standard, though we did not conduct formal statistical tests of this hypothesis.

If a model included only 'mode of migration', or included 'day of year' and 'mode of migration' but not the interaction between the two factors (total of 24 cases), the estimated T:M ratio was constant (not equal 1.0) throughout the range of available data. If the model contained an interaction between 'day of year' and 'mode of migration' (14 cases), the estimated T:M ratio included a trend through time (either upward or downward). See Table B2 and Figures B1-B42.

Color-coded charts (Figures 6-9) similar to those for LGR dam provide visual means to assess temporally varying estimated T:M ratios from the best fitting models relative to the standards for comparison.

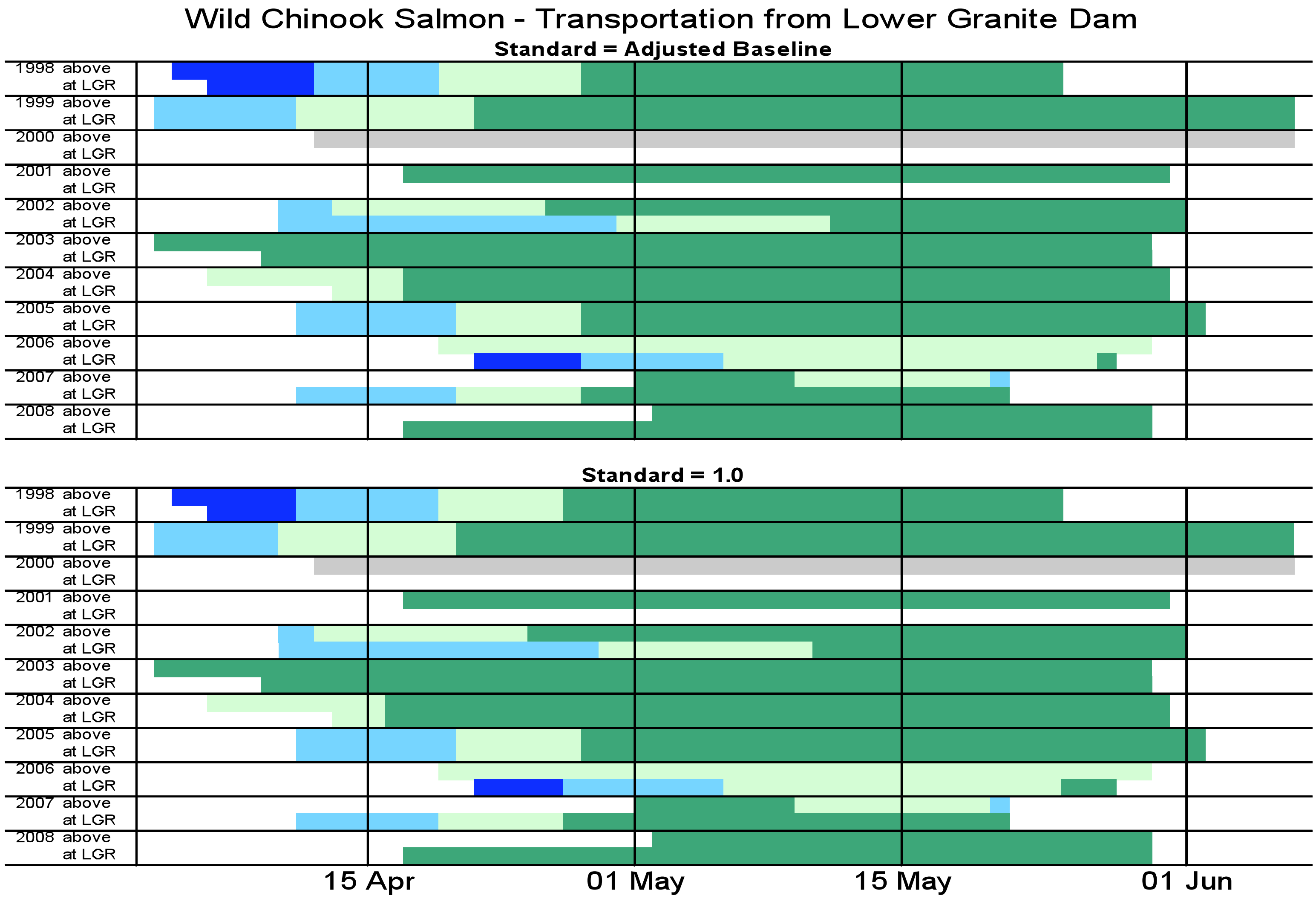

Figure 2. Color-coded summary of daily estimated Transport:Migrant ratios (T:M) from Lower Granite Dam for Snake River wild spring/summer Chinook salmon. Fish were tagged upstream from ("above") or at Lower Granite Dam. Color coding: Dark blue cells--T:M was significantly < the standard on that date; Light blue cells--T:M was < the standard, but not significantly; Light green cells--T:M was > the standard, but not significantly; Dark green cells--T:M was significantly > the standard; Gray cells--T:M was = 1.0; White cells—No data. "Significance" determined from 95% confidence envelope around fitted curve.

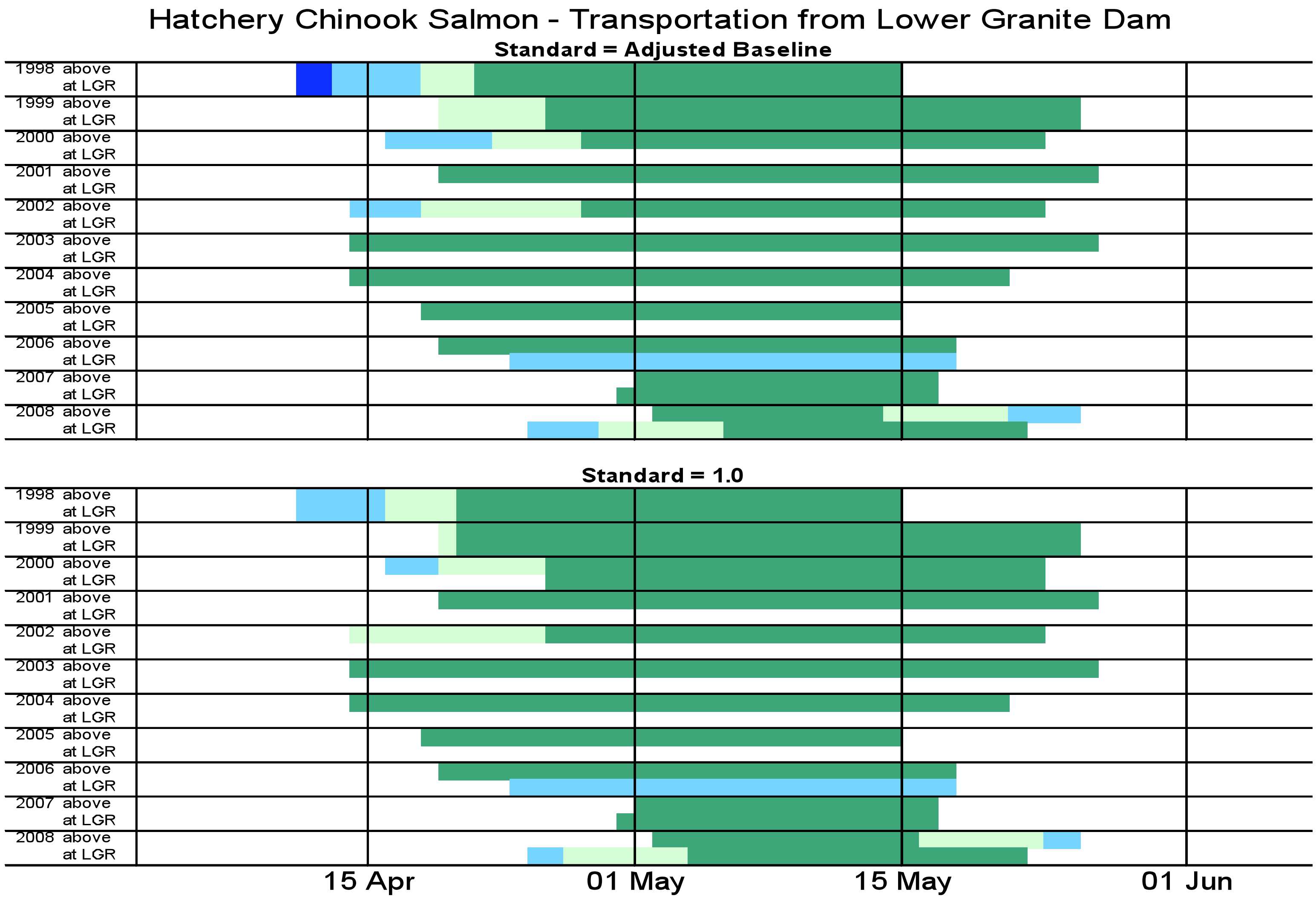

Figure 3. Color-coded summary of daily estimated Transport:Migrnt ratios (T:M) from Lower Granite Dam for Snake River hatchery spring/summer Chinook salmon. Fish were tagged upstream from ("above") or at Lower Granite Dam. Color coding: Dark blue cells--T:M was significantly < the standard on that date; Light blue cells--T:M was < the standard, but not significantly; Light green cells--T:M was > the standard, but not significantly; Dark green cells--T:M was significantly > the standard; Gray cells--T:M was = 1.0; White cells—No data. "Significance" determined from 95% confidence envelope around fitted curve.

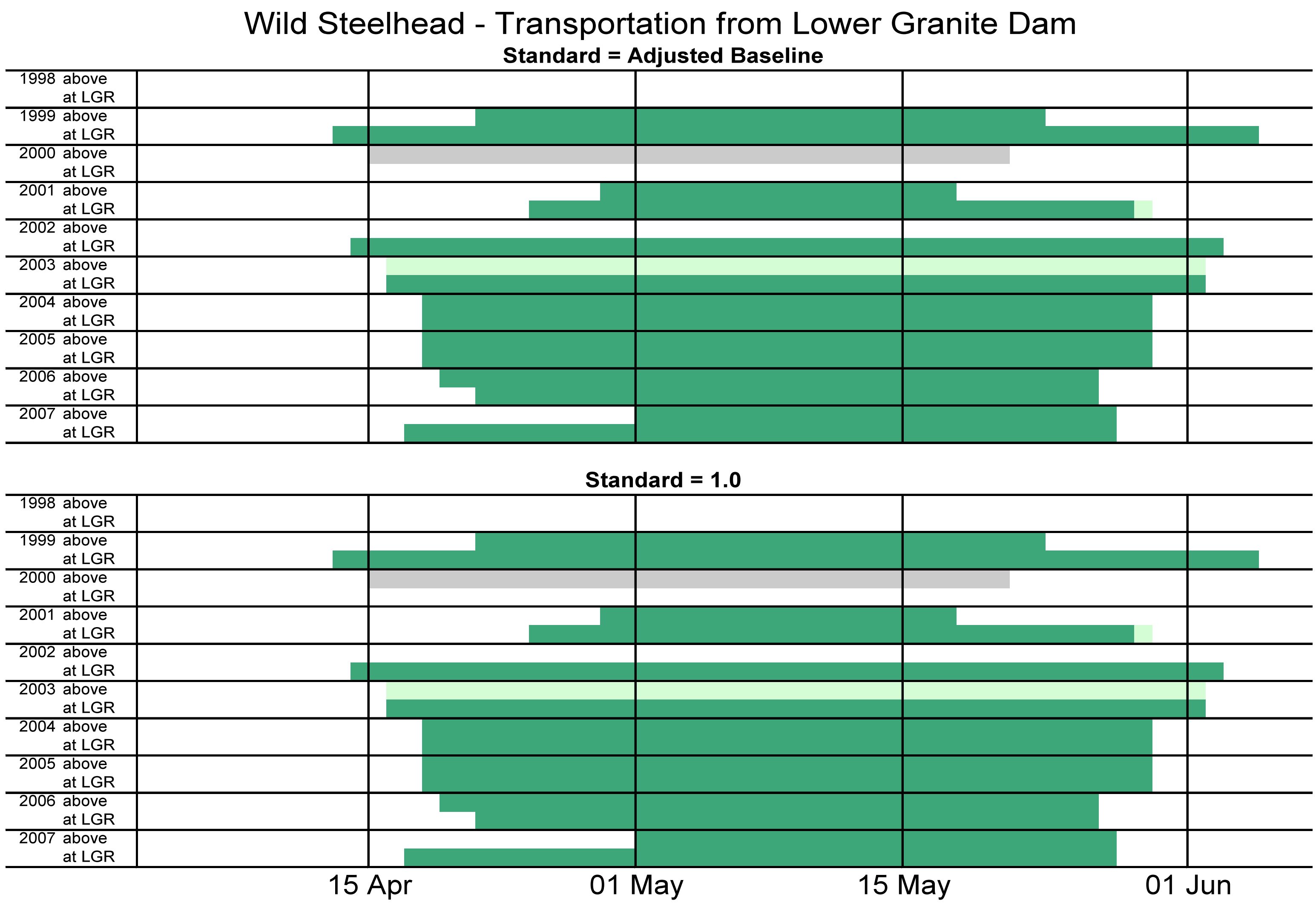

Figure 4. Color-coded summary of daily estimated Transport:Migrant ratios (T:M) from Lower Granite Dam for Snake River wild steelhead. Fish were tagged upstream from ("above") or at Lower Granite Dam. Color coding: Dark blue cells--T:M was significantly < the standard on that date; Light blue cells--T:M was < the standard, but not significantly; Light green cells--T:M was > the standard, but not significantly; Dark green cells--T:M was significantly > the standard; Gray cells--T:M was = 1.0; White cells—No data. "Significance" determined from 95% confidence envelope around fitted curve.

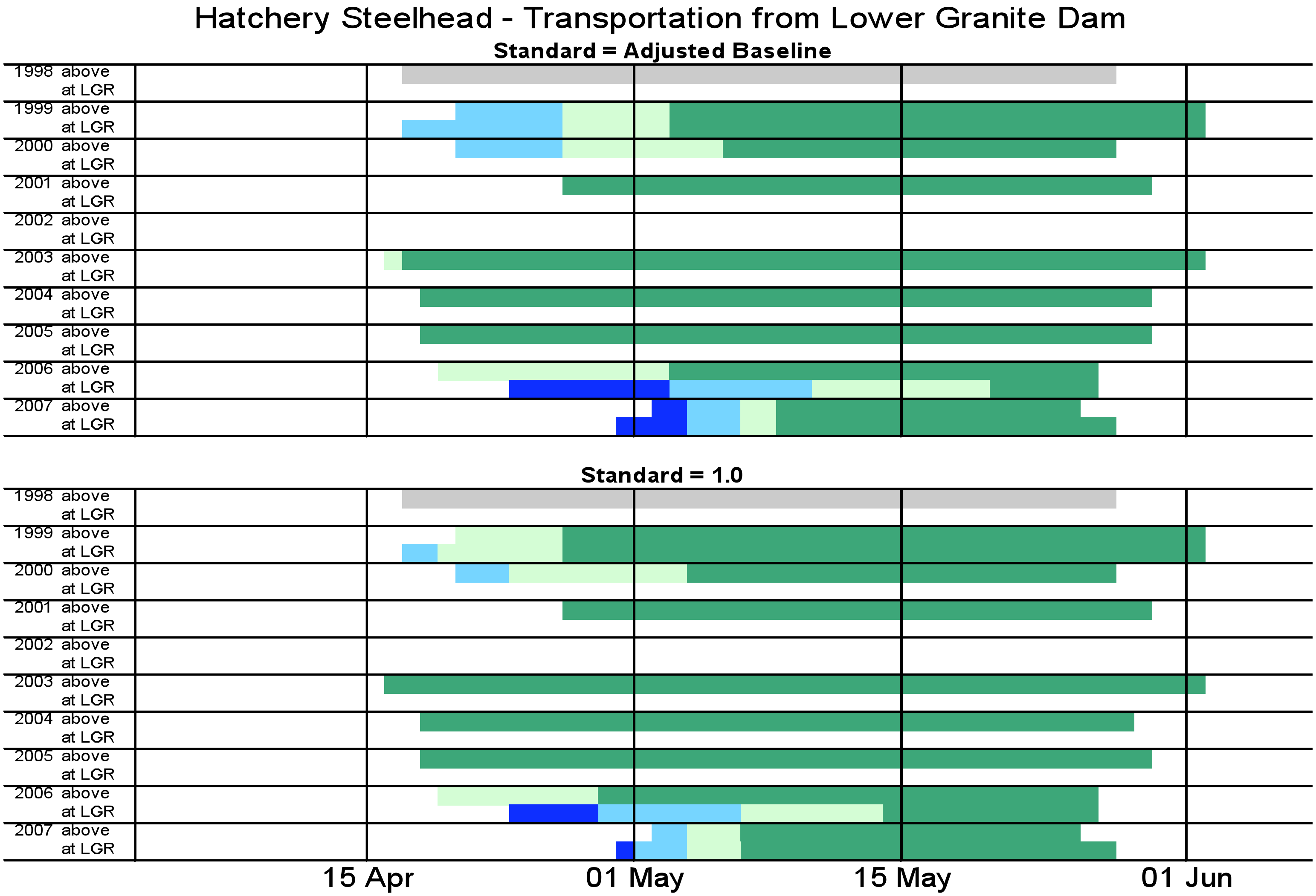

Figure 5. Color-coded summary of daily estimated Transport:Migrant ratios (T:M) from Lower Granite Dam for Snake River hatchery steelhead. Fish were tagged upstream from ("above") or at Lower Granite Dam. Color coding: Dark blue cells--T:M was significantly < the standard on that date; Light blue cells--T:M was < the standard, but not significantly; Light green cells--T:M was > the standard, but not significantly; Dark green cells--T:M was significantly > the standard; Gray cells--T:M was = 1.0; White cells—No data. "Significance" determined from 95% confidence envelope around fitted curve.

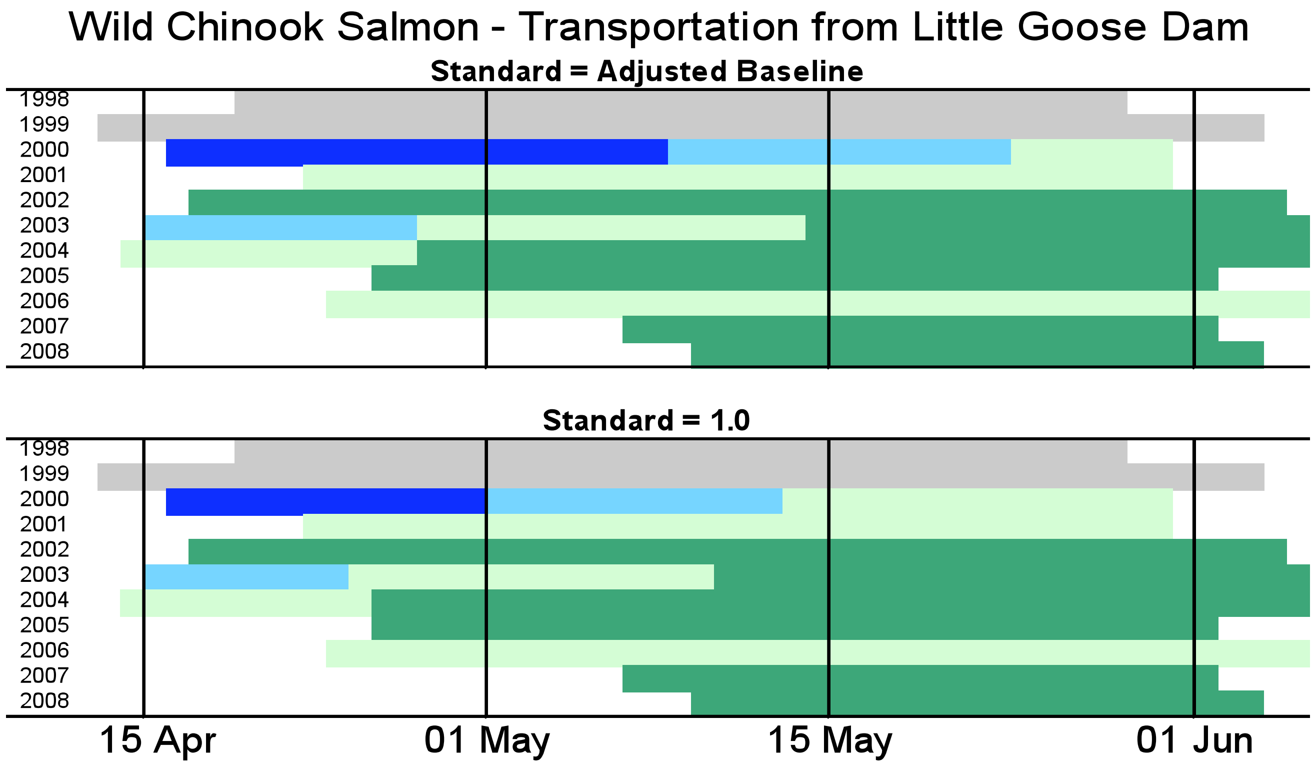

Figure 6. Color-coded summary of daily estimated Transport:Migrant ratios (T:M) from Little Goose Dam for Snake River wild spring/summer Chinook salmon. Color coding: Dark blue cells--T:M was significantly < the standard on that date; Light blue cells--T:M was < the standard, but not significantly; Light green cells--T:M was > the standard, but not significantly; Dark green cells--T:M was significantly > the standard; Gray cells--T:M was = 1.0; White cells—No data. "Significance" determined from 95% confidence envelope around fitted curve.

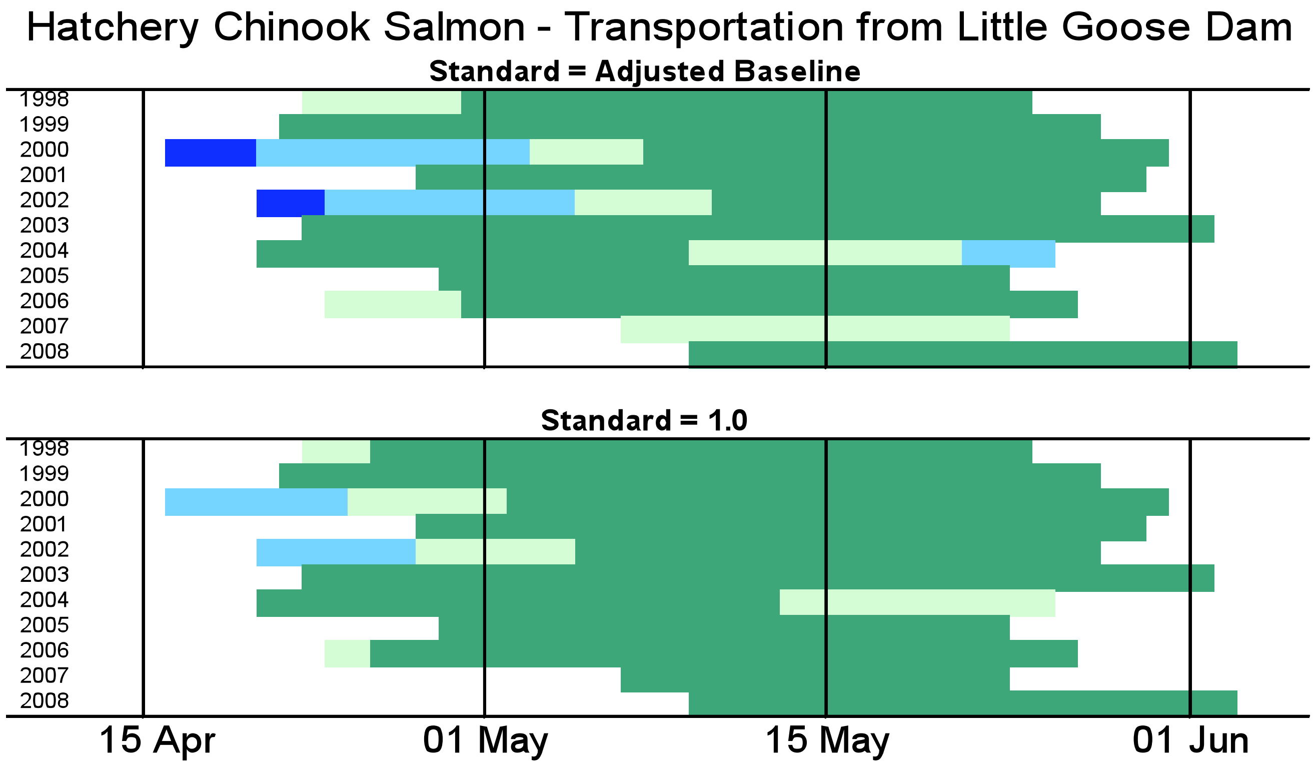

Figure 7. Color-coded summary of daily estimated Transport:Migrant ratios (T:M) from Little Goose Dam for Snake River hatchery spring/summer Chinook salmon. Color coding: Dark blue cells--T:M was significantly < the standard on that date; Light blue cells--T:M was < the standard, but not significantly; Light green cells--T:M was > the standard, but not significantly; Dark green cells--T:M was significantly > the standard; Gray cells--T:M was = 1.0; White cells—No data. "Significance" determined from 95% confidence envelope around fitted curve.

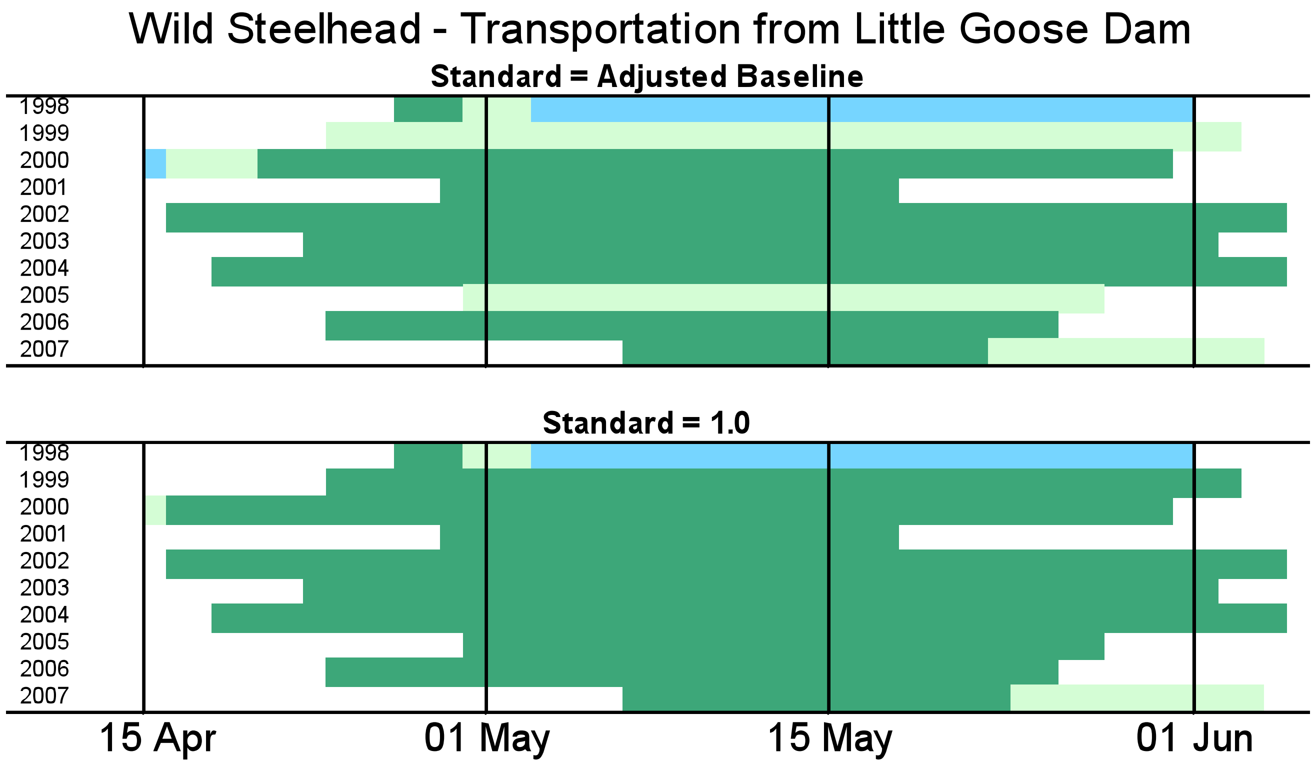

Figure 8. Color-coded summary of daily estimated Transport:Migrant ratios (T:M) from Little Goose Dam for Snake River wild steelhead. Color coding: Dark blue cells--T:M was significantly < the standard on that date; Light blue cells--T:M was < the standard, but not significantly; Light green cells--T:M was > the standard, but not significantly; Dark green cells--T:M was significantly > the standard; Gray cells--T:M was = 1.0; White cells—No data. "Significance" determined from 95% confidence envelope around fitted curve.

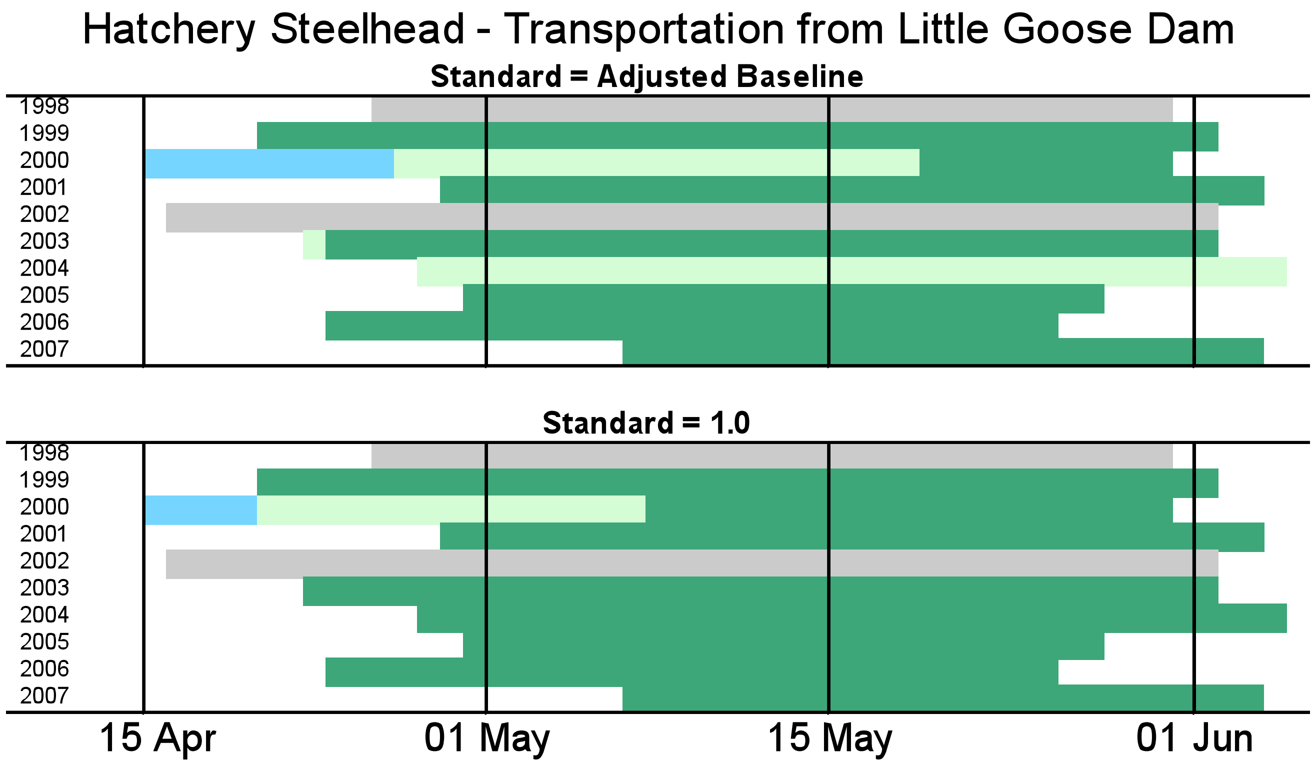

Figure 9. Color-coded summary of daily estimated Transport:Migrant ratios (T:M) from Little Goose Dam for Snake River hatchery steelhead. Color coding: Dark blue cells--T:M was significantly < the standard on that date; Light blue cells--T:M was < the standard, but not significantly; Light green cells--T:M was > the standard, but not significantly; Dark green cells--T:M was significantly > the standard; Gray cells--T:M was = 1.0; White cells—No data. "Significance" determined from 95% confidence envelope around fitted curve.

Discussion

Though temporal patterns of *SAR*s and estimated T:M ratios varied considerably across years, across tagging groups, and between release locations (Figures A1-A42 and Figures B1-B42), a few general summary statements are possible. In analyses of LGR data, *SAR*s were generally greater for fish tagged above the dam than for those tagged at the dam. From both LGR and LGO, *SAR*s typically decreased throughout the season for both transported and migrant fish for both species.

Curves for estimated T:M ratios were quite variable and included periods both significantly below and significantly above the standards. However, for the majority of the time, estimated T:M ratios were above the standards for all groups (light and dark green areas in Figures 2-9). The few periods when estimated T:M ratios were significantly below the standards were early in migration seasons, with a few notable exceptions. For wild steelhead, estimated T:M ratios almost always significantly exceeded the standards.

It is difficult to determine at this point whether altered spill operations and the return of all fish to the river during the early part of the migration during 2006-2008 have resulted in changes to T:M ratios compared to earlier years. Estimated T:M ratios for some groups at LGR were apparently lower, at least early in the season (e.g., hatchery steelhead and hatchery Chinook 2006, wild Chinook 2006, and hatchery Chinook in 2008), though some of these analyses are based on incomplete adult returns. Results from LGO did not indicate that results changed from previous years. Although, here, we had no data early in the season as all fish were bypassed and none put into barges.

The re-analysis of past data to evaluate within-year temporal patterns in estimated T:M ratios provided comparisons to the original 1:1 standard and to a higher standard reflecting the expected return of the overall population of fish (including fish never detected). The results indicated that transported fish had significantly higher rates of return compared to migrant fish over the majority of most of the outmigrations. These results essentially corroborate results produced by COMPASS modeling, the outputs from which formed much of the basis for the 2008 BiOp. In our re-analysis, most cases when transported fish had lower return rates than migrants occurred in the early part of the migration season.

The ISAB (2008) review of transport also noted the seasonal variation in the effects of transport and that relative benefits of transport varied with species, time of year, flow conditions, and the absolute and relative number of migrant smolts. They evaluated the seasonal effects of transport using un-weighted medians of T:M ratios, with second and third quartiles to represent the middle 50% of the T:M ratios. They found that hatchery and wild Chinook salmon and hatchery and wild steelhead benefited from transport between May 7 and May 20. Further, they found that as spill increased, survival of migrant steelhead also increased. Additionally, they recognized that structural and operational improvement for fish passage at Snake and Columbia River dams made in 2006 and 2007 increased survival of spring/summer Chinook salmon, steelhead, and sockeye salmon migrants to Bonneville Dam, but were uncertain of how this would change relative *SAR*s of transported and migrant fish without seeing the adult returns. The ISAB was also concerned about the effects of increased straying caused by transport.

The summary of estimated T:M ratios presented in Figures 2-9 indicate when significant differences existed between *SARs* of transported and migrant fish, but not the magnitude of the differences. Appendix Figures A1-A42 and B1-B42 show the extent of differences based on estimated T:M ratios. For the period 2006-2008 under the new management strategy to return some of the unmarked population to the river when collected at Snake River dams, during periods when estimated T:M ratios were lower than the standard, the estimates are generally within 60-85% of the standard. On-the-other hand, when estimated T:M ratios were significantly greater than the standard, sometime the estimates were 2-5 times higher than the standard and often the higher ratios occurred closer to the peaks in fish passage (based on passage index), particularly for wild steelhead. The decision to transport or not, and operations that lead to greater or lesser proportions of the population passing through bypass systems at dams can significantly affect the total number of adults that will return in future years. We did not attempt to estimate potential changes in relative adult abundance based on different possible management strategies.

The analyses of recent migration years presented here, based on complete (migration years 2006) or partial (2007-2008) adult returns for wild and hatchery Chinook salmon and complete (2006) and partial (2007) adult returns for wild steelhead did not indicate radical departures of the patterns in temporal T:M ratios compared to earlier years, when all collected, non-tagged fish were transported throughout the migration season. On the other hand, T:M ratios of hatchery steelhead may have changed – the only instances in the eleven years of data of significantly lower returns for transported hatchery steelhead occurred in the early parts of the 2006 and 2007 migration seasons.

The data used in these analyses were not originally collected with the intent of analyzing temporal T:M ratios. Thus, sample sizes during some periods within years were too small to estimate either *SAR*s of transported fish, migrant fish, or both. As a consequence, on the tails of the outmigration we often could not estimate T:M ratios. Further, in some cases the confidence bounds were very broad around the weekly *SAR* estimates and around the outputs from the Poisson models. Thus, information pertaining to the tails of the outmigration remains uncertain; however, during the period of peak passage of fish (in general middle 25-75% of passage) the weekly *SAR* estimates typically had tighter confidence bounds, and the modeled ratios provide a reasonable estimate of differences in return rates between transported and migrant fish.

All of the data on *SAR*s came from fish that were PIT-tagged as juveniles, and provide a sound basis to compare relative rates of return of transported and migrant fish. However, we caution that the absolute return rate for any segment of the unmarked population (whether transported fish or downstream migrants) was likely substantially higher, based on analyses showing that PIT-tagged fish return at rates lower than the unmarked population (Knudsen et al. 2009; Williams et al. 2005).

We had complete adult returns for migration years 1998 through 2006, but only partial returns for 2007 and 2008. These two years had the most radical departure from earlier management strategies of transporting all unmarked collected fish from the beginning of the migration season. The 2007 outmigration year had quite low flow (not much higher than 2001), but with a high percentage of spill. Data from the 2008 and 2009 outmigration years will determine if the recent trend in hatchery steelhead T:M ratio holds, especially considering that PIT-tag detections of adult hatchery steelhead that migrated in 2008 already are nearly 4-times higher than the total adult returns for hatchery fish from all of the preceding years combined.

For Chinook salmon, the 2008 outmigration year produced a very large return of jacks in 2009. To determine the utility of using jacks as an indication of T:M ratio for the entire cohort, we compared the modeled T:M ratios for earlier outmigration years using data solely from jacks to models based on complete returns data. Although the jack models had wider confidence bounds, the shape of the curves were similar to those with complete returns (This analysis is available upon request). Thus, we feel the Chinook salmon jack returns in 2009 provided a reasonable expectation of the T:M ratio we will obtain for the 2008 outmigration once we have complete returns.

The T:M ratios and models that we derived were based on available data. Only limited experimental tests designed to evaluate the new management strategy employed beginning in 2007 were implemented (relatively small numbers of wild Chinook salmon and wild steelhead were tagged and barged prior to the start of general transport at LGR). Thus, in most cases we have little to no data on transported fish prior to 1 May at LGR and prior to 8 May at LGO, thus we have no way to determine if a transport or migration strategy would have returned more fish in the early part of the season. To fully assess effects of the new management strategy will require putting some PIT-tagged fish into barges prior to 1 May. Although we can mark fish at LGR and put them into barges prior to 1 May, some concerns have been expressed that marking fish at LGR may affect relative adult return rates. We are currently not PIT tagging any fish at LGO. To determine the overall shape of T:M curves under the new management strategy earlier in the season will require a better experimental design to determine exactly how the temporal trends in T:M ratio relate to the 1:1 or adjusted-baseline standards and will require marked fish in barges early in the season.

Finally, the data presented here do not provide a complete basis for determining when to transport and when not. We direct readers to the Independent Scientific Advisory Board Report on transportation for more details about this subject (ISAB (Independent Scientific Advisory Board) 2008).

References

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