INDEPENDENT SCIENTIFIC ADVISORY BOARD

SNAKE RIVER SPILL-TRANSPORT REVIEW

A scientific review of seasonal variation in the benefit of transportation of smolts from four Snake River Evolutionary Significant Units (spring/summer Chinook, steelhead, sockeye, and fall Chinook)

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ISAB 2008-5

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ISAB Snake River Spill-Transport Review

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Executive Summary

At NOAA Fisheries' March 28, 2008 request, the ISAB conducted this scientific review of seasonal variation in the benefit of transportation of smolts from four Snake River Evolutionary Significant Units (spring/summer Chinook, steelhead, sockeye, and fall Chinook). NOAA Fisheries' request included several questions, and in April 2008 the Columbia River Inter-Tribal Fish Commission (CRITFC) and the Oregon Department of Fish and Wildlife (ODFW) raised some additional questions. The three sets of questions had substantial overlap, and some questions were more related to policy and hence not appropriate for scientific review. Accordingly, the ISAB combined and condensed the three sets of questions into the five general questions presented below.

Structural and operational changes to the hydrosystem in 2006 and 2007 are not yet fully reflected in the data available for review in this report. Moreover, very few data are available to assess the impact of alternative spill-transport operations on species such as sockeye, coho salmon, and Pacific lamprey. Even the more plentiful data for Snake River spring/summer Chinook and steelhead do not yield unequivocal results about seasonal variation in the effectiveness of smolt transport. Given the magnitude of uncertainty imposed by the nature and extent of available information, the ISAB continues to see merit in a strategy of "spreading the risk" to balance the possible risks against the perceived benefits of juvenile salmonid transportation.

Question 1. Based on available data and analyses, what is the relative benefit of transportation versus in-river migration during April and May, in terms of smolt-to-adult return rates, fish travel time, and survival rates to below Bonneville dam for spring/summer Chinook and steelhead? Does the relative benefit of transportation vary during April and May?

ISAB Response 1. The timing and relative benefits of transportation versus in-river migration vary with species, time of year, flow conditions, and the absolute and relative abundances of transported and in-river fish. Most existing data show that transportation in the late-April through May migration season benefits hatchery and wild Chinook, as well as hatchery and wild steelhead. However, the magnitude of the benefits in smolt-to-adult return ratios (SARs), fish travel times, and survival rates vary substantially among species, within the migration season, and between years. Data are insufficient to determine whether transportation benefits or harms Snake River sockeye.

Question 2. Based on the data and analyses presented, is there evidence that the new FCRPS Biological Opinion's Reasonable and Prudent alternative action to terminate voluntary spill from May 7 to May 20 is better for spring/summer Chinook and steelhead than continuing spill throughout May?

ISAB Response 2. Some analyses of data presented here and elsewhere indicate that transportation between May 7 and May 20 benefits hatchery and wild Chinook, as well as hatchery and wild steelhead. If transportation during this migration period is beneficial, then it could be argued that increasing transportation by terminating spill during this time would be even more beneficial. However, other analyses presented here and elsewhere indicate that as spill increases, in-river survival increases and the relative benefit of transportation decreases. Increased spill may also benefit sockeye and lamprey, but definitive data are lacking. Further, terminating spill would eliminate the possibility of learning about the effect of partial spill during this critical period, thereby reducing opportunities for improved decision-making in the future.

Question 3. Based on available data, is there evidence that results from recent years (2006, 2007) are different for spring/summer Chinook and steelhead? [e.g., different in travel time, downstream survival]

ISAB Response 3. Preliminary results suggest that recent structural and operational changes have improved the survival of in-river migrating spring/summer Chinook, steelhead, and sockeye, but a more complete answer to this question must await return of surviving adults and the calculation of SARs.

Question 4. What are the possible impacts of alternative spill-transport scenarios on other native species, in general, and on Pacific lamprey and Snake River sockeye, in particular?

ISAB Response 4. The impacts of alternative spill-transport scenarios on native species are expected to vary greatly, and careful consideration of several viewpoints, including impact on many populations, groups of species, ecological processes and habitats, is advised. Unfortunately, the limited data impede quantitative analyses of alternative scenarios.

For example, the magnitude of the impact of spill-transport scenarios on Pacific lamprey is unknown, due to a paucity of data. Evidence exists that juvenile lamprey are killed during downstream migration through the hydrosystem by impingement on bar screens, but the magnitude of this mortality is unknown. There is some evidence that bar screens could be designed to reduce mortality due to impingement. However, dams also impede the upstream migration of adult lampreys, and that modifications to improve upstream passage may do more to improve the viability of lamprey populations than modifications to bar screens.

As another example, evaluation of the effect of transportation on Snake River sockeye has not been possible due to insufficient data. Sockeye salmon smolts are thought to be more susceptible than other species to descaling in bypass systems, which suggests that increased spill might reduce harm. However, data are not adequate to compare descaling rates between smolts that are spilled rather than bypassed and transported, and little is known about the risk of mortality from partial descaling in sockeye.

Question 5. What are the ecological/evolutionary issues related to transportation and spill operations? What factors should be considered in defining what is meant by "optimal" when considering spill and transport?

ISAB Response 5. Transportation influences the success of in-river fish. Increasing the proportion of in-river migrants increases the density of smolts in the river. As smolt density increases, the proportion killed by predators will likely decrease because mortality due to predation appears to be depensatory (based both on theoretical expectations and limited empirical evidence). Increasing spill percentage could increase the number of in-river migrants and temporarily buffer all potential prey species inhabiting the river from predation risk. If such depensation occurs, the relative benefit of transportation could decrease as spill percentage increases. It seems that this potential benefit of spill has not yet been considered in comparing alternative spill-transport scenarios.

In-river migration likely entails lower risk of epizootics (i.e., local disease outbreaks that can rapidly affect many animals) due to pathogens or parasites, whereas crowded conditions in the barges increase this risk.

Barging may increase the incidence of straying, at least for steelhead. Increased numbers of strays due to barging could have deleterious fitness consequences for other wild populations, especially those at low abundance.

Implementation of a particular spill-transport regime year after year tends to homogenize environmental conditions experienced by fish and likely has evolutionary implications for subsequent downstream migratory behavior, such as migration timing or swimming depth in the water column.

ISAB Recommendations:

1. Spill-transport decisions require a multi-species perspective that considers differing seasonal effects for all species of interest. A recommendation from ISAB Report 1992-2 remains relevant: "Spreading the risk of negative outcomes among alternative routes of hydroelectric passage is advisable to prevent a recovery action that is designed to improve survival of one listed species from becoming a factor in the decline of another species." The ISAB believes that, whenever river conditions allow during the late April-May period, a strategy allowing for concurrent transportation and spill is prudent.

2. Spill-transport operations like those of 2006 and 2007 should be continued long enough to determine how much influence such operational changes have on downriver migration and total adult returns. Continuing recent spill-transport operations is advised to improve future evaluations of the trade-offs associated with spill and transport decisions.

3. Studies should be conducted to reduce critical uncertainties related to the impact of spill-bypass-transport operations on downstream juvenile lamprey migration, including estimation of the population; evaluation of the effect of bar screen design on mortality and migration route; and estimation of mortality rates due to route of hydrosystem passage. Furthermore, the hydrosystem's impact on the entire life cycle of Pacific lamprey should be thoroughly investigated in a timely manner.

4. Further study is needed to define rates of mortality of sockeye smolts caused by partial descaling and injury for the various routes of passage through the hydrosystem during the peak migration period (mid-May to mid-June). The ISAB realizes that quantifying dam passage survival studies of the limited number of endangered Snake River sockeye smolts is problematic. Alternatives should be considered to supplement the limited data on Snake River sockeye; for instance, conducting passage and survival studies on Upper Columbia River sockeye passing lower Columbia River dams could provide valuable insights.

5. Evaluations of spill-transport operations should include studies designed to reduce uncertainties about relative amounts of straying for transported versus in-river fish for both hatchery and wild stocks of Snake River steelhead and spring Chinook. Another recommendation from ISAB Report 1992-2 is germane: "Spreading the risk of negative outcomes among alternative routes of hydroelectric passage is advisable in the face of uncertainties associated with potential negative effects of transportation on genetic and life history diversity."

6. Finally, the perspective on spill included in ISAB Report 1999-4 deserves special recommendation in this report: "Spill: The general principle is that all juvenile passage alternatives should be evaluated against the baseline of spill. As an avenue of hydroelectric project passage, spill more closely mimics natural situations and ecological processes than other available routes. Spill should be considered as an alternative when the improvements anticipated from other bypass technologies are not large enough to meet the passage goals." That is to say, spill should be considered the default recommendation rather than simply one of the alternatives.

I. Assignment Background

On March 24, 2008, the ISAB received an assignment from Dr. Usha Varanasi, NOAA's Science and Research Director, to provide a scientific review of seasonal transportation benefit. Dr Varanasi requested that the ISAB address several questions (presented below) related to the "relative survival benefit of alternative Lower Snake River spill and transport operations." The ISAB was subsequently provided with additional questions and analyses for consideration by Ed Bowles, ODFW Fish Division Administrator and by CRITFC in an April 22, 2008 memo entitled "CRITFC Questions to the ISAB: Review of Lower Snake River Spill and Transport Operations." The questions posed by CRITFC and ODFW, also presented below, reiterated the need to address some NOAA questions but also expanded the potential scope of the ISAB review with other concerns. The ISAB response is framed in the context of questions that the ISAB synthesized from those posed by these three entities.

To inform the ISAB's review, representatives from NOAA, ODFW and CRITFC provided presentations and verbal responses to questions to the ISAB in Portland on May 2, 2008. More details are provided in the appendix.

II. Questions from NOAA, ODFW, and CRITFC

Not all of the questions initially posed by NOAA, ODFW, and CRITFC are explicitly addressed in this response. The original questions are reproduced here to provide context for the questions ultimately addressed in subsequent sections of our review.

NOAA (Request for review of seasonal transport benefit, March 24, 2008)

1. What is the relative benefit in terms of smolt-to-adult return rates, if any, of transportation versus in-river migration during April and May for each of the four ESUs mentioned above? [*sic*, Snake River spring/summer Chinook, Snake River steelhead, Snake River sockeye, Snake River fall Chinook] If the transportation benefits (relative to in-river migration) for a given ESU vary during the month [season], please describe the nature of the within season variation.

2. What is the likelihood that the new FCRPS Biological Opinion's Reasonable and Prudent Alternative action, which calls for termination of voluntary spill from May 7 to May 20 when average May flows are expected to be greater than 65 kcfs, would return more adult Snake River spring/summer Chinook, Snake River steelhead, Snake River sockeye, and Snake River fall Chinook than an alternative that continues voluntary spill from May 7-20? [*sic,* The alternative that continues voluntary spill would reduce the proportion of fish collected and transported at Snake River collector projects from May 7-20.]

3. Is there any other operational alternative for using a combination of spill and transportation at the Lower Snake River collector dams during April and May that is likely to provide significantly more adults from these four ESUs, other than the alternative described in (2) above? Stated another way, what combination of transportation and spill operations would likely optimize return rates for the various ESUs?

ODFW (Additional questions and analyses, April 21, 2008)

1. Is there evidence that the RPA action could result in increased fish travel time and/or reduced in-river survival rates of juvenile yearling Chinook, steelhead, sockeye, or subyearling Chinook compared to a spill operation under the same flow? Is there evidence that maximizing transportation under the RPA action could increase straying rates into other systems and therefore hinder recovery of other ESUs?

2. The Region has invested considerable resources and implemented numerous actions in recent years in an attempt to improve mainstem conditions for in-river-migrating salmonids. However, transportation evaluations primarily rely on data collected prior to migration year 2004 that do not incorporate the effects of recent efforts to improve mainstem conditions for in-river-migrating salmonids. Is it possible that transport-to-in-river survival ratios (TIR) under current or recent conditions may differ from those under past conditions? Has there been any rigorous evaluation of transportation benefits under in-river migration conditions comparable to those in recent years?

3. Is there evidence that fish collected, tagged, and bypassed at the collector dams may have lower smolt-to-adult return rates (SARs) than fish that pass the collector dams undetected (i.e., through spill and turbines)? If so, might these differences tend to increase the NOAA Fisheries estimates of annual and seasonal TIRs?

4. There are several examples where TIRs for wild steelhead and yearling Chinook have been low when in-river survival rates were relatively high. Is it possible that TIRs may similarly be low for migration years 2006 or 2007, when in-river survival rates were relatively high?

CRITFC (Review of Snake River spill and transport operations, April 22, 2008)

1. Considering available existing smolt-to-adult return rates and in-river survival data for juveniles that migrated in recent years under court-ordered spill operations, what is the relative benefit in terms of smolt-to-adult return rates, if any, of transportation versus in-river migration during April and May for each of the four ESUs mentioned above? Is there sufficient transport and in-river survival data for Snake River sockeye and fall Chinook for the ISAB to make a judgment for those ESUs? If the transportation benefits (relative to in-river migration) for a

given ESU vary during the month or season please describe the nature of the within-season variation, including the confidence intervals or measures of error around those estimates.

2. What is the likelihood that the new FCRPS Biological Opinion's RPA, which calls for termination of voluntary spill from May 7 to May 20 when average May flows are expected to be greater than 65 kcfs, would return more adult Snake River spring/summer Chinook, Snake River steelhead, Snake River sockeye, and Snake River fall Chinook than an alternative that continues voluntary spill from May 7-20 (and which would therefore substantially reduce the proportion of fish collected and transported at Snake River collector projects)? A related question for the ISAB: Is 65 kcfs the appropriate flow trigger for the May transport operation, or does the data support a different flow trigger, or any flow trigger?

3. Is there any other operational alternative for using a combination of spill and transportation at the Lower Snake River collector dams during April and May that is likely to provide significantly more adults from these four ESUs, other than the alternatives described in (2) above? Stated another way, what combination of transportation and spill operations would likely optimize adult return rates for the various ESUs?

4. What are the possible impacts to the small remaining populations of Pacific lamprey in the Snake River and Upper Columbia with the continuation of the use of screen bypass systems and transportation and the reduction of spill and surface bypass? Will the continued use of these systems increase the probability of extirpation of Pacific lamprey in these areas?

5. Given:

- That transportation has been the primary mitigation action in place since the late 1970's while stocks have continued to decline and have been ESA listed;
- That recent data shows transport in-river ratios for wild spring Chinook are equal or favor in-river migration;
- That the NOAA hypothesis that transportation collection system is size selective for smaller fish;
- That recent SARs indicate that transport SARs of wild fish are lower than SARs for hatchery fish;
- Recent studies have shown that disease transmission occurs in the barge and is a serious problem for unaffected fish;
- and, that wild fish are smaller than hatchery fish;

could the transportation program be a limiting factor and cause of decline?

6. Given that before court-ordered spill, transport TIRs appear beneficial for steelhead because in-river survival for steelhead is lower than that for Chinook, would the recent improvements documented for in-river steelhead juvenile

survival under court ordered spill change the steelhead SAR to be more like that of spring Chinook – that is to say, not be beneficial?

III. Scope of ISAB Review

The ISAB is specifically charged with reviewing existing research data and analyses related to the relative survival benefit of alternative Lower Snake River spill and transport operations in April and May, addressing the questions provided by NOAA and the other entities.

The amount of spill at each collector project (Lower Granite, Little Goose, and Lower Monumental Dams) influences the number of fish that can be collected in the bypass system and transported. As spill increases, more juveniles pass the dams over the spillways and fewer fish are collected and transported. A key point of debate is how changes in spill and transportation can influence SARs for in-river migrants and fish that are barged to below Bonneville Dam. SARs are viewed as critical metrics in the evaluation of spill and transport, so it is essential that other factors that may influence SARs, such as density dependent mortality from predation, be considered. In addition to a comparison of SARs for transported versus in-river migrants, fish travel time and survival rates to below Bonneville also are of interest. The unresolved problem of delayed estuary and ocean mortality also must be considered. Finally, the ISAB has been asked to consider the impact of alternative spring spill-transport protocols on the following species and populations:

- Snake River spring/summer Chinook
- Snake River steelhead
- Snake River sockeye
- Snake River fall Chinook
- Pacific lamprey

IV. Response to Questions

The questions, information, and perspectives provided by NOAA, CRITFC, and ODFW inform the scope of this ISAB review. These have been restated for simplicity as the five questions listed below. Note that the ISAB has chosen not to respond directly to some of the original questions. Specifically, the influence of spring spill and transport on Snake River fall Chinook is not considered in this review because peak migration of this species occurs later in the season. Also, the request that the ISAB identify a specific combination of transportation and spill operations that is likely to provide significantly more adult returns for the various ESUs requires much more time for analysis than we had, and would require at least several more years of adult return data, due to the uncertainties in existing data. Moreover, identification of an optimal spill-transport strategy for all species involves policy decisions concerning tradeoffs among species and is beyond the scope of the ISAB assignment.

Question 1. Based on available data and analyses, what is the relative benefit of transportation versus in-river migration during April and May, in terms of smolt-to-adult return rates, fish travel time, and survival rates to below Bonneville Dam for **Snake River** ***spring/summer Chinook and steelhead? Does the relative benefit of transportation vary during April and May?***

The relative benefits of transportation versus in-river migration vary with species, time of year, and flow conditions. As noted in the ISAB and Independent Scientific Review Panel's review of the Comparative Survival Studies' (CSS) 10-year retrospective review (ISAB/ISRP 2007-6), "conclusions that transportation provided, or did not provide, benefit to a species or wild/hatchery group requires qualification with the possibility of selection bias of fish for transportation due to size, condition, location in the water column, etc." In addition, it is clear from available data that transportation benefits vary annually and seasonally and also depend on species and whether fish originate in a hatchery or in the wild. Therefore, general conclusions about the relative benefit of transportation versus in-river migration, aggregated on a yearly basis, will need to be modified for particular species, and for hatchery and wild groups, season, flow conditions, and life history.

For example, the CSS 10-year retrospective report suggests that the SAR net benefit of transportation decreases in the order hatchery and wild Steelhead > hatchery Chinook > wild Chinook, with wild Chinook showing no consistent evidence of any net benefit. Those conclusions were based on yearly aggregate data, and while they are correct for an aggregate yearly timeframe, the data were not separated by season and flow conditions, and the outcomes would be expected to depend on season and flow conditions.

Fish travel time from Lower Granite to below Bonneville Dam is considerably less for transported fish (approximately two days) than for in-river migrants (between 8 and 30 days), regardless of species, season, or flow conditions. It follows that both the reduction in travel time and the benefits of decreased travel time due to transportation depend on species, season, and flow conditions.

Data are available to estimate within season variation in smolt-to-adult return rates (SAR_T or SAR_M),[1] fish travel time (FTT), and survival rates (S_T or S_M) for transportation and in-river migration. However, there are several possibilities for selecting data that result in different estimates of the parameters of interest. The overall difference in the smolt-to-adult return rates between transported and in-river migrant fish that survived to pass Bonneville Dam has been summarized as a T:M ratio (SAR_T / SAR_M). A T:M ratio of less than 1.0 indicates that smolts that were transported by barge to below Bonneville Dam subsequently died at a higher rate than smolts that survived the in-river migration to

[1] "T" represents transported fish. "M" represents in-river migrants.

below Bonneville Dam.. Not surprisingly, the T:M ratios also vary with species, season, and flow conditions.

Alternative methods for analyzing each data set could reveal differing views of the seasonal variation in the relative benefits of transportation versus in-river migration. The remainder of this section provides a summary of some results from alternative methods and points to other analyses that may help to clarify how relative benefits of transportation vary seasonally. These alternative analyses are presented to illustrate how different analytic approaches may provide alternative views of spill-transport issues. We do not assert that the methodology presented here is the best. It is worth noting again that conclusions about the effect of seasonal variation on estimated SARs, fish travel times, and survival rates will depend on species, hatchery/wild proportion and flow conditions.

NOAA analyzed data for hatchery and wild Chinook and hatchery and wild steelhead for selected years between 1997 and 2006 for which sufficient data were available (NOAA materials for spill transport review were provided on April 8, 2008). For the transport group, only fish transported from Lower Granite Dam were used. The migrant group included fish that were detected or tagged at Lower Granite Dam, returned to the river and not subsequently transported from a downstream dam. The migrant group also included fish that were detected and returned to the river at downstream dams.

For weeks in which more than 200 juveniles were released, the numbers of PIT-tagged juveniles arriving at Lower Granite Dam each day in the transport and the migrant categories were summed. The subsequent numbers of returning adults detected at Lower Granite Dam for each weekly juvenile cohort were summed and separate SAR values were calculated for the transported and in-river cohorts.

For hatchery Chinook salmon, the analyses focused on smolts tagged upstream of and detected at Lower Granite Dam, because of the number of juveniles and returning adults available. However, because insufficient numbers of wild Chinook salmon and hatchery and wild steelhead were tagged upstream of Lower Granite Dam, those tagged upstream were combined with those tagged at Lower Granite Dam. The results for hatchery Chinook salmon are thus based on somewhat different data than are results for wild Chinook, wild steelhead, and hatchery steelhead. Furthermore, based on results for steelhead (Schaller et al. 2007), the relative benefit of transportation from Lower Granite Dam, the first dam encountered in the hydrosystem, may not represent benefits from Little Goose and Lower Monumental dams. However, the Schaller et al. (2007) results only address the full migration season, rather than being partitioned within season.

NOAA scientists concluded that for hatchery spring-summer Chinook salmon tagged upstream of Lower Granite Dam, the transport-to-migrant (in-river) SAR ratios (T:M) were generally lowest early in the migratory season, with a peak during the middle of May, followed by a decline. This interpretation is supported by a graphical summary of geometric means of T:M across years, weighted by the number of juveniles released, with year 2001 omitted (NOAA materials for spill transport review provided April 8, 2008). There was very little spill (and very little in-river migration downstream) in 2001, and the few fish that did return upriver were almost all from the transported cohort.

There are other representations that may be chosen to show different features in the data. As one example, an alternative view of the data (Figure 1) shows the unweighted medians of T:M across years, along with first and third quartiles, to provide an indication of the variation in the seasonal ratios across years. Note that although medians and quartiles are robust statistics, these results are based on limited data. The first and third quartiles provide information on where the middle 50% of the yearly T:M ratios would fall. Year 2001 is not included in the calculation of the medians and quartiles presented in the figures below because so few fish migrated in-river, and because extremely low flows necessitated maximum transportation, resulting in insufficient data to estimate SAR_M.

The relative benefit of transportation for hatchery Chinook varies but generally increases across the season (Figure 1). The quartile lines also show that there is much variation across years in the T:M ratio. The position of the first quartile line indicates that the estimated ratio is above 1 after April 23 in at least 75% of the years considered here. This suggests that, based on the data provided by NOAA, transportation is beneficial for hatchery Chinook in late April and May in most years. Note that due to insufficient data the quartiles are not available for April 2.

The data for wild Chinook show a similar pattern (Figure 2) to hatchery Chinook, with an increase in the (T:M) ratio across the season and considerable variation from year to year, as indicated by the distance between the first quartile line plot and the third quartile line plot. However, the position of the estimated first quartile line suggests that transportation does not benefit wild Chinook through May in approximately 25% of the years. Alternatively, we could observe that transportation is a benefit in approximately 75% of the years.

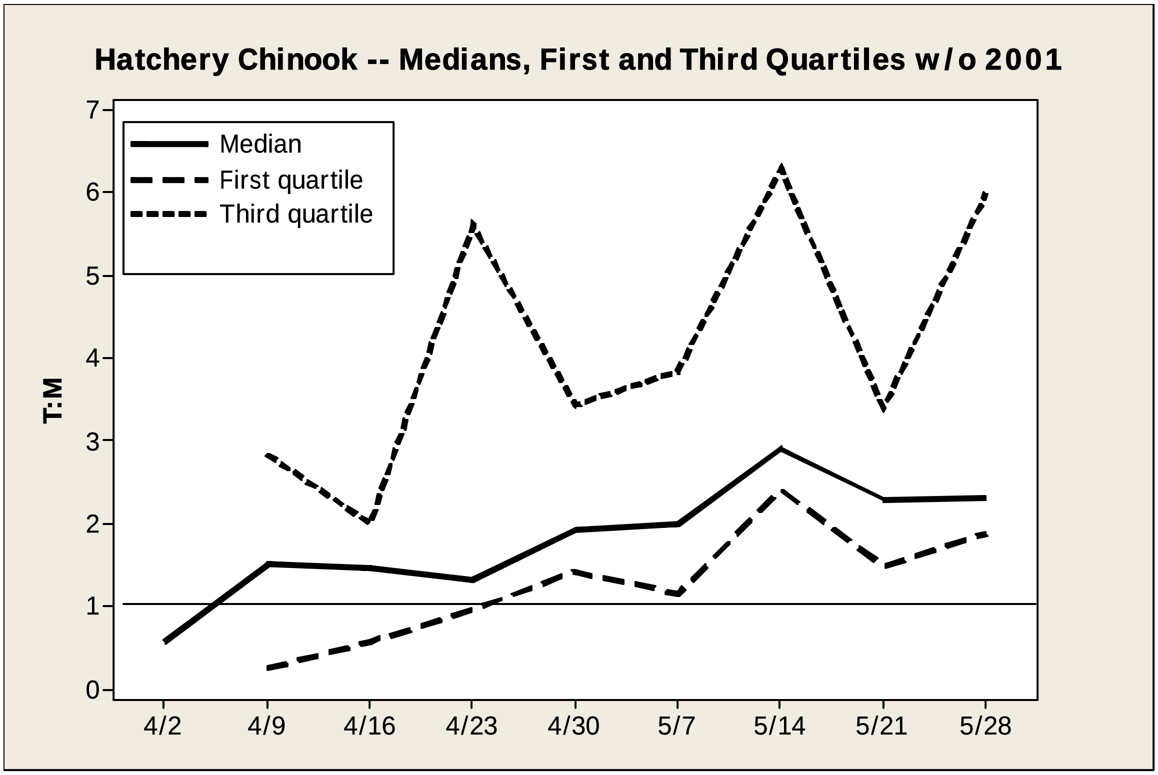

Figure 1. Unweighted medians, with first and third quartiles, of T:M ratio for hatchery spring/summer Chinook salmon (migration years 1997-2005, excluding data from 2001).

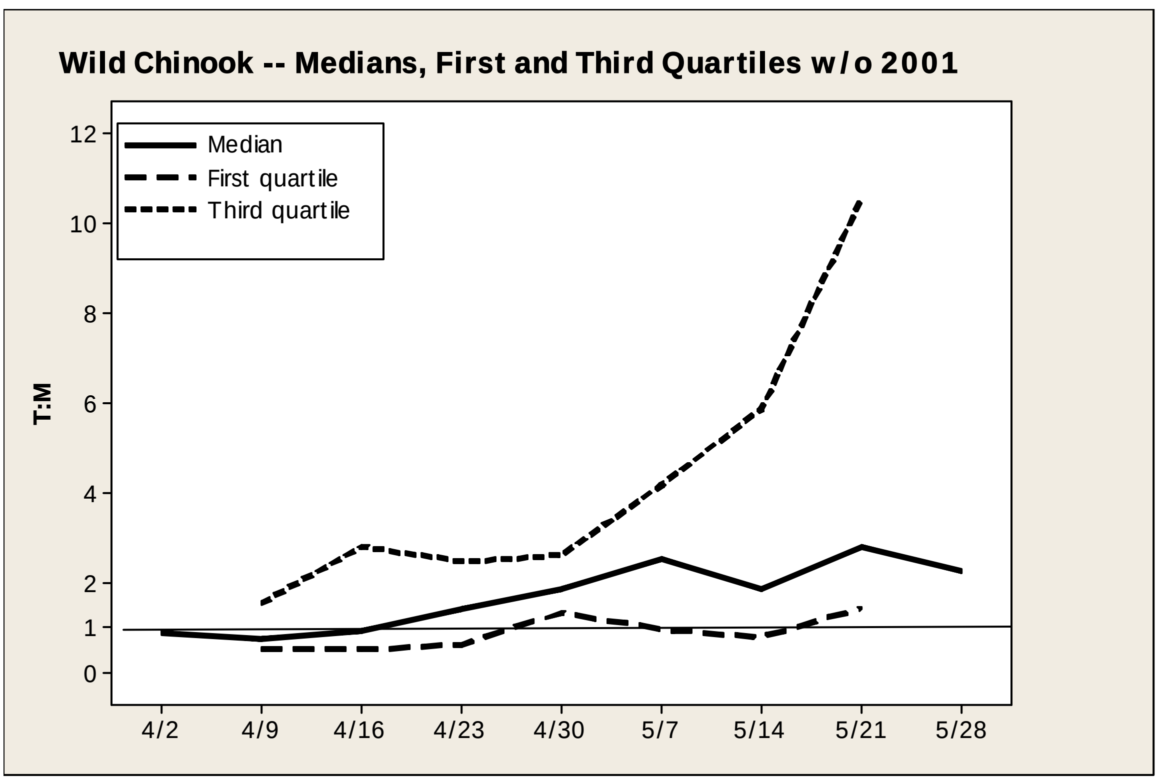

Figure 2. Unweighted medians, with first and third quartiles, of (T:M) ratio for wild spring/summer Chinook salmon (years 1998, 1999, 2002-2005).

The same general conclusion is indicated for hatchery steelhead (Figure 3). That is, there appears to be an increase in the (T**:**M) ratio over the season, but cautious interpretation is warranted, because only four years of data are represented in this figure. The position of the median line, as well as the first quartile line, suggests that transportation in late April and May benefits hatchery steelhead in at least 75% of the years. Due to insufficient data the quartiles were not computed for the first three weeks in April.

Higher variability over years in the T**:**M ratio for wild steelhead is evident from the wildly fluctuating nature of the third quartile line in Figure 4. It is not clear from Figure 4 that there is an increasing trend in the ratio over the season. The estimated first quartile line is above a T**:**M ratio of one throughout the season, indicating that transportation is beneficial to wild steelhead in more than 75% of the years represented by these data but provide little, if any, benefit in approximately 25% of the years.

The T:M ratio results presented above are based on estimation of SAR_M for fish detected or tagged at Lower Granite Dam. These fish were returned to the river at Lower Granite Dam and were not subsequently transported from a downstream dam (C_1 group discussed below in the response to Question 2). The in-river migrant group included fish detected and returned to the river at downstream dams. In-river fish detected at one or more dams have lower SARs than fish that pass the dams undetected. Therefore, fish that are used to evaluate seasonal effects of spill and transport provide an overestimate of the benefit of transportation for the undetected in-river tagged fish (C_0 group discussed below). Clearly, undetected fish cannot be used directly to evaluate seasonal effects of spill and transportation because their passage dates are unknown. It is possible to adjust for this overestimation by multiplying the T:M by a factor reflecting the discrepancy in annual SARs between detected and non-detected in-river fish. The effect of this adjustment is to delay the date at which T:M ratio exceeds 1, indicating when transportation would be beneficial to undetected fish. The adjustment factor is estimated from annual SARs and may not be the appropriate value for adjusting seasonal SARs.

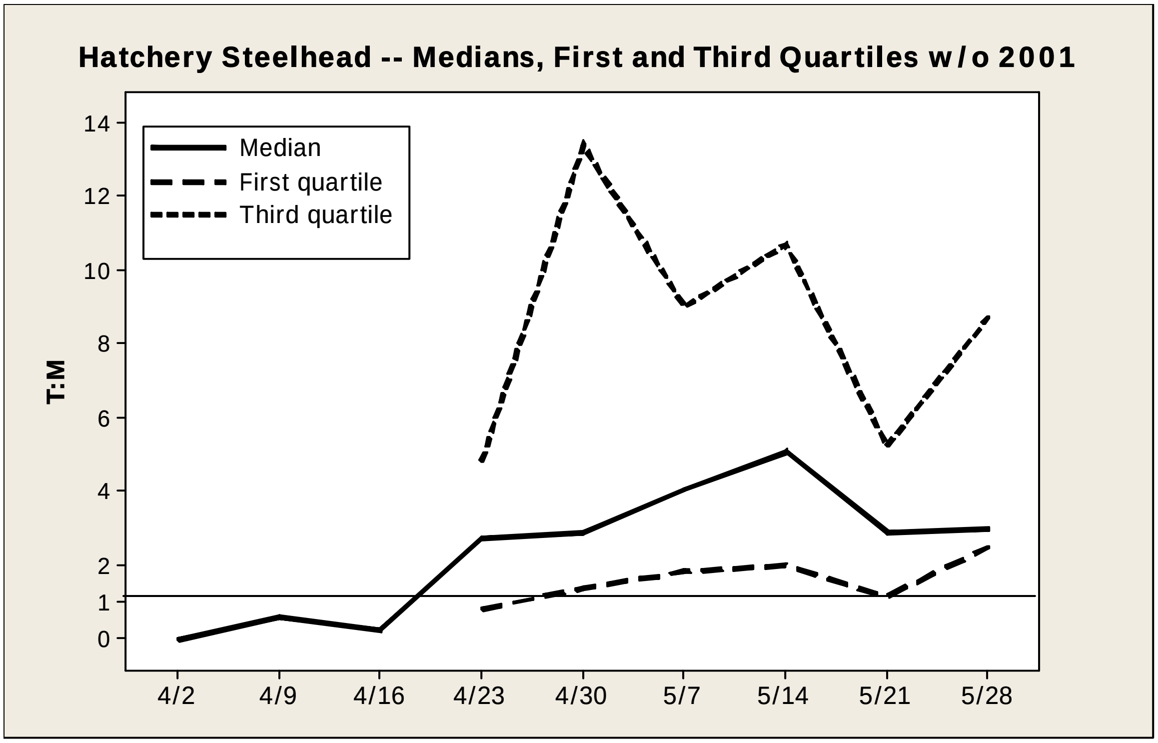

Figure 3. Unweighted medians , with first and third quartiles, of (T:M) ratio for hatchery steelhead salmon (years 1999, 2003, 2005, 2006).

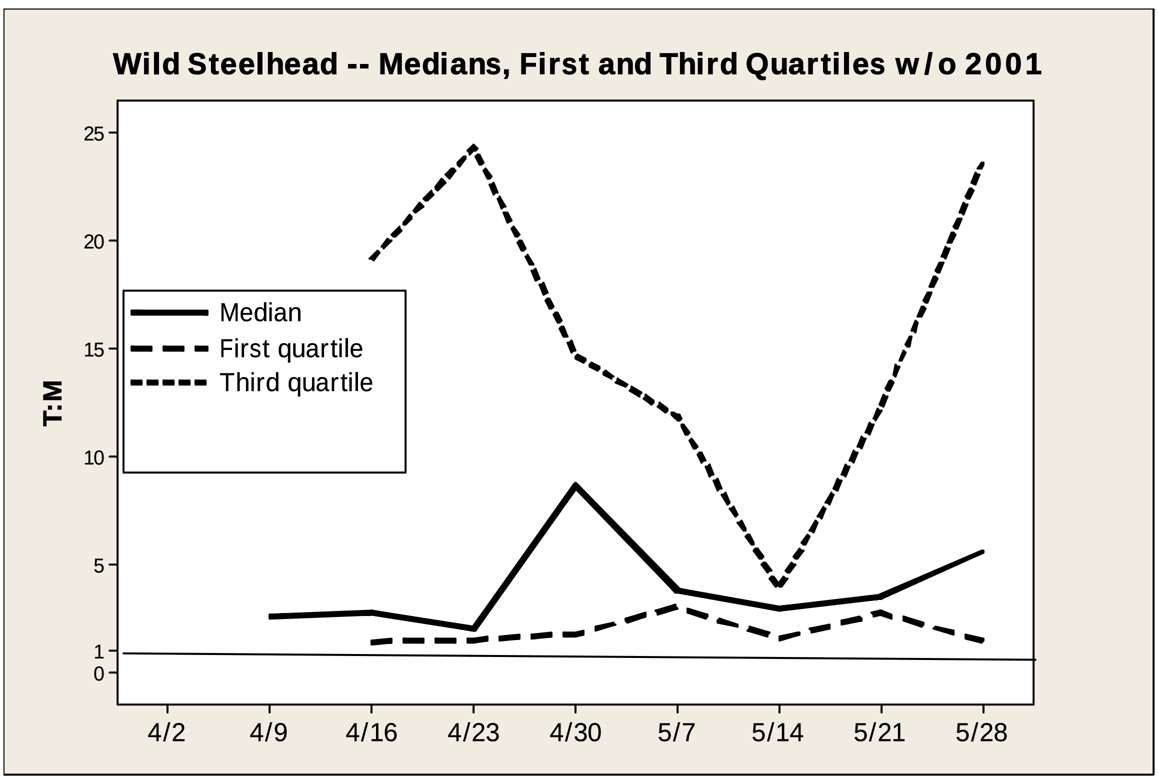

Figure 4. Unweighted medians, with first and third quartiles, of (T:M) ratio for wild steelhead salmon (years 1999, 2002-2006).

Question 2. Based on the data and analyses presented, is there evidence that the new FCRPS Biological Opinion's Reasonable and Prudent alternative action to terminate voluntary spill from May 7 to May 20 is better for Snake River spring/summer Chinook and steelhead than a continuing spill throughout May?

The new FCRPS Biological Opinion's Reasonable and Prudent alternative action (RPA) to terminate voluntary spill from May 7 to May 20 would increase the proportion of fish collected and transported at Snake River collector projects during this time period. The RPA could therefore be characterized as the maximum transport alternative from May 7 to May 20. Based on the data provided by NOAA, and the analyses of the (T:M) ratio presented in Figures 1 - 4 above, it appears that hatchery Chinook, wild Chinook, hatchery steelhead, and wild steelhead would benefit from the RPA. However, this conclusion is subject to question if other data are considered and other consequences of transportation are examined. For example, a recent analysis showed that increased average spill percentage for Lower Snake and Lower Columbia River dams was associated with increased steelhead smolt-to-adult return from Lower Granite to Lower Granite for migration years 1998 to 2005 (FPC. 2007. Data Request Memorandum 189-07. Fish Passage Center, Portland, OR. December 3, 2007). This result suggests that any decision to reduce spill should be made with caution.

Results presented to the ISAB by Charlie Petrowsky, member of the CSS Oversight Team, showed that the in-river SARs computed by NOAA are lower than the corresponding SARs computed by CSS. Similar results hold for transport SARs, but the magnitude of those differences is less. The discrepancy may be due to differences in the mix of smolts used in the estimation of SARs. The CSS group used smolts migrating through the hydrosystem that were not detected at Lower Granite (LGR), Little Goose (LGS), and Lower Monumental (LMN) transport projects, identified as the C_0 group, or smolts migrating through the hydrosystem that were collected and bypassed at one or more of the transport projects, identified as the C_1 group. NOAA used "fish detected or tagged at Lower Granite Dam and returned to the river that were not subsequently transported from a downstream dam (including fish detected and returned to the river at downstream dams)" for the migrant group and "used only fish transported from Lower Granite Dam" for the transport group (NOAA Material for Spill Transport Review April 2008). Material presented to the ISAB by NOAA on May 2, 2008, in which T:M ratios were adjusted to account for differences in survival of C_0 and C_1 groups, was in better agreement with the results obtained by CSS. The CSS results showed that benefits of transportation increase later in the migration season.

In order to further examine the influence that spill management may have on metrics of interest, weekly spill percentage data were obtained from the DART web site for river environment conditions (www.cbr.washington.edu/dart/river.html). Figures 5 through 8 below illustrate the relationships between in-river survival to Bonneville Dam and spill percentage at Lower Granite Dam for hatchery Chinook, wild Chinook, hatchery steelhead, and wild steelhead, respectively. Figures 5 and 6 show that there is very little association between in-river survival of wild and hatchery Chinook and weekly average spill percentage. Figures 7 and 8 strongly suggest that increases in spill percentage at

Lower Granite Dam are associated with increases in the in-river survival of both hatchery and wild steelhead.

A question of interest is whether the relationship of in-river survival rate to spill percentage depends on date. An analysis of the data indicted that the relationship between in-river survival and spill percentage was not significantly different, due to date. That is, the slope of the line relating in-river survival to spill percentage did not change significantly across season, showing that the positive relationship is consistent across dates (results not shown).

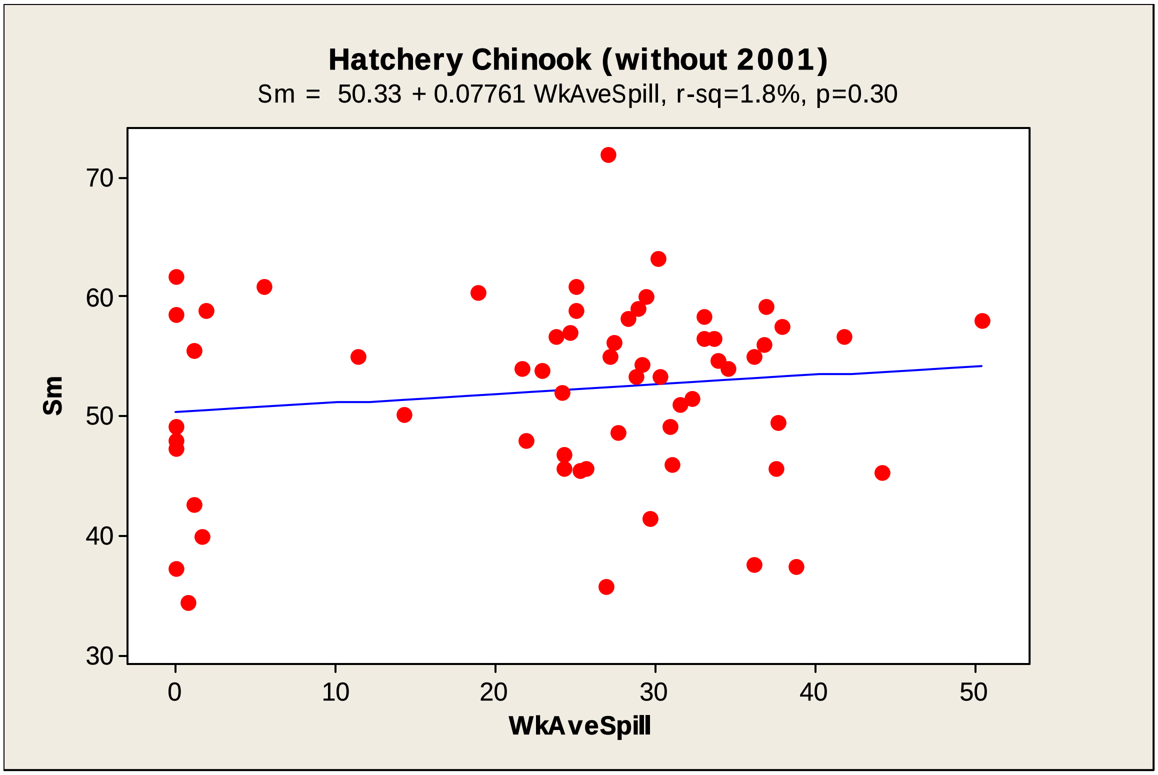

Figure 5. In-river survival, S_m, for hatchery spring/summer Chinook salmon versus spill percentage at Lower Granite Dam with regression line (years 1997-2000, 2002-2005).

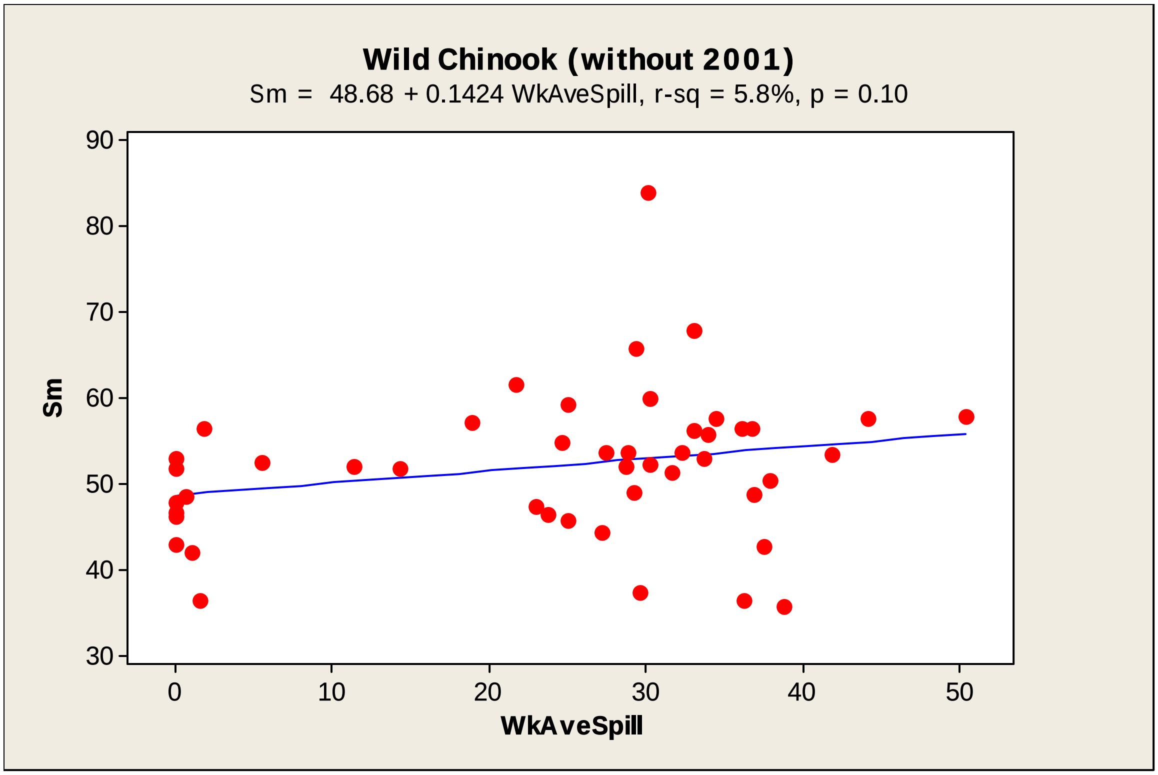

Figure 6. In-river survival, S_m, for wild spring/summer Chinook salmon versus spill percentage at Lower Granite Dam with regression line (years 1998-1999, 2002-2005).

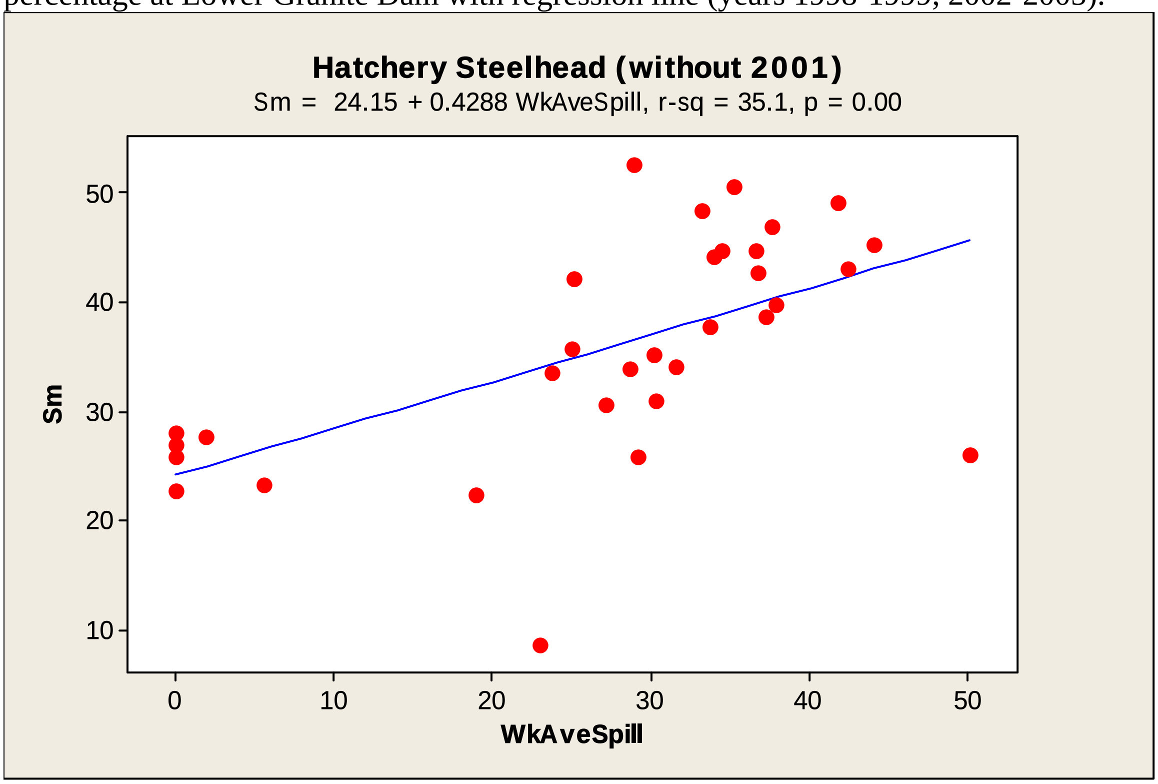

Figure 7. In-river survival, S_m, for hatchery steelhead versus spill percentage at Lower Granite Dam with regression line (years 1999, 2003, 2005, 2006).

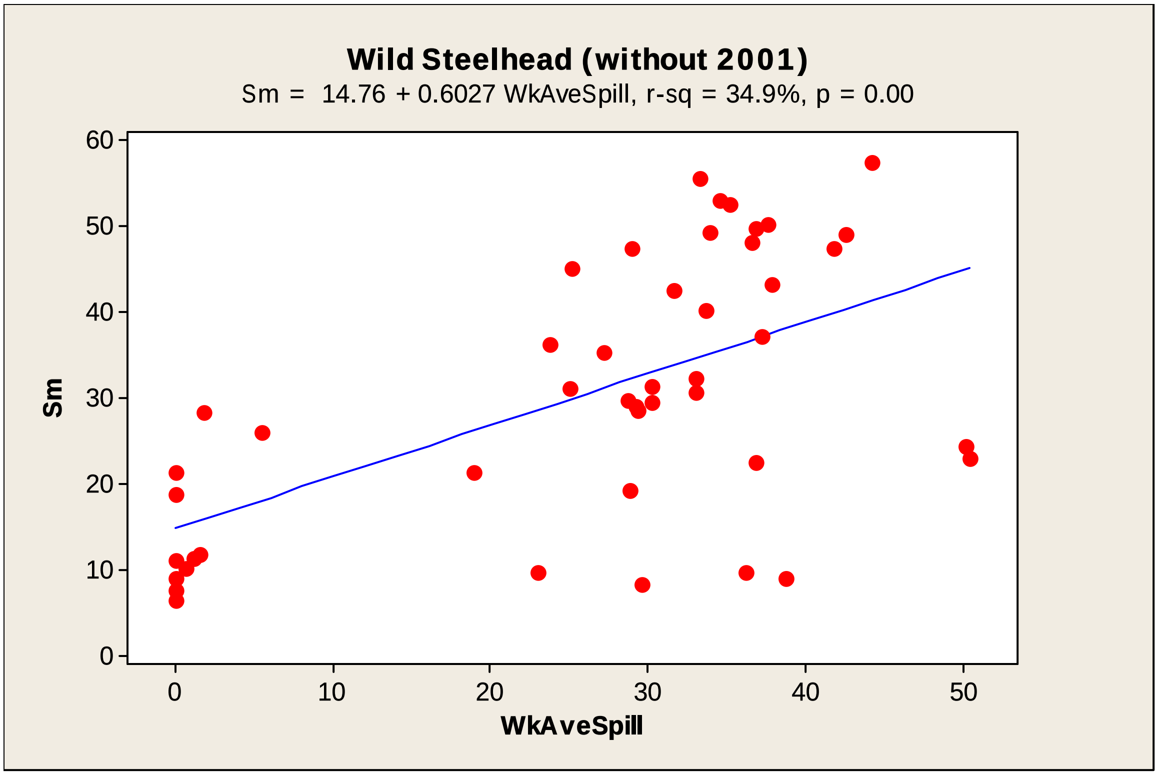

Figure 8. In-river survival, S_m, for wild steelhead versus spill percentage at Lower Granite Dam with regression line (years 1999, 2002-2006).

In addition to examining the relationship between in-river survival and spill percentage, Figures 9 - 12 examine how SARs are related to spill percentage at Lower Granite Dam. In general as spill percentage increases, SAR_T and SAR_M increase, but they do so at slightly different rates that is, the slopes of the two lines in each graph differ slightly. Hatchery steelhead (Figure 11) provide an exception, where SAR_T has a negative slope, but this phenomenon appears to be due to one influential observation having a SAR_T of 3.61 for a week (April 30) with zero percent spill. The regression line representing the T:M ratio versus spill percentage is greater than one over the range of spill percentage presented here, but there is considerable scatter in the data around these lines. The differences in slopes for SAR_T and SAR_M result in a decreasing T:M ratio as spill percentage increases in all cases presented here. That is, the benefit of transportation decreases as spill percentage increases.

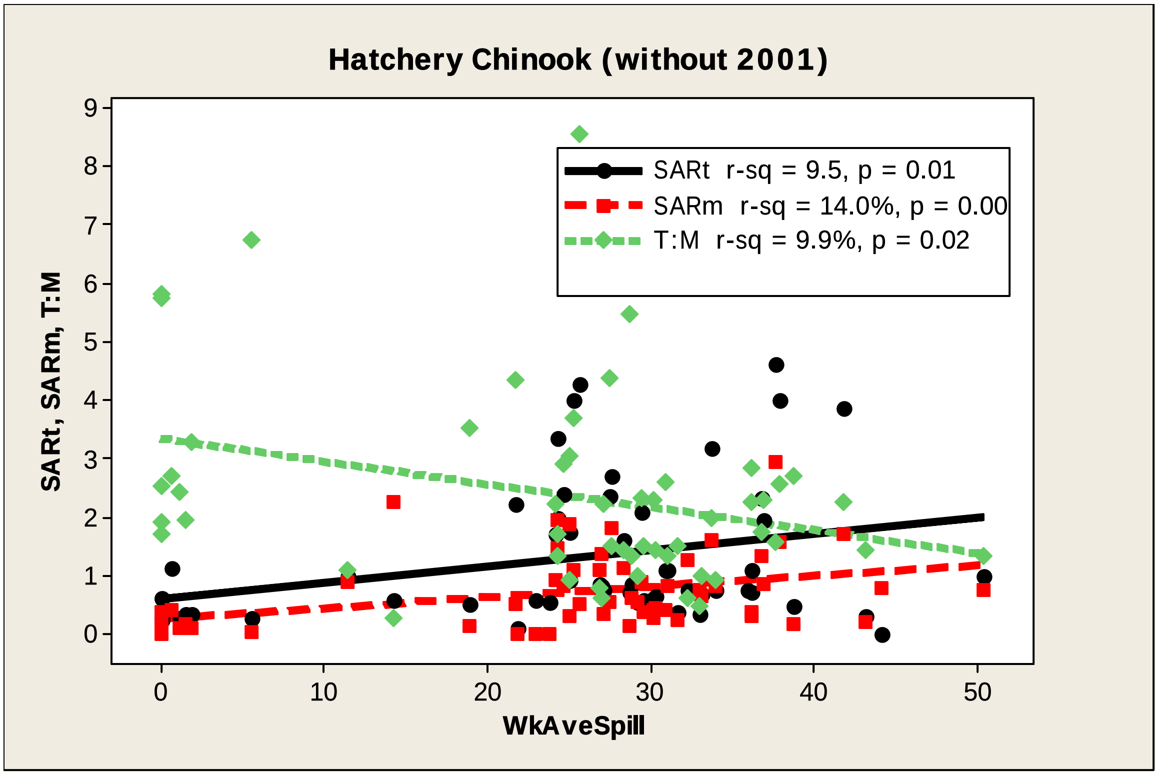

Figure 9. T:M, SAR_T and SAR_M for hatchery spring/summer Chinook salmon versus spill percentage with regression lines (years 1997-2000, 2002-2005).

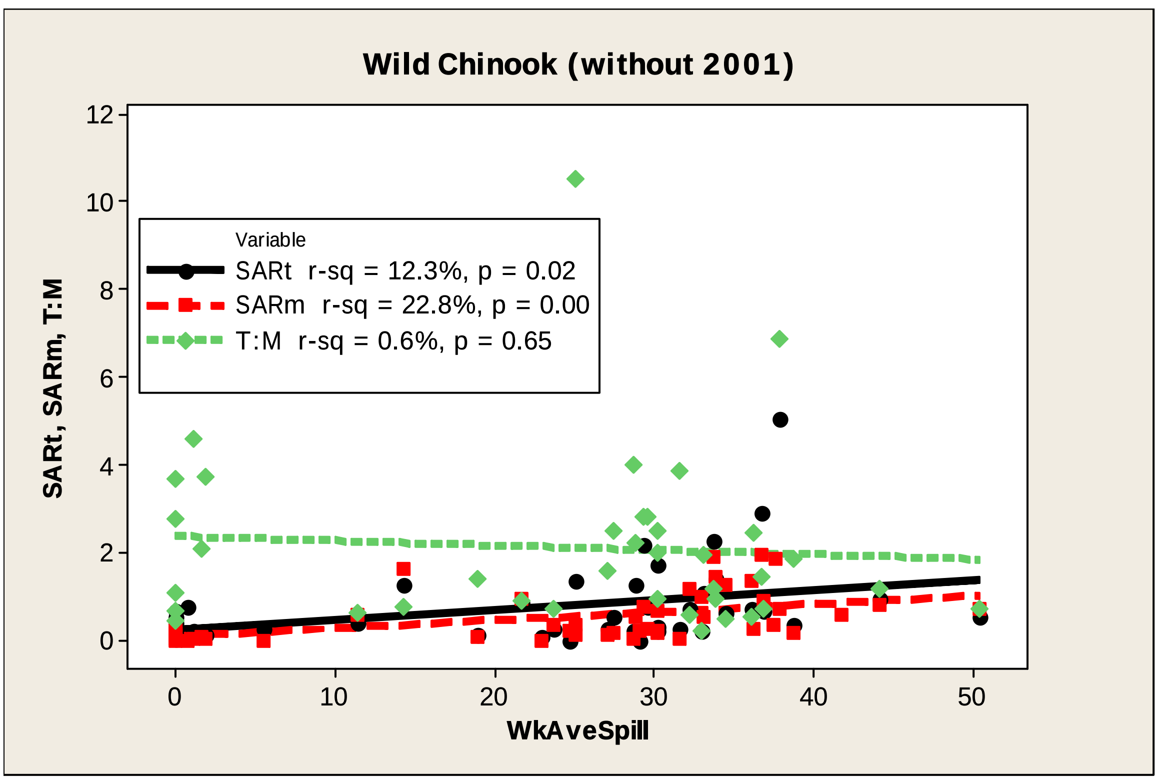

Figure 10. T:M, SAR_T and SAR_M for wild spring/summer Chinook salmon versus spill percentage with regression lines (years 1998-1999, 2002-2005).

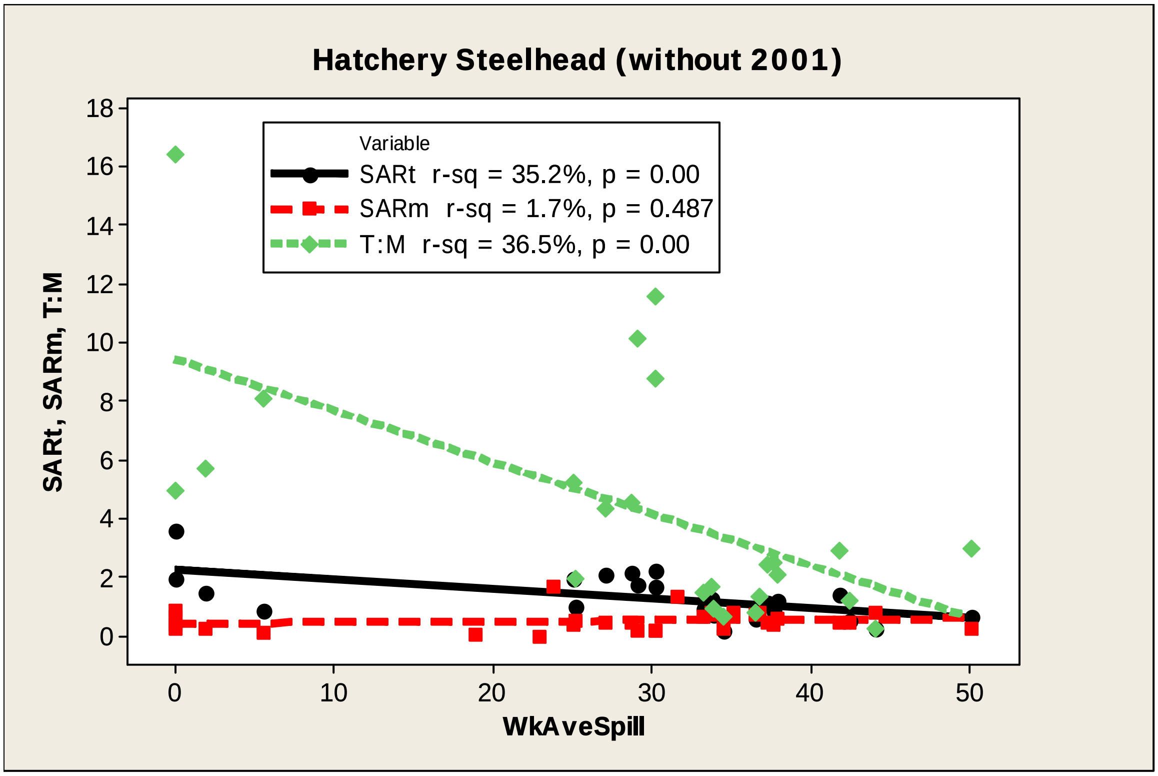

Figure 11. T:M, SAR_T and SAR_M for hatchery steelhead versus spill percentage with regression lines (years 1999, 2003, 2005, 2006).

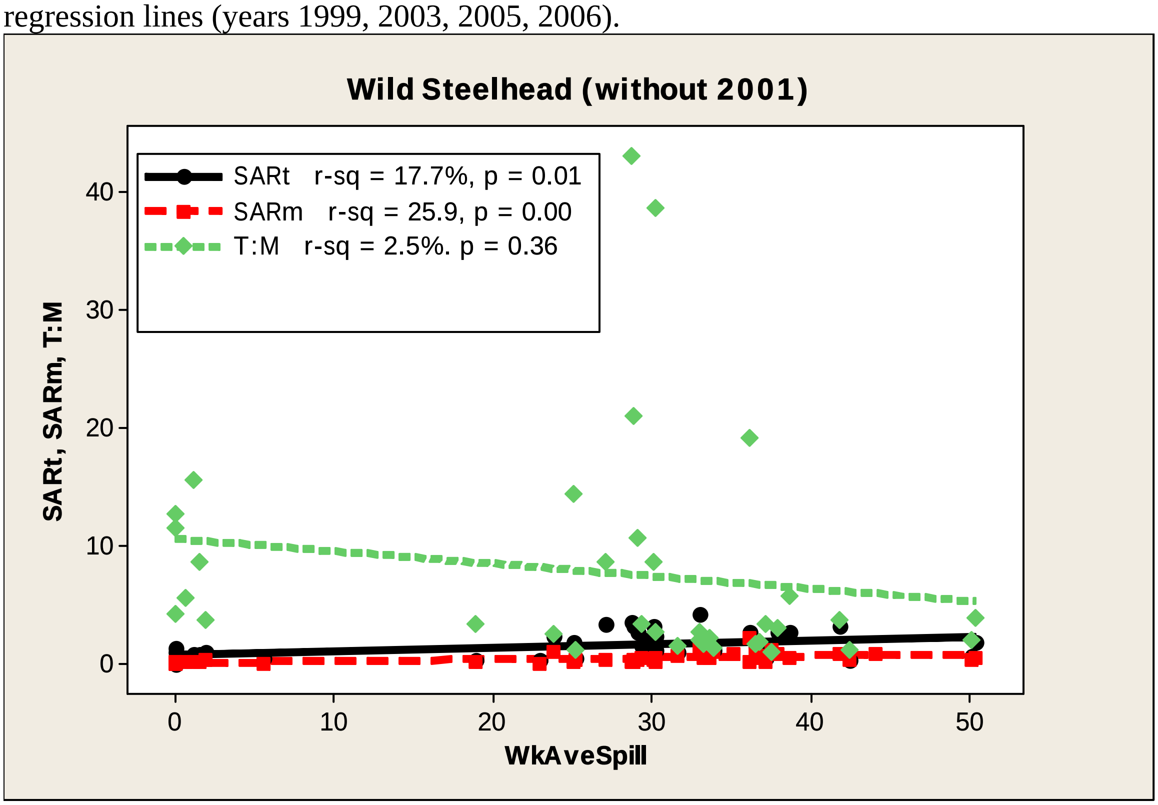

Figure 12. T:M, SAR_T and SAR_M for wild steelhead versus spill percentage with regression lines (years 1999, 2002-2006).

Survival rates to below Bonneville dam are assumed to be 0.98 for transported fish of all species independent of the number of fish transported. In contrast, survival rates for in-river migrants are known to vary depending on species, season, and flow conditions. Survival rate for in-river migrants also depends on the total number of fish in the river. This total number depends on the number of in-river migrants as well as the number of fish removed from the river for transportation. When prey are easily available to predators, because they are either especially vulnerable or at high density, total consumption by individual predators is limited by handling time, and ultimately, by satiation (Holling 1959). Under this scenario, mortality ***rate*** would decrease as the number of in-river migrants increases because the number killed becomes a smaller fraction of the total number available, even though the total number of prey killed would increase. Depensation of this sort might not occur if the number of predators increased in response to prey density, either through a short-term aggregative response, or a longer-term reproductive response (Holling 1965). However, such numerical responses by predators are generally insufficient to prevent depensation during a short period of downstream smolt migration (Wood 1987). Indeed, analysis by Faulkner et al. (2008) indicates that the in-river survival of PIT-tagged smolts increased as the in-river density of (mostly non-tagged) smolts increased. If mortality from predators is depensatory for in-river migrants but not for transported fish, at least until they have been released below Bonneville Dam and have mixed with in-river migrants, then the T:M ratios would be expected to decrease as spill percentage increases.

Question 3. Based on available data is there evidence that results from recent years (2006, 2007) are different for Snake River spring Chinook and steelhead? [e.g., different in travel time, downstream survival]

Recent Mainstem Passage Improvements (FPC 2008)

Over the past several years, a number of significant changes have been made in the hydrosystem and in operation in an effort to improve in-river migration conditions for juvenile salmonids in the Columbia River Basin. These include both structural changes (removable spillway weirs, temporary spillway weirs, and extension of a spillway wall) and operational changes (spill). A brief summary of the recent mainstem passage improvements is given below.

Structural Modifications:

Removable Spillway Weirs (RSW)

- Lower Granite Dam: operational spring 2002 (Tested Sept. 2001)
- Ice Harbor Dam: operational spring 2005
- Lower Monumental Dam: operational spring 2008

Temporary Spillway Weirs (TSW)

- McNary Dam: operational spring 2007

- John Day Dam: operational spring 2008
- Little Goose Dam: projected for spring 2010

Extended Spillway Wall
- The Dalles Dam: operational spring 2004
- The Dalles Dam: new larger wall projected for spring 2010

24-Hour Spring Spill (various volumes):

Lower Monumental, Ice Harbor, The Dalles, and Bonneville dams: spring 2001
Lower Granite Dam: spring 2006-08
Little Goose Dam: spring 2006-08
McNary Dam: tested against nighttime spill 2005-06, operational spring 2007-08
John Day Dam: spring 2008

The only structural changes that have been in place long enough for their effect to be reflected in the recent (2006 or 2007) in-river migration data are the removable spillway weirs at Lower Granite and Ice Harbor Dams, the temporary spillway weir at McNary Dam, and the extended spillway wall at The Dalles Dam.

Spill has been a part of dam operations at many of the Columbia Basin dams for a number of years and has taken on several different forms over that period. The most recent changes in spill operations which potentially affected 2006, 2007, and 2008 in-river migrations include the initiation of 24-hour spring spill at Lower Granite Dam, Little Goose Dam, and McNary Dam.

The impact of these recent structural and operational changes on the success of in-river migrating spring/summer Chinook, steelhead, coho, and sockeye can not be fully accounted until the surviving adults return. A preliminary indication of their success may be found in downriver travel times and survival data, but such data may not fully reflect increased SAR success, if SAR success is partially due to a reduction in delayed mortality, resulting from reduced stress during downriver migration, exhibited as increased survival beyond the hydrosystem.

Figure 13 (Faulkner et al. 2008) shows the median fish travel time from Lower Granite Dam to Bonneville Dam for weekly release groups of Snake River yearling Chinook salmon and steelhead for the years 2001 through 2007. These comparisons show that fish travel time in 2006 is fastest or nearly so at every point in the season for both species, while the 2007 data show travel times closer to the middle of the cluster, if one excludes 2001 (an extremely low flow year).

An examination of downriver survival data for years 2002 - 2007 provides a somewhat clearer picture (Figure 14). For Chinook in 2006, juvenile survival through the hydrosystem was better than the previous four years through all but the earliest part of the season. In 2007, a year in which early-season flows were near average but later-season flows were lower than average, the survival rates were above 60% for much of the season, but dropped off to about 40% in later May. Downriver migration success for both hatchery and wild steelhead in 2006 was the greatest since 2002. In 2007 downriver survival was approximately 40% early in the season but declined to below 30% by the second week in May. The downriver migration success rates were generally higher for Chinook and steelhead in 2006 and 2007 than those of previous years.

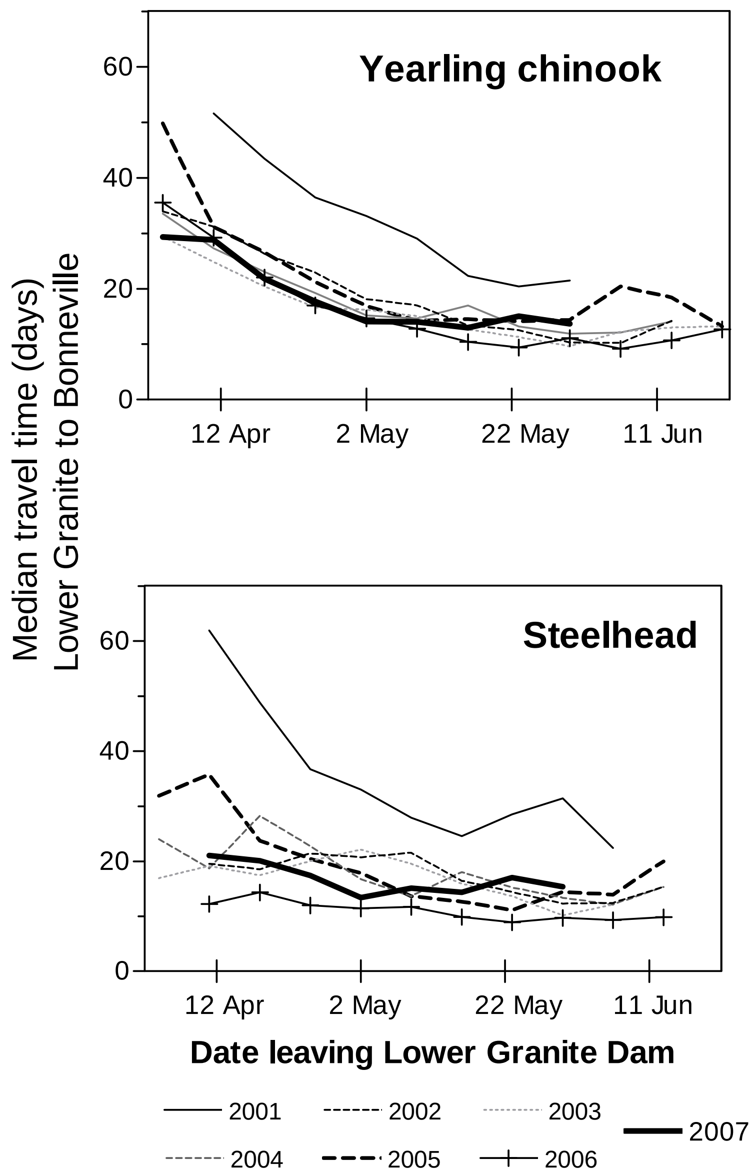

Figure 13. Median travel time (days) from Lower Granite Dam to Bonneville Dam for weekly release groups of Snake River yearling Chinook salmon and steelhead from Lower Granite Dam, 2001-2007. From the 2007 draft BPA survival report (Faulkner et al. 2008).

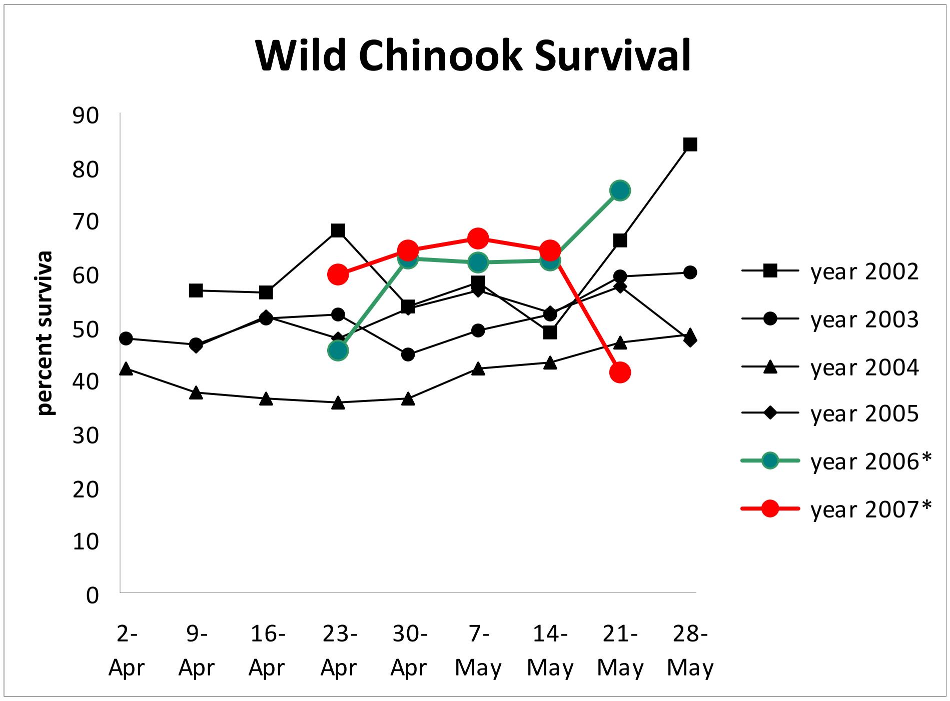

Figure 14. Wild spring/summer Chinook salmon downriver migration survival. * 2006 and 2007 are computed from survival of wild salmon from Lower Granite to McNary and combined wild and hatchery fish from McNary to Bonneville, since a separate estimate for only wild smolt was not available for this reach. (Compiled from Faulkner et al. 2007, Faulkner et al. 2008, and Williams et al. 2008)

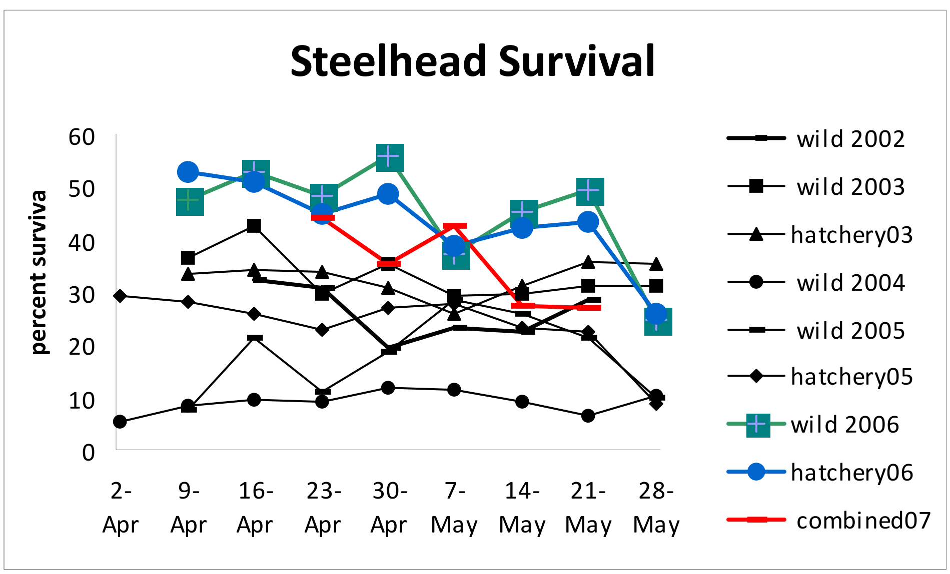

Figure 15. Steelhead downriver survival: wild fish for migration years 2002 - 2006, hatchery fish for 2003, 2005 and 2006, and combined for 2007 (Compiled from Faulkner et al. 2007, Faulkner et al. 2008, and Williams et al. 2008)

We do not have controlled experiments, but, on balance, we can say that data suggest that the recent modifications of structures and operations have improved conditions for downriver survival for spring/summer Chinook and steelhead. However, whether these improvements are sufficient to provide better overall return rates than for the case of maximum transport of juveniles during the middle of May remains unclear. The larger point is that we must wait for the adult returns before we will have any sense of how the 2006 and 2007 passage improvements translate into SAR_M or the T:M ratio.

In the absence of controlled experiments the ISAB's sense is that NOAA's Comprehensive Passage (COMPASS) model is a valuable tool for predicting the impact of structural and operational modifications to the Columbia River hydrosystem on juvenile migration survival, travel time, and return rates for spring/summer Chinook and steelhead. In its current state, it should yield rough indications of a good balance between transportation and spill, and once reliable data become available for more projects and configurations, it will be possible to better evaluate project and hydrosystem survival under various water management scenarios.

Optimizing return rates for Snake River spring/summer Chinook and steelhead is a balancing act, since management scenarios that improve circumstances for one species may be detrimental for the other. In the long term, it may be possible to address the issue of optimizing survival through particular projects or the entire hydrosystem by fine-tuning Compass.

Question 4. What are the possible impacts of alternative spill-transport scenarios on other native species, in general, and on Pacific lamprey and Snake River sockeye, in particular?

The focus of this review, up to this point, has been on the impacts of spill-transport on Snake River spring Chinook and steelhead. The impacts of alternative spill-transport scenarios for lamprey and sockeye exemplify the larger point that what benefits one species may sometimes harm another. Downes et al. (2002) commented that, "Impact can be manifest as changes in a variable of interest in either direction, either increase or decrease in value. It is then a social decision whether that detected change is deemed to be desired and/or acceptable, or their converse." Such changes can include impacts on particular populations, groups of species, ecological processes, or habitats. Consideration of possible impacts on these species should acknowledge that insufficient information is available on the ecology and habitat requirements, including passage, of lamprey and the factors affecting year class strength of sockeye.

Pacific Lamprey

A. Background

Pacific lamprey (*Lampetra tridentata*) were present historically in the interior Columbia River basin and well into the Snake River basin (Kostow 2002). They are now absent above several dam complexes, including Hells Canyon on the Snake River, Pelton/Round Butte on the Deschutes River, and Powerdale on the Hood River. In addition, adult passage has decreased at Bonneville and other mainstem dams. Habitat degradation and small passage barriers, such as road culverts, have caused distribution to decline in unblocked areas as well. The result is that Pacific lamprey are often limited to the lowest reaches of many basins.

As identified by the ISAB in an earlier review (ISAB 1999), during both juvenile and adult migrations, lamprey may encounter a variety of obstacles to passage in the Columbia River. Dams can delay or obstruct adult passage and are also known to result in mortality of downstream migrating lamprey as a result of turbine entrainment or screen impingement. These impacts of salmon screen bypass systems on Pacific lamprey populations are of great concern (Close 2002).

Adult passage is acknowledged to be a major factor (Moser et al. 2002) limiting recovery of lamprey populations in the Columbia River Basin, as the fishways are designed for salmonids able to travel through swiftly flowing water. Lamprey migrating upstream, on the other hand, take advantage of slow-moving currents along the edges of natural river rapids. A number of bioengineering initiatives have improved passage of adult lamprey through fishways at dams (Moser et al. 2006; Moser et al. 2007 cited in Nez Perce et al. 2008). Efforts to better understand and improve upstream lamprey passage are underway. Some lamprey passage improvements have been made, and others are being tested at Bonneville Dam.

In an internal memo to CRITFC, Lorz (1998) provided early empirical evidence of impingement of juvenile lamprey on extended-length bar screens (ESBS) used to direct juvenile salmonids to bypass systems at dams. Depending on the screen size of the guidance structure, lamprey are injured or killed by wedging in the screens. ISAB (1999) pointed out that installation of extended-length bar screens that harmed lamprey or other non-salmonid species would be inconsistent with objectives to restore lamprey populations and maintain biodiversity in the Columbia River Basin.

B. Technology to reduce impingement

At this time, the impact of impingement on migrating juvenile lamprey is unknown. Nevertheless it is worthwhile to consider factors, such as screen removal, modification of screen mesh size, and changes in spill-transport operations, that can potentially reduce impingement and thereby impact survival.

1. Screen removal

The simplest way to reduce the mortality due to screen impingement would be to remove the screens during lamprey migrations. The lamprey would then go through the turbines of the dam. According to a consultant report by Moursund et al. (2003) there is evidence that turbine passage may not be as detrimental for lamprey as it is for larger fish. Laboratory studies conducted by Moursund et al. (2000 and 2001, cited in Moursund et al. 2003) demonstrated that lamprey do not exhibit the negative effects associated with shear or pressure changes coinciding with dam passage, likely because lamprey do not have swim bladders. However, cumulative effects, including any effects of strike, have not been tested.

Structures designed to guide surface-oriented juvenile salmonids away from turbines and into the juvenile bypass system are probably ineffective at guiding bottom-oriented juvenile lamprey. This makes some juvenile lamprey prone to turbine passage, but immune to impingement, as they would pass under the screens. Moursund et al. (2003) used video cameras to record behavior around a modified extended-length bar screen at John Day Dam and showed that the vertical distribution of lamprey can be bimodal. The authors found that 86% of juvenile lamprey were within the top 10% and bottom 10% of the screen face (their Figure 3.7). Their sample size was small; 50 animals were filmed during the observation period, but the finding is intriguing.

2. Screen size

The effects of decreasing the mesh size of the extended-length bar screens fitted into the bypass systems on juvenile lamprey survival were investigated by Moursund et al. (2003) and previous reports by the same authors at John Day. They found that decreasing the bar screen gap size from 3.175 mm to 1.75 mm was effective in preventing the permanent wedging of lamprey between the bar spacing. Replacement of existing screens with smaller bar spacing could therefore reduce juvenile lamprey mortality from screens.

3. Spill

Juvenile lamprey passing over the dams during spill may or may not survive better than those going through the turbines. If the bypass systems were fitted with screens that caused significant impingement then passage over the dams during spill would increase survival proportions. However, there are no data on lamprey spillway use or on their survival via spillway migration.

4. Transport

Modifying the screen size would result in increased numbers of viable juvenile lamprey being moved into the bypass systems and hence to transport. Because the effects of transport have not been evaluated for lamprey, we cannot say how this would affect survival.

C. Reduction in the probability of extirpation

Pacific lamprey are anadromous, and as for salmon, survival to maturity is determined by factors that operate in fresh water, estuarine, and marine habitats. These factors will also influence the viability of lamprey populations.

The relative impact on population viability of mortality caused by dams during juvenile downstream migration versus adult upstream migration cannot be assessed with present data. With the limited data available on the population dynamics of lamprey at all life history stages, it is difficult to determine what incremental increases in juvenile lamprey would be required to result in more adults returning to spawn. The few relevant papers in the scientific literature have focused on adult passage, and these clearly show that dams significantly impair lamprey spawning migrations. Moser et al. (2002) found that overall passage efficiency (number of radio-tagged lamprey that passed over Bonneville Dam, divided by the number that approached it; N = 755) ranged from 40 – 48 %. The cumulative adult mortality resulting from impaired downstream migration past mainstem dams on the upper Snake and Columbia Rivers is almost surely a major limiting factor for this species. Improving lamprey survival on their downstream migration by modifying screen size could lead to a decrease in the probability of extirpation, since increased numbers of juveniles successfully migrating through the three dams fitted with extended-length bar screens (Lower Granite, Little Goose and McNary) would mean there would be more juveniles heading to sea below Bonneville Dam.

Although the freshwater ecology of lamprey is poorly documented, it is widely acknowledged that data on their marine phase are weaker. Changes in lamprey survival at sea or in the estuary therefore could mask improvements in survival in fresh water. Almost nothing is known about factors in the ocean, but it may be that marine survival regimes shift for lamprey as they do for salmonids. Changes in lamprey abundance may therefore occur coastwide. Lending support to this suggestion are the observations of lamprey declines in recent years in the Fraser River in British Columbia (McPhail, 2007) and the Klamath River in California (Lewis, 2007). It is clear that effective management of lamprey requires more knowledge of all parts of their life cycle.

Snake River Sockeye

The available information for Columbia River stocks suggests that transportation does not benefit sockeye, although a transportation evaluation of Snake River sockeye has not been conducted (Dawley et al. 1982, 1984, Chapman et al. 1997, Williams et al. 2005, J Fryer in preparation citing Ad Hoc Transportation Review group 1992).

A. Effect of spill

Spill might reduce harm to sockeye salmon smolts because sockeye are thought to be more vulnerable than other species to descaling in bypass systems. The proportion of natural origin sockeye salmon with scale loss of more than 20% averaged 15.5% (range 4.3 - 30.1%) at Lower Granite Dam over seven years (J. Fryer in prep, Columbia River

Inter-Tribal Fish Commission), and these fish probably suffer high mortality following release (Hawkes et al. 1991). Little is known about mortality rates of partially descaled fish (those recorded as missing 3-19% of scales), which are even more prevalent than descaled fish in samples from bypass systems (J. Fryer, pers. comm.). To our knowledge, descaling rate has not been assessed for sockeye smolts spilled over dams, so a quantitative comparison of mortality from spill or transport is not yet possible, but is needed.

Descaling of sockeye smolts in bypass systems is of special concern for this review, because the majority (average 63% from 1998 to 2007) of the juvenile sockeye run from the Snake River basin migrates past Lower Granite Dam during the period of "Max-Transport/No spill" proposed by the 2007 BiOp (Table 1 in Memorandum 49-08 from Fish Passage Center). The same table shows that an average of 39% of the juvenile sockeye run occurs during the period of interest under the new FCRPS Biological Opinion's Reasonable and Prudent alternative action to terminate voluntary spill from May 7 to May 20. The proportion of the sockeye migration for the entire migration season that would be bypassed and transported is estimated at 86% under the 2007 BiOp maximum transport proposal, while terminating voluntary spill May 7 to 20 results in an estimated 82% transported over the entire season (Table 7, FPC memo of 21 April 2008).

The information available for Columbia River stocks suggests that transportation does not benefit sockeye salmon (Dawley et al. 1982, 1984; Chapman et al. 1997; Williams et al. 2005; J. Fryer in prep, citing Ad Hoc Transportation Review Group 1992), although a transport evaluation of Snake River sockeye has not been conducted. In view of the uncertainty about relative rates of descaling during bypass versus spill, the effect of the 2008 BiOp recommendations on sockeye salmon is largely unknown.

B. Recent sockeye results

Returns of adult sockeye salmon at Bonneville Dam in 2008 are the highest in recent history. As of 24 August 2008, there were 213,589 returning sockeye compared to a ten-year average of 58,628. A large majority of these were destined for the Mid-Columbia (192,214 at Priest Rapids Dam by 24 August 2008, compared to a ten-year average of 56,165). Eighty percent of the PIT-tagged sockeye returning to the mid-Columbia migrated downriver in 2006 with a downriver survival rate from Rock Island Dam to John Day Dam of 0.88 (Table 2, FPC memo, July 14, 2008, Sockeye adult returns in 2008). The average spill percentage for this reach in 2006 was similar to most years in the 1998-2007 decade, but individual projects differed. One possible factor was the release of over 350,000 hatchery-reared fry into Skaha Lake in 2005 and over 1,200,000 in 2006, which would likely contribute to the return of adults in 2008 and 2009, respectively. However, even after including the additional hatchery releases to Skaha Lake, wild smolts still accounted for over 80% of the total smolt migration from the mid-Columbia populations in 2006, which was roughly equal to the recent 10-year average.

Sockeye from the Snake River also returned in greater numbers, but these numbers are still modest. At Lower Granite Dam, the August 24 return count was 884, compared with a ten-year average of 74. The downriver survival rates from Lower Granite Dam to McNary Dam were 0.86 and 0.62 for 2006 and 2007, respectively, the highest for the decade in 2006 and better than average in 2007 (Table 4, FPC Memo, July 14, 2008, Sockeye adult returns 2008). Some of these fish would have encountered the structural and operational modifications to the hydrosystem listed above, so these passage improvements may have contributed to the record high SARs.

While 2006 and 2007 downriver migration success rates were higher than the decadal averages of 0.49 for the mid-Columbia and 0.59 for the Snake River; the adult return rates are substantially disproportionate to these downriver success rates. Clearly, the observed improvement in in-river survival alone cannot account for the magnitude of increase in adult returns. Other factors must also be considered, such as improved timing of arrival of in-river fish at the estuary related to more favorable spill and flow. Another factor to consider is more favorable ocean conditions, independent of river conditions and timing. However, sockeye populations outside the Columbia River appear to have experienced only average marine conditions in 2006. In-season estimates of total sockeye returns to the Fraser River and to Barkley Sound (Vancouver Island) have not exceeded pre-season forecasts. Moreover, in other years, good ocean conditions for other species in the Columbia River have not resulted in correspondingly large returns of sockeye.

Question 5. What are the ecological/evolutionary issues related to transportation and spill operations? What factors should be considered in defining what is meant by "optimal" when considering spill and transport?

In a comprehensive evaluation of the relative merits of spill versus transport, it is useful to consider separately the effects of route past a dam (through the spillway versus through the turbine intake, with most diverted to the bypass system) from the effect of subsequent mode of travel downstream (in the river versus in a barge).

A. Route past dam: proportion spilled versus proportion entering turbine intake (and bypass system)

Spill reduces overall travel time downstream by reducing delays in the forebay at each dam (Budy et al. 2002). It may also reduce stress and the probability of injury at each dam (Budy et al. 2002, Wilson 2003). However, both of these benefits to the survival of in-river migrants will likely be captured in the T:M ratio for the target population. Observed T:M ratios might be biased if bypass screens work more effectively to collect smaller smolts, as appears to be the case for some dams, although not at Lower Granite Dam (Zabel et al. 2005).

B. In-river migration versus transportation by barge

1. Physiological and behavioral implications

Although in-river migration might reduce stress (Budy et al. 2002), the overall mortality rate from the cumulative affects over eight dams (Lower Granite to Bonneville) is likely to exceed the delayed effects of stress from bypass collection and barging under some conditions (Muir et al. 2006). The benefits of in-river migration are known to vary with species, flow conditions, and time of year (Figures 1-12). Again, these physiological and behavioral benefits of in-river migration will likely be captured in the T:M ratio for the target population.

However, in-river migration also reduces straying and fallback behavior in returning adults (C. Peery, University of Idaho unpublished report; J.R. Ruzycki and R.W. Carmichael, unpublished report; provided by ODFW, see appendix). This observed reduction in straying may be due to in-river migration providing route-finding experience or imprinting opportunities for smolts that barging does not. We note in passing that returning adults that stray and fail to contribute to the viability of the target population should not be counted in estimating SARs. Reported T:M ratios exclude fish that stray below Lower Granite Dam, but they include an unknown number of fish that stray above Lower Granite Dam, and some of these strays may fail to contribute to the viability of the target population.

2. Ecological implications

Increasing the proportion of in-river migrants will increase the overall density of smolts in the river. Migrating smolts are highly vulnerable to avian predators in certain reaches, and under these circumstances the risk of predation mortality tends to decrease as smolt density increases (called depensation).[2] For example, Faulkner et al. (2008) show that the in-river survival of PIT-tagged smolts increased as the in-river density of (mostly non-tagged) smolts increased. Depensation typically occurs because total consumption by individual predators is limited by the time required to capture and handle each prey item, and ultimately, by reduced motivation and satiation (Holling 1959). Even though the total number of prey killed by predators increases with prey density, the mortality *rate* decreases (i.e., is depensatory) because the number killed becomes a smaller fraction of the total number available. Predation mortality will be depensatory unless the number of predators increases more than prey density because of aggregation or reproduction, or less likely, because the functional response to prey density for individual predators is sigmoid (type III) such that the *slope* of the functional response increases with prey density due to learning or switching behavior. During a short period of downstream smolt migration, numerical responses by predators are generally insufficient to prevent depensation (Wood 1987). Recent research for Caspian terns nesting on Crescent Island near the Snake River indicates that mortality of steelhead smolts from tern predation is lower in years of high river flows (Antolos et al. 2005; Roby et al. 2008) and/or when

[2] The ISAB discusses this depensation issue in the response to Question 3 but elaborates further here.

large numbers of steelhead migrate past the island in a relatively short period of time. Roby et al. (2008) note that although predation rates were lower for most species/run-types in 2007 the overall impact on salmonid ESUs is not necessarily proportionally lower because estimates of predation rate apply only to the in-river component of each species/run-type and do not include the component of the run that was transported and therefore unavailable to the terns on Crescent Island.

In effect, the increased number of in-river migrants may buffer all potential prey species inhabiting the river from predation risk. Depensatory mortality should cause reach survival and SARs for PIT-tagged in-river migrants to increase for any given time period and flow condition (consistent with Figures 5-12). The ecological benefit of spill percentage to in-river migration should already be reflected in the T:M ratio for the target population, but will likely extend to other populations and species as well. However, the concept of depensatory mortality is not captured by ratios, but by numbers. For example, if avian or fish predators of smolts take a fixed number in a certain time (Ricker's Type 1 predation), then it is the actual NUMBER of in-river migrants compared to the actual number of barged fish that will ultimately dictate relative values of SARs and T:M ratios.

In-river migration could reduce the risk of epizootics due to disease or parasite transmission, whereas crowded conditions in the barges could increase this risk (Budy et al. 2002, citing an IDFG report). The potential benefits of this risk reduction in the long-term are unlikely to be evident in a short time series of T:M ratios, especially if the probability of an epizootic on barges is low.

3. Evolutionary implications

There are a number of evolutionary implications associated with spill and transportation operations including straying, migration timing, and migration behavior. The consequences of these changes are uncertain.

Increased numbers of strays due to barging could have deleterious fitness consequences for other wild populations, especially those at low abundance and near lower-river dams (like steelhead trout in the John Day River and Deschutes rivers). Interbreeding of hatchery and wild fish is known to affect the fitness of wild populations. The proportion of returning adults that stray will be increased under the 2008 BiOp RPA (two weeks of maximum transport) and will decrease monotonically, although not to zero, with the proportion of fish spilled. Similarly, if barged fish survive better than in-river migrants (despite delayed mortality from transport), the number of returning adults that stray will also be increased in the absence of spill and will decrease monotonically with the proportion of fish spilled. Returning adults that stray and interfere with the reproduction of fish in other populations should not be counted in estimating SARs for the target population, and should be counted as a cost against the policy (barge versus in-river migration) that produced them because the consequences of straying are generally negative.

Increasing spill (and in-river migration) would also increase the opportunity for natural selection to promote earlier migration to compensate for cumulative delays. Phenological traits like the timing of downstream migration generally have high heritability, among the highest of traits compared by Carlson and Seamons (2008), and are likely to evolve in response to changes in temperature and flow regime (e.g., for Chinook salmon transplanted to New Zealand, Quinn et al. 2000). Zabel and Williams (2002) conclude from PIT-tag data for spring/summer Chinook salmon that survival to adult return was higher for early-migrating than late-migrating smolts, and that this advantage would tend to select for earlier migration. They speculate, however, that selection for earlier downstream migration might be constrained by growth rate in fresh water and by the advantage of larger size during early ocean migration. It is also true that if the fish "get used to being barged" for a few generations, they will evolve a life history that optimizes "arriving at the barge at just the right time." Whether the fish are transported or run the river their behaviors are going to shift to optimize their life histories, and that will vary by headwater stream and major drainage.

Crozier et al. (2008) predict that rising temperature and earlier snow melt due to climate change will favor earlier emergence, smoltification, and migration in salmonids, but that the delayed but more intense upwelling predicted by some climate models could favor later ocean entry, the opposite tendency. However, the two responses would seem to favor adaptation to in-river migration in the Columbia River, where the major problem is delayed passage from the headwaters to the estuary, due to increased travel time past successive dams.

Williams et al. (2008) point out that hydropower development in the basin and changes in climate to date have had the opposite effect, making water temperatures warmer in fall and cooler in the spring, and that these changes in water temperature have delayed spawning times in Snake River fall Chinook salmon and decreased the spring growth rate of juveniles. The overall effect has been to delay the time at which downstream migration is initiated. Williams et al. (2008) use life history fitness models to demonstrate that natural selection should increasingly favor the yearling life history type, given the observed delay in the time at which sub-yearling Chinook can begin downstream migration, together with the increased travel time required to pass to dams. After calculating survival probabilities of spring/summer Chinook salmon as a function of release date, Zabel and Williams (2002) conclude that barging will probably promote the evolution of later downstream migration timing to compensate for the artificially rapid transit from Lower Granite Dam to Bonneville Dam.

By similar reasoning, the pervasive changes in river conditions due to the hydropower system will likely promote the evolution of increased freshwater residency in steelhead trout, as reported in the Sacramento and San Joaquin rivers (McClure et al. 2008).

A decision to implement a particular spill-transport regime year after year could also have evolutionary implications for downstream migratory behavior. For example, under a high spill policy, with a large spill percentage, bypass screen efficiency is reduced, and turbine survival is relatively low (i.e., $S_{turbine} << S_{bypass}$), natural selection might favor surface swimming that avoids the turbine intakes and earlier downstream migration that compensates for delays due to dams during in-river migration, thereby increasing the probability of reaching the estuary at a favorable time. In contrast, under a no spill/ maximum transport policy natural selection might favor later migration because the trip downstream will be quicker by barge than by river. A policy that shifts from a high spill percentage to no spill/maximum transport after a specified date would likely cause disruptive selection on these traits and might accentuate both extremes of behavior as well as reduce the scope for adaptive management under changing ocean, estuary, and freshwater ecosystems.

C. Factors to consider in defining "optimal" spill-transport policy

The decision to review alternative spill-transport regimes acknowledges that both the magnitude and timing of spill percentage can be manipulated, and that small changes in spill percentage may provide disproportionate benefits to fish populations. River flow appears to be an important covariate and should be considered to the extent it can be reliably predicted ahead of the decision period. However, these statistics do not reflect all of the biological factors that index success, so broader ecological context is needed for such analyses.

In our opinion, some important ecological considerations for making spill-transport decisions are the following:

- *Maintain heterogeneity*. The philosophy espoused in "Return to the River" – that one should strive for heterogeneity in populations -- remains relevant. Narrowly selecting life history strategies by either spill or transport policies runs the risk of losing important heterogeneity.

- *Straying rate*. Because transportation appears to promote straying, the extent to which straying fish threaten the viability of wild populations should be carefully considered as a consequence of spill and transport decisions. Comparisons of straying rates by species and origin should be continued.

- *Effect on sockeye salmon*. Descaling of sockeye smolts in bypass systems is of special concern because the majority of the sockeye smolt run from the Snake River basin migrates past Lower Granite Dam during the period of "Max-Transport/No spill" specified by the 2008 BiOp. To the extent that descaling might cause higher mortality in sockeye smolts that are bypassed, rather than spilled, any decision to maximize transportation at Lower Granite Dam during late May might pose a higher risk to sockeye salmon. The reasons for the surprising return of sockeye in 2008 may be due to factors outside the hydrosystem or perhaps may be due to higher spill percentage and reduced transportation in 2006 and 2007 (FPC memo of 6 Aug 2008). Other explanations are also possible and need evaluation.

- *Effect on lamprey*. Limited data indicate that some lamprey are injured or suffer direct mortality by impingement on bypass screens. There is much concern about these impacts and reports that Pacific lamprey populations in the Columbia River Basin have been declining in recent years.

- *T:M ratios*. For the target populations, these ratios capture the net physiological and behavioral consequences of alternative spill-transport regimes. As noted previously, returning adults that stray and fail to reach their natal spawning habitat should not be counted in estimating T:M ratios of either their populations of origin or their populations of arrival.

- *Other ecological issues*: The framework for questions and responses related to questions 1 and 2 has revolved around the changes in RATIOS of SARs and T:M. The emphasis on simple ratios rather than the NUMBERS of fish may be an oversimplification. For example, close evaluation of the number of fish moving in-river versus the number being barged is informative. If Type 1 mortality is acting on migrating fish running a gauntlet of predators, as the number and percentage of them decreases it would be natural that the in-river fish would perform progressively worse than the transported fish, especially in depleted stocks. Decisions based mainly on T:M ratios in this case would lead to a conclusion that barging is preferred, when the situation instead is that the more fish are barged the worse the in-river migrating fish do and the better barging looks. However, it would be also possible that if a limited number of fish were barged, the transported fish would not do as well as in-river migrants. A recommended solution now might be to keep a mix of transportation and spill while striving to decrease the impact of predation.

V. Conclusions and Recommendations

Table 1 is designed to provide some context for spill-transport decisions that may be influenced by the conclusions and recommendations of the ISAB. The table also lists concerns that have been raised in the ISAB review of spill-transport issues. Data come from FPC. 2008. Data Request Memorandum 49-08, April 21, 2008 and DART www.cbr.washington.edu/dart/river.html.

Table 1. Context and concerns for spill transport decisions.

	Context/ concerns for spill and transport	Smolt[1] Transport % 2007 BiOp w/o max transport	Smolt[1] Transport % 2007 BiOp	Smolt[1] Transport % 2008 BiOp	Smolt[1] Passage Timing at LGR Average/ range of 10 and 90 percentile date	Yearly smolt at LGR (x1000) Average, Min, Max (2002-07)	% of smolt at LGR Hatchery (2002-07)
Chinook - Wild	Transport little benefit[2]	77%	81%	87%	4/21, 5/21 5 days, 12 days	2025, 1184, 2814	78%
Chinook - Hatchery	Transport some benefit[2]	77%	81%	87%	4/21, 5/21 5 days, 12 days	7172, 6886, 7605	
Steelhead - Wild	Transport benefit[2], straying	76%	83%	86%	4/25, 5/24 9 days, 11 days	1150, 805, 1490	86%
Steelhead-Hatchery	Transport more benefit[2], straying	76%	83%	86%	4/25, 5/24 9 days, 11 days	6963, 6527, 7325	
Sockeye - Wild	Descaling in bypass and transport	76%	86%	82%	5/03, 6/09 43 days, 73 days	5, 1, 14	90%
Sockeye – Hatchery	Descaling in bypass and transport	76%	86%	82%	5/03, 6/09 43 days, 73 days	47, 22, 89	
Lamprey	Screens impinge juveniles	NA	NA	NA	NA	NA	NA

[1] Common value used for wild and hatchery, because separate data are not available.
[2] Benefit of transportation may be overestimated and date for transportation benefit shifted earlier than optimal due to bias in detection, tagging, and bypass.

The major points identified in the ISAB response to key questions include:

1. The relative benefits of transportation versus in-river migration vary with species, time of year, and flow conditions. The best timing for transporting fish varies, depending on species, flow conditions, estuary conditions, and near-ocean conditions.

2. Recent structural and operational changes look promising to improve the survival success of in-river migrating spring/summer Chinook, steelhead, and sockeye, but final analysis must await return of surviving adults.

3. There are insufficient data to provide an assessment of the impact of extended length bar screens, spill, and transport on downstream migrating lamprey in the Columbia River Basin. Existing data point to adult passage mortality at mainstem dams as a key factor limiting recovery of lamprey populations in the Basin, but juvenile mortality during passage through the hydrosystem also could be influential.

4. The impact of spill-transport on sockeye, particularly due to descaling with passage through the hydrosystem, is of concern. Limited data suggest that transportation does not benefit sockeye. Furthermore, the timing of maximum Snake River sockeye migration coincides with the two-week no-spill maximum-transportation operation proposed under the 2008 BiOp.

5. Straying by returning adults is a major biological threat to other wild populations. There is evidence that transportation increases the incidence of straying.

6. Estimates of the benefits, consequences, and optimal timing of transportation vary among reasonable choices of analyses, metrics, and data. Therefore decisions should be supported by multiple analyses, using different metrics, and more than a single choice of data.

Recommendations:

1. Spill-transport decisions require a multi-species perspective that considers differing seasonal effects for all species of interest. A recommendation from ISAB Report 1992-2 remains relevant: "Spreading the risk of negative outcomes among alternative routes of hydroelectric passage is advisable to prevent a recovery action that is designed to improve survival of one listed species from becoming a factor in the decline of another species." The ISAB believes that, whenever river conditions allow during the late April-May period, a strategy allowing for concurrent transportation and spill is prudent.

2. Spill-transport operations like those of 2006 and 2007 should be continued long enough to determine how much influence such operational changes have on downriver migration and total adult returns. Continuing recent spill-transport

operations is advised to improve future evaluations of the trade-offs associated with spill and transport decisions.

3. Studies should be conducted to reduce critical uncertainties related to the impact of spill-bypass-transport operations on downstream juvenile lamprey migration, including estimation of the population; evaluation of the effect of bar screen design on mortality and migration route; and estimation of mortality rates due to route of hydrosystem passage. Furthermore, the hydrosystem's impact on the entire life cycle of Pacific lamprey should be thoroughly investigated in a timely manner.

4. Further study is needed to define rates of mortality of sockeye smolts caused by partial descaling and injury for the various routes of passage through the hydrosystem during the peak migration period (mid-May to mid-June). The ISAB realizes that quantifying dam passage survival studies of the limited number of endangered Snake River sockeye smolts is problematic. Alternatives should be considered to supplement the limited data on Snake River sockeye; for instance, conducting passage and survival studies on Upper Columbia River sockeye passing lower Columbia River dams could provide valuable insights.

5. Evaluations of spill-transport operations should include studies designed to reduce uncertainties about relative amounts of straying for transported versus in-river fish for both hatchery and wild stocks of Snake River steelhead and spring Chinook. Another recommendation from ISAB Report 1992-2 is germane: "Spreading the risk of negative outcomes among alternative routes of hydroelectric passage is advisable in the face of uncertainties associated with potential negative effects of transportation on genetic and life history diversity."

6. Finally, the perspective on spill included in ISAB Report 1999-4 deserves special recommendation in this report: "Spill: The general principle is that all juvenile passage alternatives should be evaluated against the baseline of spill. As an avenue of hydroelectric project passage, spill more closely mimics natural situations and ecological processes than other available routes. Spill should be considered as an alternative when the improvements anticipated from other bypass technologies are not large enough to meet the passage goals." That is to say, spill should be considered the default recommendation rather than simply one of the alternatives.

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Appendix: Acknowledgements and list of briefings and review materials provided

To complete this review, the ISAB members were briefed, provided materials, and had discussions with many research scientists in the Columbia River Basin including representatives from NOAA Fisheries, Columbia River Inter-Tribal Fish Commission (CRITFC), Oregon Department of Fish and Wildlife (ODFW), and the Comparative Survival Study (CSS) Oversight Team. During these interactions, we received numerous presentations of data and reports that are not published in peer reviewed journals but are the most up-to-date analyses addressing the many biological trade-offs to consider in developing a spill and transport strategy. These documents were not only provided to the ISAB but also to all the interested entities participating in the discussions. We thank all those who provided us briefings and review materials, sometimes on very short notice. This high level of participation, interaction, and responsiveness was invaluable to our review.

On April 21, 2008, to start our review, John Ferguson, NOAA Fisheries, provided us with analyses titled, Seasonal patterns in the efficacy of transportation.

At our May 2, 2008 meeting, we received the following briefings:

- Briefing to ISAB on Transportation, John Williams, Bill Muir, Rich Zabel, Northwest Fisheries Science Center

- ODFW organized presentations:

    - Opening and c losing remarks, Ed Bowles, ODFW Fish Division Administrator
    - Snake River Steelhead Straying, Rich Carmichael, Oregon Recovery Planning Coordinator for the Interior Columbia River Basin and Member of the Interior Columbia Technical Recovery Team,
    - Effects of Spring Spill at Lower Snake River Collector Projects in 2007 on Juvenile Salmonids and TIRs, Steve Haeseker, Member of the CSS Oversight Team,
    - Potential for Bias in NOAA TIR Estimates as a Result of Tagging at LGR, Charlie Petrowsky, Member of the CSS Oversight Team,
    - Seasonal Timing of CSS Groups, Margaret Filardo, Member of the CSS Oversight Team

Bob Heinith, CRITFC, also briefed the board on multi-species issues including lamprey passage and distributed a report by Moursund et al. 2003, titled Evaluation and effects of extended length submerged bar screens on migrating juvenile Pacific Lamprey (Lampetra tridentata) at John Day Dam in 2002. He also distributed a paper on sockeye descaling in dam bypass systems: Annual variations in timing, duration, and success of seaward migration by sockeye salmon (*Oncorhynchus nerka*) smolts originating from the

Okanagan and Wenatchee subbasins; Jeffrey K. Fryer, Columbia River Inter-Tribal Fish Commission, 729 NE Oregon Street, Portland, OR. 503-731-1266. fryj@critfc.org.

At the meeting, the ISAB made a general request for more information on the effects of spill and transportation operations on other species besides steelhead and spring Chinook. In response, the Fish Passage Center provided a July 14, 2008 memo titled, Sockeye adult returns in 2008, prepared for Liz Hamilton, and later provided an updated analysis in a July 21, 2008 memo titled, Adult sockeye return and ocean conditions. These documents are available at www.fpc.org/documents/FPC_memos.html. NOAA Fisheries also provided the ISAB an internal NOAA memo, July 24, 2008, from Ritchie Graves to Bruce Suzumoto that provided an initial critique of the Fish Passage Center's July 14 analysis of sockeye adult returns in 2008. The ISAB did not provide a peer review of these analyses and memos but used the information for context on potential effects of various passage strategies on sockeye.

On July 24, the ISAB asked the May 2 presenters from NOAA Fisheries, CRITFC, ODFW, and the CSS Oversight Team a set of questions to clarify the spill-transport deliberations:

1. What are the justifications for and against use of C_0 and/or C_1 for estimating SARs?
2. How does the choice of C_0 or C_1 impact spill-transport management decisions?
3. What is the impact of spill-transport decisions on the incidence of straying for both hatchery and wild steelhead and spring/summer Chinook?
4. What is the impact of spill-transport decisions on juvenile Pacific lamprey survival?
5. What is the impact of spill-transport decisions on Snake River sockeye survival?

NOAA Fisheries' John Williams, Rich Zabel, and Bill Muir provided written answers and discussed those answers at the ISAB's July 25 meeting. In a follow-up email, John Williams provided the ISAB the article: Achord et al. 2007. Migration timing, growth, and estimated parr-to-smolt survival rates of wild Snake River spring-summer Chinook salmon from the Salmon River Basin, Idaho, to the Lower Snake River. TAFS. 136:142-154.

CRITFC's Bob Heinith answered the question on the impact of spill-transport decisions on juvenile Pacific lamprey survival. For added context, he also provided the final draft of the Tribal Pacific Lamprey Restoration Plan for the Columbia River Basin, July 17, 2008.

ODFW's Rich Carmichael joined on the phone and provided answers to questions on straying. ODFW also provided written answers to the ISAB's questions. However, due to scheduling conflicts and the short notice for the meeting, the CSS Oversight Team was unable to attend, and a teleconference was scheduled the next week. On July 30, the ISAB, ODFW representatives, and the CSS Oversight Team held a several-hour teleconference to discuss the ISAB's questions.