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Review of NOAA Fisheries'2010 Low Flow Fish Transport Operations Proposal

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ISAB Review of NOAA Fisheries' 2010 Low Flow Fish Transport Operations Proposal

I. Executive Summary

On February 25, 2010, NOAA Fisheries requested ISAB assistance with a question related to a low flow transportation proposal for the spring 2010 juvenile salmon outmigration. Current river forecasts predict a low flow year for 2010, prompting NOAA Fisheries to propose maximizing the transport of Snake River juvenile steelhead and spring/summer Chinook in the month of May. NOAA's specific charge to ISAB was:

> Taking into account the ISAB's 2008 recommendation "*whenever river conditions allow during the late April-May period, a strategy allowing for concurrent transportation and spill is prudent*," NOAA (in looking at the data from the 2007 low-flow year), determined that if flow conditions in 2010 were similar to those in 2007 (i.e., < 65 kcfs), it would not be "*prudent*" to continue spilling water in May at the three collector projects as in 2007. The question for the ISAB was whether NOAA Fisheries had correctly interpreted the ISAB's recommendation. If not, NOAA requested further explanation of ISAB's reasoning in the 2008 recommendation.

Other parties have contributed data and analyses on this same issue, have raised additional questions, and/or have expressed their opinions on the proper course of action relative to spring spill for 2010. The NOAA Fisheries request asks for a review by early April 2010 to allow the ISAB findings to be considered in final operational decisions for this spring. In the interest of a timely decision on spring spill, we have concentrated on meeting the initial charge, but have commented on the ancillary issues as time has allowed.

The question of whether "river conditions allow" must necessarily involve a wide variety of other considerations. Among these considerations are projected power requirements and water demands, which are beyond the legitimate purview of the ISAB. From the standpoint of protecting the region's biotic resources, however, the ISAB's assessment of scientific data, references, and analyses that were reviewed leads us to the same conclusion as expressed in our previous review (ISAB 2008-5), specifically that spill should be viewed as a default condition and that a mixed strategy of transportation and spill, as implemented in recent years, is once again the strategy most in accord with the available scientific information.

As indicated in our previous review (ISAB 2008-5), "*other analyses … indicate that as spill increases, in-river survival increases and the relative benefit of transportation decreases.*" The new data on steelhead and spring/summer Chinook are in accord with and reinforce the conclusions from that earlier report, to the effect that there are survival benefits to be gained from increased spill. However, available evidence indicates that there are overall benefits of transportation for steelhead and spring/summer Chinook under most environmental conditions. In reviewing additional information available since the 2008 ISAB review, smolt to adult return ratios (SARs) for transported fish (T), relative to those for in-river migrants (M), produce T:M ratios that may be summarized as:

- *Steelhead*, T:M (hatchery stocks) > T:M (wild stocks)
- *Spring/Summer Chinook*, T:M (hatchery stocks) > T:M (wild stocks)
- T:M (*steelhead*) >> T:M (*spring/summer Chinook*) > 1
- T:M ratios increase from early April through the end of May
- Increasing spill reduces the transportation SAR, relative to the in-river migrant SAR, but T:M ratios generally remain > 1.

There are, however, other species-specific and ecological considerations that require examination. The earlier data on sockeye were preliminary and inconclusive, and more and better data are available from the new reports. These new data indicate that the 2007 survival of sockeye was much better than that from 2005. A notable difference in hydrosystem management was court-ordered spill in 2007. Sockeye returns in 2007 were strong in both mid-Columbia and Snake River populations and it appears that favorable oceanic conditions may have been partly responsible for the increased survival of both stocks from the 2007 cohort. It appears that in-river Snake River stocks benefited more than did mid-Columbia stocks. A clear interpretation of the effect of a mixed transportation and spill strategy on Snake River sockeye survival is not yet available. The proposed NOAA Operations Proposal would result in transport of a major proportion of migrating juvenile sockeye from the Snake River.

Straying of Snake River steelhead into Lower Columbia River tributaries (e.g., John Day River) appears to be elevated for transported fish, relative to those that migrate in-river. Some straying is to be expected, under natural conditions, but the rates from transported fish are increased. A detailed assessment of the adaptive consequences of genetic introgression of Snake River stocks into the local gene pools lies mostly in the future, but early results are reason for concern for the Middle Columbia stocks, some of which are listed under the Endangered Species Act (ESA).

There are other species in the Columbia River and its tributary watersheds that require attention, among them Pacific lamprey. Data are too limited at this time to clearly evaluate the likely effects of NOAA’s proposed transport operations on Pacific lamprey. In summary, there are a number of competing considerations that must be weighed in the decision on spring spill, some of which favor transportation, some of which favor spill. Snake River steelhead and spring/summer Chinook are not the only species of interest, as important as they are. Snake River sockeye and Middle Columbia steelhead are also major factors, and lamprey though still poorly understood warrant consideration. There will be other species that will become matters of concern in the future, none of which had transportation as their normal travel vector. Further, a low flow year, such as is projected for 2010, allows proactive evaluation of the utility of spill under conditions likely to be faced in the future.

The new data buttress and extend the earlier data, but uncertainties remain. Thus, the ISAB conclusion is the same now as it was in 2008. From a scientific standpoint, a mixed strategy for spill and transport is best supported by the available science. Ecological and evolutionary considerations provide an important framework in support of this strategy.

II. Background and Charge to the ISAB

On February 25, 2010, Barry Thom, NOAA Fisheries Acting Regional Administrator, asked for ISAB assistance with a question related to a low flow transportation proposal for the spring 2010 juvenile outmigration. The request notes that the latest river forecasts predict a very low flow year for 2010[1] and that "new information in a 2010 Northwest Fisheries Science Center Report demonstrates there is significant benefit to maximizing the transport of Snake River juvenile steelhead and spring/summer Chinook under low flow conditions in the month of May." The NOAA Fisheries request asks for a review by early April 2010 to allow the ISAB findings to be considered in final operational decisions for this spring.

NOAA Fisheries' specific question to the ISAB is posed in the 2010 Northwest Fisheries Science Center document titled, NOAA's "Low Flow" Transport Operations Proposal Request for ISAB Review by the NMFS Northwest Regional Office:

> Taking into account the ISAB's 2008 recommendation "*whenever river conditions allow during the late April-May period, a strategy allowing for concurrent transportation and spill is prudent*," NOAA Fisheries looked at the data from the 2007 low-flow year and determined that if flow conditions in 2010 were similar to 2007 (i.e., <65 kcfs), it would not be "prudent" to continue spilling water in May at the three collector projects as in 2007.
>
> Question: Has NOAA Fisheries correctly interpreted the ISAB's recommendation? If not, please further explain your reasoning in the 2008 recommendation.

The 2010 Northwest Fisheries Science Center report also contains information and references concerning smolt to adult survival rates (SARs) and transport to in-river migrant ratios (T:M), as well as other considerations, such as the effect of straying on Middle Columbia River steelhead and the effect of transportation on Snake river sockeye and Pacific lamprey. The report also mentions the influence of new configuration

[1] The NOAA-Northwest River Forecast Center's April forecast for April-July runoff at Lower Granite Dam is 12.0 million acre-feet, or 56 percent of average. April-August runoff for the Columbia River at The Dalles is forecasted to be 60.9 million acre-feet, or 65 percent of average. Using this runoff forecast, the Corps estimates seasonal average spring flow at Lower Granite will be about 50 kcfs.

changes, surface passage structures installed at Lower Monumental Dam (LMN) and John Day Dam in 2008, and at Little Goose Dam (LGS) in 2009, and a spill wall at The Dalles Dam in 2010.

In response to the NOAA proposal, the Oregon Department of Fish and Wildlife (ODFW) raised questions and provided information for the ISAB in the document, "NOAA Fisheries Max Transport Proposal ODFW Questions and Information for the ISAB, March 5, 2010."

Oregon's questions include:

1. Does the ISAB consider NOAA Fisheries' risk assessment adequate to conclude that "[r]epeating the 2007 spill/transport operation in future low flow years places too great a risk on the wild SR steelhead and spring/summer Chinook populations…" and thus warrants further degrading river conditions in May and elevating other risks (e.g., steelhead stray rates, in-river predation, lamprey mortality, and sockeye mortality) in order to maximize transportation?

2. Does the ISAB consider data from spread-the-risk spill and transport operations compelling enough to reverse their earlier recommendation for further evaluation of these operations at a range of flows?

3. Does the ISAB consider NOAA Fisheries' assessments of risks to other species sufficiently rigorous and robust to eliminate spill in May at collector dams?

4. Given that maximizing transportation further degrades river conditions by slowing migration, increasing turbine passage and increasing predation rates for in-river migrants, does the ISAB consider migrants not collected and left to migrate in river to be at significant risk? Does the ISAB consider those fish left in the river to be ecologically and evolutionarily expendable? If low flows trigger transport operations that further degrade river conditions, would it be prudent to prioritize available resources in an attempt to help avoid low flows?

In addition, the Fish Passage Center (FPC) prepared responses to queries by the Fish Passage Advisory Committee and the Oregon Department of Fish and Wildlife (ODFW) that are relevant to the questions before the ISAB.

In preparing this review, the documents examined are listed in Section VI with the references. In addition, this ISAB review benefited from presentations on March 12, 2010 by NOAA, ODFW, and US Fish and Wildlife Service (USFWS). The presentations and other review materials submitted to the ISAB are posted at www.nwcouncil.org/library/isab/2010-2/Default.asp.

III. Synopsis of Primary Material Provided by NOAA, FPC, ODFW, and USFWS

In reviewing these documents and PowerPoint presentations, the ISAB found the information provided by NOAA, FPC, ODFW and USFWS to be very informative. Each presentation provided different aspects of the spill transport question, both in terms of the relevant scientific evidence available and of its ecological complexity.

The major emphasis of the NOAA report concerned analyses of SARs and T:M ratios for two species of concern, spring/summer Chinook salmon and steelhead. NOAA concluded that transport provides higher SARs for both species and would be favored in 2010 under projected conditions of low flow and unfavorable ocean conditions.

The FPC review of the NOAA report focused mainly on the potential effects on other species, effects of transport on straying, and a comparison of spill versus transport in years with similar ocean conditions (2005 vs. 2007). Survival between Lower Granite (LGR) and McNary (MCN) was compared for smolt release groups, and higher in-river survival was found between these dams in 2007, a higher spill year, compared with 2005, a lower spill year. This result does not necessarily contradict overall results of the NOAA analysis in showing higher SARs for transported, rather than in-river migrant, steelhead. That is, survival may be better between these dams with more spill, but overall SARs for the entire life cycle still may be higher for transported fish.

ODFW also presented the same survival information as the FPC, which clearly showed that increased spill was associated with increased in-river survival for Chinook and steelhead between LGR and MCN. They also argued strongly for the benefits of maintaining the river as a migratory habitat, beneficial effects on other salmonid and non-salmonid species, straying impacts from transported fish, and impacts of potentially depensatory predation on the fish remaining in the rivers under no spill. Further, they emphasized the potential usefulness of using this year as an opportunity to evaluate the benefits of spill in a low flow year.

The USFWS presentation noted that 2007 was the only low-flow year where spill was provided at the juvenile fish collection and transportation projects. They too emphasized that additional years would help improve understanding of spill effects under low-flow conditions. Further, they emphasized the potential costs of no spill to depressed lamprey populations.

Immediate benefits of higher SARs and T:M ratios from proposed May 2010 transportation, versus spill, were emphasized in the NOAA report and presentations. NOAA briefly discussed impacts on other species and potential straying, but indicated that data were not adequate to evaluate their impacts accurately. The observed benefits of spill on in-river survival of spring/summer Chinook and steelhead were deemed insufficient to overcome the benefits of May transportation of steelhead and spring/summer Chinook.

The FPC, ODFW, and USFWS emphasized: 1) less quantifiable impacts to other species, including sockeye and lamprey, 2) well-documented increased straying impacts from transported fish, 3) potential effects of no spill on the fish not transported, 4) the benefits of maintaining an ecologically functioning river, and 5) the need to corroborate and compare benefits of spill in 2007 with a second low flow year.

IV. ISAB Conclusions

1. Multi-species Perspective

Based on ecological principles and considering the uncertainties of the data, using combinations of transport and in-river migration with spill spreads the risk across species, stocks, and the ecosystem, while offering an approach that can shed light on uncertainties in the longer-term dataset.

2. Operational Changes – Lessons Learned

The ISAB concluded (ISAB 2008-5) that a mixed strategy of spill and transport during the critical spring migration period allows learning from spill conditions and supports potential advances in knowledge to improve decision-making in the future. This conclusion remains as valid in 2010 as in 2008. A mixed strategy in low-flow conditions provides an important opportunity to learn from the concurrent spill and transport mix of recent years.

3. Addressing Uncertainties – Lamprey

There remains a gap in knowledge of the effects of various spill-transport operations on downstream juvenile Pacific lamprey migration. Development of a suitable means of tracking migrating juvenile lamprey is a critical need. Information on Pacific lamprey response to hydrosystem operations, including spill-transport, would be vastly improved if mark-recovery methods were available for juveniles.

4. Addressing Uncertainties – Sockeye

Studies to examine the relative benefits of spill and transport for sockeye were initiated in 2009 and anticipated to continue in 2010. These studies could provide important additional information to reduce uncertainties relevant to sockeye juvenile migration.

5. Addressing Uncertainties – Straying

Out-of-basin straying remains a concern for some steelhead stocks. The reports that steelhead transported from the Snake River on barges have a higher straying rate and lower homing rate than fish migrating in-river adds to the concern. Information is needed to inform efforts to minimize the number of out-of-basin strays spawning in Lower Columbia tributaries.

6. Spill as the Baseline – Ecological and Evolutionary Considerations

The premise that spill more closely mimics natural situations and ecological processes than maximum transportation leads to a mixed strategy of concurrent spill and transport to conserve diversity and future potential of the ecosystem.

V. Examination of the ISAB's 2008 Recommendations Given New Information

This ISAB review focuses on new data, analyses and conclusions within the context of the previous ISAB spill-transport report (ISAB 2008-5), though not all material cited in 2008-5 is incorporated in this review. This review does not make policy recommendations but rather attempts to present current scientific understanding in a form that can be used by policy makers.

The ISAB also referred to the NPCC 2009 Fish and Wildlife Program (NPCC 2009-9) for guidance, specifically the Hydrosystem Passage and Operations Strategies section. This section identifies primary strategies designed to provide conditions within the broader hydrosystem for fish that: "1) most closely approximate the natural physical and biological conditions; 2) provide adequate levels of survival to support fish population recovery based in subbasin plans; 3) support expression of life history diversity; and 4) ensure flow and spill operations are optimized to produce the greatest biological benefits for the targeted species with the least-adverse effects on other fish populations and species important to the Program …".

For reference, the recommendations from ISAB-2008-5 are numbered and indented below:

A. Multi-species Perspective

> ISAB 2008-5 Recommendation #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."

As stated in 2008, with maximum transport some species survive at a higher rate and return more adults, and other species and stocks face higher survival risk. If flow in 2010 is similar to 2007, a mixed strategy of concurrent spill and transport would provide a second year of results on spill in a low flow year, thereby providing a more robust evaluation of spill during low flow years. Based on ecological principles and considering the uncertainties of the data, using combinations of transport and in-river migration with spill spreads the risk across species, stocks and the ecosystem, while offering an approach to shed light on uncertainties in the data. Allowing a significant proportion of the Snake River stocks to run the river, even in a low flow year, provides more natural river conditions than barging.

B. Operational Changes—Lessons Learned

> ISAB 2008-5 Recommendation #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."

SARs and In-river Survival

The evidence presented in the 2010 NOAA Fisheries document (NOAA 2010) indicates that for the May period, SARs are generally higher for transported fish than for the in-river migrants, so T:M ratios were above 1 for both species. These conclusions are supported by Figures 2-9 (NOAA 2010). There are some exceptions, however. As indicated in our previous review (ISAB 2008-5), "*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."*

The results shown in Table 7 of the FPC report and Slide 8 of the ODFW presentation indicate that higher spill favors in-river survival of hatchery and wild Chinook salmon and steelhead, as well as sockeye. As indicated in our previous review (ISAB 2008-5), *other analyses … indicate that as spill increases, in-river survival increases and the relative benefit of transportation decreases."* Results from analysis of 2007 migration year data show the benefits of increased spill to in-river survival, but available evidence indicates that it is insufficient to compensate for the higher SARs for transported fish, compared to SARs for in-river migrants.

Adaptive Management Considerations

The ISAB's 2008 review recommended, *"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."* This recommendation supports an *active* adaptive management approach, where scientific uncertainties phrased as specific hypotheses can and should be tested to inform and improve management decisions. Active adaptive management is not merely a response to conditions, but rather an active, scientifically informed approach to gaining the data needed for future management decisions (Holling, 1978; Walters, 1986).

A clearer understanding is needed of the various short-term and long-term benefits of transportation versus spill for salmon recovery. In this case, transportation has been ongoing for decades, but until 2006, little information was available on the absolute and relative benefits of spill. Actions beginning in 2006 and expanded in 2007 and 2008 have resulted in a decrease in the percentage of transported fish (NOAA Report, Table 1, page 2). It can be argued that more effective and more rapid evaluation of tradeoffs between spill and transport are best evaluated in years of more extreme conditions. In extreme years, undocumented environmental factors and sampling error are less likely to mask measurable biological and ecological responses.

An active adaptive management approach was recommended by ODFW. They argued that 2010 would provide a good year to test flow-spill results from 2007 (the other low flow year where May spill occurred) and that spill in May 2010 would provide a “valuable opportunity to learn” (Slide 17), whereas the transport option would result in a “lost opportunity to test 2007 results” (Slide 19). It was argued that benefit can be gained from the evaluation of spill in a low flow year, no matter what the ocean conditions, as long as appropriate monitoring occurs. The USFWS also noted this potential by listing three benefits of spill in 2010:

- 2007 is the only low-flow year where spill was provided at the [juvenile fish collection and] transportation projects. Additional years would help improve understanding of spill effects under low-flow conditions.

- The first large-scale release of PIT-tagged sockeye for evaluating transportation versus in-river migration with spill occurred in MY [migration year] 2009, with adults returning in 2010 and 2011.

- Second year of large-scale release of sockeye is MY 2010, with adults to return in 2011 and 2012. Eliminating spill in 2010 would severely limit the information obtainable on sockeye in 2010.

The scientific benefits may be especially important in low flow years, because projected declines in water availability in this century may result in more years having low flow projections, compared with historical levels (ISAB 2007-2). The active view of adaptive management outlined by ODFW and USFWS is action oriented, emphasizing the use of management strategies for hypothesis testing and generating knowledge to inform future decisions. In contrast, the FCRPS BiOp Adaptive Management Implementation Plan (AMIP) describes a more reactive approach, emphasizing monitoring and detection of “trigger” conditions.

Comparison of Years 2001, 2005, 2007

Although PIT tags have been used to study the migrations of Columbia Basin salmonids since the mid-1990s, Snake River flows were relatively high from 1995 through 2000. Flows have been lower in recent years with the exception of 2006, with the lowest flows in 2001 (3^{rd}-lowest flow in the past half-century), 2005 (8^{th} lowest), and 2007 (10^{th} lowest). Currently, flows for 2010 are projected to be lower than in 2005 and 2007 but higher than in 2001 (National Weather Service Northwest Forecast Center (www.nwrfc.noaa.gov). Migration and survival data obtained from PIT-tagged fish in 2001, 2005, and 2007 are of interest for evaluating how effective transportation and enhanced spill might be as river-management strategies in 2010. An analysis based primarily upon data for these three years is summarized in Table 1, which compares river and marine environmental conditions, in-river migrant survival rates, and smolt-to-adult survival rates for Snake River spring/summer Chinook salmon, steelhead, and sockeye salmon for 2001, 2005, and 2007. The data in this table are intended to be representative of the three years and cannot represent many of the nuances and intra-seasonal trends and changes discussed in detail in NOAA Fisheries and FPC reports and memos.

In 2001, the water supply in the Snake River Basin was exceptionally low resulting in low spring flows and warmer than average water temperatures. Federal management agencies decided to eliminate spill at the Snake River dams during the juvenile migration season, so that almost all (95-99%) juvenile fish entered bypass systems and were diverted into fish-transport barges. This strategy appeared to avert disaster, as only small percentages of the fish remaining in-river survived passage through the FCRPS (in-river survival, S_R, was 23 to 33% for Chinook and sockeye salmon, and 4% for steelhead; Table 1), and smolt-to-adult returns (SARs) for in-river fish (category C_1, Table 1) ranged from 0.02 to 0.14%. Transported fish, on the other hand, returned at relatively high rates (SARs of 1.1 to 2.5%; category T_0, Table 1). Ratios of SARs for transported versus in-river fish (i.e., C_1:T_0, designated as T:M in Table 1 were extremely high, ranging from 9:1 to 60:1. The relatively high return rates for transported fish were likely also a consequence of favorable ocean conditions (Table 1). However, the absence of spill in 2001 precluded gaining information on the in-river survival and SARs of fish passing through the FCRPS under conditions that facilitated dam passage.

Indices of marine conditions (see footnote 2, Table 1) remained high from 1999 through 2002, and returns of adult fish from the juvenile migrations in those years were the strongest seen for decades (Columbia River DART, University of Washington; www.cbr.washington.edu/dart/). Ocean-condition indices began to decline in 2003, reaching a low point in 2005 before improving in 2007.

The poor ocean conditions in 2005 coincided with a low-flow year in the Snake and Columbia rivers. Flows during the mid-April to late May juvenile-migration season were higher than in 2001, however, and more water was diverted over spillways than in 2001 (Table 1). As in 2001, most (86 to 94%) of the juvenile fish migrating in the Snake River were collected and transported downstream. In-river survival rates (S_R) were higher than in 2001, particularly for steelhead, presumably due to the moderately higher flows and spills in 2005. The SARs of in-river fish (C_1) were also generally higher in 2005 than in 2001 (although about the same in the two years for wild Chinook and sockeye salmon). SARs for transported fish (T_0) were, however, much lower in 2005 than in 2001 (hatchery steelhead were an exception), corresponding to the low ocean-condition indices. Higher SARs for in-river migrants (C_1) and lower SARs for transported fish (T_0) resulted in lower T:M values in 2005 (2:1 to 8:1) than in 2001 (9:1 to 60:1).

A third low-flow year occurred in 2007, after marine conditions had improved from the low levels of 2005. In contrast to 2001 and 2005, spill was provided at Snake River dams with the specific intention of assisting the dam passage and migration of juvenile salmon and steelhead. This mixed spill and transport program began in 2006, so 2007 is the only low-flow year to date with increased spill operations. Because many fish passed the dams via spillways, rather than entering juvenile-fish bypasses, much smaller percentages of fish were transported in 2007 (17 to 53%) than in the two preceding low-flow years (86 to 99%). The migration rates of in-river Chinook salmon were increased (travel times were decreased; FPC, 2009 Annual Report), and S_R rates were higher than in 2001 or 2005 (Table 1). In-river survival rates (S_R) were comparable with survival rates in 2002 and 2003, higher-flow years with intermediate spill levels (FPC, 2009 Annual Report).

Returns of two-ocean steelhead adults from the 2007 juvenile migration are not complete at the present time so SARs cannot be estimated. Returns of two-ocean Chinook salmon adults are complete, and SARs have been estimated for the 2007 outmigration, but will be revised after data for three-ocean returns are available in the summer of 2010. SARs for two-ocean wild and hatchery Chinook salmon juveniles that migrated in-river in 2007 (C_1: 0.59 and 0.25%) were considerably higher than for Chinook salmon juveniles that migrated in-river in 2001 (0.14 and 0.05%) or 2005 (0.11 and 0.12%). SARs for wild and hatchery Chinook salmon juveniles that were transported in 2007 (T_0: 0.93, 0.45%) were higher than in 2005, presumably reflecting improved ocean conditions, but lower than in 2001, when ocean conditions were also favorable. The relatively high SARs for in-river migrants and intermediate SARs for transported fish result in the lowest T:M values (1.2:1 for wild fish and 1.8:1 for hatchery fish) estimated for Chinook salmon over the three years.

Much of the in-river mortality of steelhead juveniles occurs in the McNary reservoir, as a result of predation by the Crescent Island Caspian tern colony. Predation rates by terns on PIT-tagged smolts were considerably lower in 2007 than 2004-2006. Roby et al. (2007) concluded that the reduced predation rate was due to several factors: declines in the population of the tern colony, and lower predation on steelhead smolts during high flow years and/or when large numbers of steelhead migrate past Crescent Island in a relatively short period of time. The high spill in 2007 resulted in more fish in the river and more rapid downstream migration for steelhead than 2005 which had less spill. In 2009, a high flow, high spill year, W. Muir (NOAA, unpublished data) reported that fewer PIT tagged steelhead were eaten by piscivorous birds near the confluence of the Snake and Columbia rivers, resulting in increased estimated survival. Hence, eliminating spill and increasing the percentage of steelhead barged suggests a detrimental effect on those remaining in-river by increasing their vulnerability to predation (Muir et al. 2008). The per capita consumption of juvenile salmonids by the Crescent Island terns in 2007, however, was similar to previous years.

These comparisons of survival data for 2001, 2005, and 2007 suggest that:

(1) Juvenile salmon and steelhead that migrate through the hydropower system in low-flow, low-spill years do not survive downstream passage as well as they do in higher flow, higher spill years.

(2) In-river survival rates increased and T:M ratios decreased; that is, the smolt-to-adult survival advantage of transported fish decreased when spill levels increased from 2001 to 2005, and again when spill levels increased from 2005 to 2007. This trend suggests that SARs of in-river migrating juveniles may be improved by provision of adequate spill.

(3) In the absence of spill and presence of unfavorable ocean conditions (El Nino), the downstream migration of any non-transported fish will be prolonged, as in 2001, resulting in poor body condition and increased predation mortality, and the surviving fish will likely encounter unfavorable conditions in coastal waters (as apparently occurred in 2005). The probable result would be very low survival rates for in-river migrating fish.

(4) With the currently available data limited to a single low-flow, high-spill year (and with no SAR estimates yet available for steelhead outmigrating in that year), no firm conclusions are possible. Regardless of the sample sizes obtained in any one year and the thoroughness of statistical analyses, a number of years of data will be needed before firm conclusions regarding the relative merits of transportation and spill under low flow conditions are possible.

Knowledge Gains for Future Decision Years

Chinook and steelhead

There is a sense of urgency in the discussion about spill and transportation in 2010, which is anticipated to be a low flow year, perhaps well below 2007. It also is anticipated that ocean conditions will be unfavorable for salmon and steelhead as well, in contrast to 2007. In response, NOAA has argued that the combined in-river and ocean conditions make it particularly important to mitigate in-river survivals via transport to the maximum extent possible.

Although this is a compelling argument, the lost ability to learn more about these effects may be equally compelling. Analyses summarized in NOAA (2010) add important detail to the seasonal patterns in T:M ratios, but they do not explain inter-annual variation for in-river survivals and SARs. They do not clarify the ecological effects of flow, spill, temperature, run size, or transport on fish left in the river. Consideration of the additional effects on SARs, in-river survival, and T:M was beyond the scope of the NOAA analysis, but these remain important questions that can be informed with larger data sets representative of the range of flow conditions that emerge. Continuing the contrast of both spill and transportation during poor years should increase information available to inform critical management decisions in future years.

The potential ecological effects on in-river migrants remain an important concern in the spill-transport tradeoff. If in-river conditions are substantially degraded in extreme years, the apparent transport benefits will be biased upward. Recent analyses attempt to correct the baseline T:M ratio for bias in survival of bypass-migrant vs. in-river fish that is caused by using only detected fish. The bias appears to be small, on average, but there does appear to be substantial variability among years and species that is still not understood. The USFWS has argued that the effect should also change seasonally and that it might be substantial. The adjusted baseline approach cannot address seasonal patterns, because the reference fish are not detected and time of migration is unknown.

The uncertainty and debate regarding transportation and spill will not be resolved in 2010, or likely in the next few years. There are too many potential interactions among season, species, flow, spill, transport and ocean conditions to allow a rapid resolution, but that should not argue against efforts to obtain better information as quickly as possible. Spill and transport are the only variables that can be controlled to any extent and understanding their interactions and potentially confounding effects remains important. Flow, spill, temperature and transport tend to be correlated; therefore, attempts to analyze their effects independently may be confounded or obscured. Continued spill and evaluation of the T:M ratio during a period of low flows and poor ocean conditions may offer a particularly important contrast. Compromising the comparison of migrant and transport effects in extreme years may only lengthen the time required to gain useful information. There is a general consensus in projections of climate change that snow packs will decline and melt will occur earlier, with anticipated shifts in the timing, magnitude and rate of recession of spring hydrographs (ISAB 2007-2). Timing of peak flows is likely to be earlier and low flow years more common and more extreme (e.g., Luce and Holden 2009). Understanding the implications of those conditions in the spill-transport tradeoffs, as quickly as possible, seems particularly important.

ISAB 2008-5 concluded that, "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." We find no compelling reason to alter this conclusion, and in fact, would suggest that the extreme conditions anticipated in 2010 may be an even more important time to maintain the spill-transport balance of recent years.

C. Addressing Uncertainties–Lamprey

> ISAB 2008-5 Recommendation #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."

In this section, we consider the question of whether reduced spill in May could elevate lamprey mortality. We note that components of this question were dealt with in some detail in two recent ISAB documents (2008-5, 2009-3) and refer below to those reports as well as to the limited new information that has appeared recently in the scientific literature. Previously, our general response to the question was that the impacts of alternative spill-transport scenarios for lamprey exemplify the larger point that what benefits one species may sometimes harm another. Consideration of possible impacts on lamprey should acknowledge that insufficient information is available on the ecology and habitat requirements, including passage, of lamprey.

In ISAB 2008-5, we noted that bottom-oriented juvenile lamprey, or macrophalmia, 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 bar screens that caused significant impingement, then passage over the dams during spill would increase survival proportions. However, there are currently no data on lamprey spillway use, on their survival via spillway migration, or the effects of bar screen impingement on survival proportions. Increased flow to bypass systems to transport more salmonids would likely also result in more lampreys being transported. Since the effects of transport have not been evaluated for lamprey, we cannot say how this would affect survival.

In a very recent study, Moser and Russon (2009) suggested that it would be advantageous to separate macrophalmia with screens at the exit raceways and move lamprey back to the river after being caught in the salmon collection bypass systems. Field and laboratory tests were conducted at McNary Dam and showed that while separator orientation and site were critically important to passage, the separator material was less important. Macrophalmia moved through both 6.5-mm square woven stainless steel mesh and 25- by 6-mm stainless steel perforated plate.

Replacing raceway screens may have unforeseen consequences for salmonid fry and other small fish species. Moser and Russon (2009) recommended field testing of any new lamprey-friendly material to ensure that it does not negatively impact other species. We concur with this recommendation.

There are many reasons for the observed reductions in range and abundance of Pacific lampreys, and no single threat can be pinpointed as the primary reason for their decline (Luzier 2009).

Transporting most salmonids would likely increase predation risk for juvenile lamprey passing through turbines (NOAA Fisheries, Smith and Muir presentation to ISAB March 12, 2010). This example reinforces the concept of taking an ecosystem approach to spill operations.

Significantly more knowledge of lamprey survival under mixed spill and transported would be gained if suitable tags were available for juveniles of this species. In our 2009 review of the draft Tribal Pacific Lamprey Restoration Plan for the Columbia River Basin (ISAB 2009-3), the ISAB was asked to comment on the Plan's proposed activities relating to juvenile lamprey passage. The Plan proposed an activity entitled "Develop route-specific dam passage and survival estimates", which would have direct application to the spill-transport question. The ISAB agreed with the Tribe's view that development of a suitable tag for juvenile lamprey should be given high priority to facilitate these estimates. While efforts continue to develop a juvenile tag (see ISAB-2009-3), and should be encouraged further, suitable technology is not yet available.

D. Addressing Uncertainties–Sockeye

> ISAB 2008-5 Recommendation #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 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, estimating passage and survival of Upper Columbia River sockeye passing lower Columbia River dams could provide valuable insights."

Returns of adult sockeye salmon to Bonneville Dam in 2008 and 2009 were the highest in recent history. It remains unclear whether to attribute these surprising returns to freshwater conditions during downstream migration in 2006 and 2007 (including increased spill and reduced transportation) or to favorable conditions at sea. Although most of these sockeye originated in the mid-Columbia, the increase in adult returns was disproportionately higher in the Snake River. Adult sockeye returns to the Snake River were 11 to 15 times greater than the mean return over the previous 8 years, whereas adult returns to the mid-Columbia were only 2.6 to 3.4 times the previous 8-year mean. The 8-year base period corresponds to smolt migration years 1998 to 2005, and is selected for comparison here because reliable estimates of smolt abundance at McNary Dam have been obtained only since 1998 (FPC memo 18 Feb 2009).

Much of the increase in adult returns in the Snake River can be attributed to increased smolt abundance. Taking smolt abundance into account, the differences in smolt-to-adult survival (SAR) between the Snake and mid-Columbia sockeye populations are less obvious. Compared with mean values over the previous 8 years, SARs for smolts migrating downstream in 2006 were 2.1 times higher in the Snake River and 2.0 times higher in the mid-Columbia River; SARs in 2007 were about 3.5 times higher in the Snake River and 2.4 times higher in the mid-Columbia. Although the reliability of these SAR estimates might be questioned, it appears that sockeye SARs have improved to a greater extent in the Snake River than in the mid-Columbia River.

New data for the 2009 returns and additional analyses by NOAA and FPC (subsequent to ISAB 2008-5) generally strengthen the ISAB's concerns about the effect of transportation on sockeye smolts. Snake River sockeye SARs now appear to be negatively correlated with proportion transported and positively correlated with in-river survival and percent spill. The negative correlation between sockeye SAR and percent transportation, coupled with extensive empirical evidence for descaling of sockeye smolts in bypass systems, strongly suggests that sockeye smolts do not benefit from transportation. However, the explanation is not completely convincing, because no data exist to confirm expectations that sockeye smolts experience less injury and descaling when they pass dams over spillways, rather than through bypass systems.

In general, SARs for the Snake and mid-Columbia populations are strongly positively correlated, suggesting a similar response to shared conditions such as marine climate (NOAA Feb 2009) or freshwater flows (FPC memo 18 Feb 2010). The ISAB recognizes that marine conditions can strongly affect SARs and that the positive correlations between SARs and percent spill described above might be spurious, driven more by marine than freshwater conditions. However, several considerations weigh against concluding that the increase in sockeye SARs is explained by marine rather than freshwater conditions. First, no specific hypothesis has been offered with supporting empirical evidence to explain how or why marine climate has been favorable to sockeye smolts, in contrast to the hypotheses about conditions that favor in-river survival. Second, any such marine hypothesis would have to explain why marine conditions in the same two years (2006 and 2007 sea-entry) have been very unfavorable to sockeye smolts from other geographically proximate populations whose SARs also have been measured (Lake Washington in Puget Sound, Chilko, and Cultus lakes in the Fraser River, Sakinaw Lake in Georgia Strait). Given this uncertainty, it seems plausible that transportation of sockeye smolts adversely affects their survival.

Knowledge Gains for Future Decision Years

Sockeye

The NOAA analysis (2010) found no evidence of spill, flow or transport effects on in-river survival or SARs for Snake River sockeye, after statistically adjusting for Upper Columbia sockeye numbers, to account for common ocean conditions. One interpretation might be that in-river conditions including flow, spill and temperature are not key factors in sockeye returns. It is important to note, however, that in-river survivals vary by more than three-fold, differences that could prove important to persistence of endangered Snake River stocks in a protracted period of poor ocean conditions. We also note that lack of statistically significant relationships does not necessarily support a conclusion that an important effect does not exist. The scatter plots presented in the sockeye analysis (Figure 8, NOAA 2009) are not inconsistent with a hypothesized negative relationship of survival with temperature and positive relationships with flow and spill. A spill-flow interaction is plausible, based on the observations in 2007.

There is also a significant negative relationship between proportion transported and in-river survival that was not considered in the NOAA (2009) analysis. The negative relationship suggests reduced survival with reduced in-river migrants consistent with depensatory mortality due to predation as hypothesized by the ISAB (2008-5), although such analysis ultimately should be conducted with smolt numbers, rather than with the proportion transported. Speculation on the potential effects on survival is clearly limited by the number of observations and the influence of outliers (e.g., 1996) or by observations with high leverage (e.g., 2001) in the NOAA figures. The number of observations also limits consideration of potentially important interactions. We cannot conclude that these relationships imply important flow, spill or transport effects, but rather that they suggest that such effects remain possible. Simply put, more observations are needed to understand whether important relationships exist.

NOAA acknowledged that the "analyses were correlative and limited by the type and amount of data currently available and that additional research will be required to develop more robust, definitive information on the factors affecting sockeye salmon in both river and ocean environments." They also argued for studies that "directly measure the effects of transportation, evaluate the high variability in smolt survival from traps in the Snake River to Lower Granite Dam, provide measures of survival past dams and downstream of Bonneville Dam, and lead to development of ocean productivity indices to predict adult sockeye return rates." Given the possibility of important in-river effects influenced by spill and transport, and the status of Snake River sockeye populations, gaining that information as quickly as possible seems particularly important.

The question remains whether no spill and maximum transport in 2010 will seriously compromise development of needed information. Direct evaluation of T:M for SARs is an important objective, but as NOAA indicates the adult returns to date have been far too low to provide any meaningful comparisons. Recent efforts to PIT tag sockeye released in the Snake River basin in 2009 and planned for 2010 provide the potential for better information. Maximum transport in 2010 would essentially negate that potential. The mark numbers (65,000 reported by USFWS in the recent meetings) are larger than those used in the past (< 45,000 between 2002 and 2007), but if ocean conditions are particularly poor, adult returns may still be too low for meaningful comparison. There is a risk that the experiment could be non-informative, even if spill is continued. As suggested above, continued development of information on in-river survivals will be important and, based on the existing relationships, the contrast of low flow with some spill could be particularly informative. The potential gain of T:M information for sockeye and other species would be an added benefit of a mixed strategy.

ISAB (2008-5) concluded, "Data are insufficient to determine whether transportation benefits or harms Snake River sockeye." We find no compelling reason to alter this conclusion. Recent work to consider the relative benefits of spill and transport for sockeye initiated in 2009 and anticipated to continue in 2010 could provide important, additional information particularly relevant to this issue. The results of further trials could continue to be equivocal, but failure to effectively carry the trials forward will ensure that they remain equivocal.

E. Addressing Uncertainties–Straying

> ISAB 2008-5 Recommendation #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/summer 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."

Steelhead

NOAA estimated a straying/wandering rate of 3-5% (based on conversion of PIT tagged steelhead passing Bonneville vs. Lower Granite). The University of Idaho (Peery 2008), Ruzycki and Carmichael (2010) and the Fish Passage Center (2010) have summarized recent data on straying of Snake River steelhead.

They reported that steelhead from the Snake River, transported on barges, had a higher straying rate and lower homing rate than fish migrating in-river, especially into the Deschutes and John Day basins. Out-of-basin strays were a significant component of the steelhead spawning in the John Day basin (where no hatcheries exist), based on PIT tag and radio-telemetry detections. These out-of-basin strays may be influencing the recent decline in the productivity of John Day steelhead (see Chilcote 2003; Araki et al. 2009). Hence, reducing these strays may provide a significant increase in productivity of Middle Columbia steelhead populations.

For unclipped steelhead, 2.0% of the in-river fish strayed vs. 7.3% of the transported fish. For clipped steelhead, these rates were 7.6% vs. 10.2% for in-river and barged fish, respectively (Peery 2008). The large number of adult steelhead entering the Columbia River means that thousands of fish stray into steelhead tributaries, mainly the Deschutes and John Day rivers. For example, the spawner escapement to the John Day was about 9,000 in 2007, and based on recovery of tags 1164 (13%) were hatchery strays, mostly originating from Snake River stocks (Ruzycki and Carmichael 2010). Since 2004, EMAP surveys in the John Day indicated that 27% of the live steelhead on spawning grounds had adipose fin clips and therefore were out of basin strays. In 2007, hatchery steelhead comprised 35% of the steelhead observed. Coded-wire tags recovered from hatchery steelhead collected on spawning grounds indicate that many of identifiable out-of-basin strays entering the John Day River originate from Snake River stocks (Ruzycki and Carmichael 2010).

Evolutionary Aspects of Straying

Some published work addresses what happens when genetic material that has been selected for good performance in habitat A is delivered into the gene pool of a population that has been selected for good performance in habitat B (Ford 2002). This work emphasized hatchery and wild populations of the same species with empirical data on the hatchery-wild exchange in fish populations. In general, if the rate of inflow is small, relative to the severity of selective differences, the local population can adjust to a small level of genetic infiltration from A, and perhaps even benefit. On the other hand, too much inflow, or too fast an inflow, can overwhelm the receiving population, and there are examples of that as well. In other words, some gene flow is the glue that holds a widespread species together, and it provides some protection against low population sizes and inbreeding, but it is possible to overdo genetic exchange. If steelhead adapted to the Snake River drainage stray and spawn in the tributaries of the lower Columbia where steelhead are naturally adapted to very different conditions, and if that straying rate is substantial as measured relative to the local population size, a reduction in fitness is probable.

The numbers of new immigrants have been characterized as either alarming or trivial, depending on one's perspective. Five percent immigration can be either a little insurance against inbreeding depression or a significant threat to local adaptations, depending on the genes coming in, relative to local adaptive norm. Straying is a natural phenomenon, even among fish that run the river, but most data suggest that the rate is substantially higher for transported fish.

F. Spill as the Baseline: Ecological and Evolutionary Considerations

> ISAB 2008-5 Recommendation #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."

Ecological Considerations

The uses of spill and transport in the Columbia River Basin have many ecological implications, as noted throughout this report. Here, we highlight one that addresses an issue that was prominent in the presentations and materials brought to this review, the consequences of spill and transport strategies for in-river conditions of predation.

In ISAB 2008-5, we identified the influence of transportation on the number of in-river migrants as an ecological concern. Reduced number of in-river migrants, with increased transportation, could result in an increased rate of avian predation on fish remaining in the river. Citing recent work on the Snake River, the ISAB speculated that predation rates could be reduced when flows are high or when fish move past bird colonies relatively quickly. The implication is that mortalities might be accentuated when flows are low or travel times reduced. Similarly, increased mortality might also result through predation by northern pikeminnow and other fishes in Columbia and Snake River reservoirs (Vigg 1988; Beamesderfer et al. 1990). Considerable work has occurred on the influence of predation in the last 20 years resulting in major efforts to reduce its effects by reducing the number or altering the distributions of avian and fish predators. Some recent efforts have explored complex ecological effects such as Wiese et al. (2008) linking bird and fish predation by outlining a complex interaction between juvenile salmonids, pikeminnow that prey on them, and terns that prey on both salmonids and pikeminnow. That work suggests a counter-intuitive response of reduced overall predation on salmonids as their numbers decline, because terns begin feeding on pikeminnow rather than salmonids. Others have shown that predation can vary dramatically with temperature and other environmental conditions that have strong seasonal and inter-annual variability indicating that predation could increase dramatically with warming in the river (Peterson and Kitchell 2001).

Despite the obvious importance of predation-related mortality and the potential for this to be related to the numbers of fish in the migration channel, the nature of any depensatory mortality caused by avian or fish predation remains largely theoretical. Because of the potential implications and lack of strong empirical information, the ISAB (2008-5) emphasized the need to consider SARs and in-river survival in relation to migrant *numbers* and not just T:M ratios used to consider transport benefits. It is clear that SARs and in-river survivals vary strongly across years, season and species, and there is some evidence that transportation or migrant number may be associated with that variation (ISAB 2008-5). Recent analyses have not focused on the potential effects of transportation and spill on in-river fish that may experience depensatory mortalities and migration delays. The potential influence of migrant numbers on in-river survival and SARs remains an important concern.

Evolutionary Considerations

River conditions, including those arising from natural environmental variation and those created deliberately or inadvertently by human actions, are major selective forces for salmonids. The latter are of particular concern when they create strong directional selection for a narrow range of adaptive strategies.

There is little question that hydropower development has fundamentally altered the environmental conditions for salmon. Selection pressures on a suite of life-history characteristics are now very different than those existing over much of the evolutionary history of fishes in the Columbia River (see Waples et al. 2007, Crozier et al. 2008; McClure et al. 2008 for reviews). There is evidence that adaptation to altered conditions is already occurring in some stocks (Quinn and Adams 1996; Waples et al. 2007; Williams et al. 2008). Anticipating and managing the effects of the artificial selection imposed on different species, populations, life history types and even run segments, however, are extremely challenging. Transportation adds to the complexity through the differential mortality experienced between transported fish and in-river migrants (Waples et al. 2007). The differential reflected in T:M ratios suggests that resulting selection may have a strong seasonal component associated with timing of transport and seasonal patterns in transportation benefits. Because that selection must interact with life history characteristics that evolved in response to other constraints on growth and survival such as thermal regimes, forage availability, flow regimes, flow and migration rate, vulnerability to predation and timing of ocean entry, transportation could both offset and aggravate other changes associated with altered river and ocean conditions (e.g., Crozier et al. 2008). It might also impose new constraints on the potential to adapt to continually changing conditions. Transportation may favor later migration, for example, while the ocean or hydrologic changes associated with climate and land use changes might impose the opposite pressures.

ISAB (2008-5), Crozier (2008) and Waples et al., (2007, 2008, and references therein) consider the implications of climate change, hydropower, and other changes in the system for life history traits with strongly heritable components. Artificial selection on size, age and timing of migration seems almost unavoidable. Arguably, strong selection for and adaptation to transport could favor the long-term persistence of stocks faced with degraded habitats, climate change, and increasingly hostile in-river migratory conditions that leave hatcheries and transportation as the only option to obtain positive demographic growth rates for at least some stocks. Alternatively, we know the hydrosystem has a limited life. Strong selection for conditions that are likely to change, perhaps radically and in unknown ways, may only restrict the possibilities by imposing a “Darwinian debt” of adaptation to artificially imposed conditions (Waples et al. 2007) that will be even harder to overcome in the future.

The literature on resilience of ecosystems emphasizes maintenance of biocomplexity, genetic diversity, and diversity in population and life history characteristics as hedges against such uncertainty and change (e.g., ISAB 2008-5; Waples et al., 2007, 2008, 2009; McClure et al., 2008; Healey 2009, NPCC 2009). If maintenance of diversity and complexity is threatened by selection imposed by the hydropower system, an important question remains whether management of transport and spill is likely to increase or decrease genetic and life history diversity. Waples et al. (2007) suggest that partitioning the runs into components such as transport and migrant with different demographic results could have similar evolutionary consequences as hatchery supplementation. Changes in life history diversity seem most problematic if transportation consistently influences one segment of a stock but not others. Strong directional selection from transportation may occur if extreme flow conditions and maximum transportation on a segment of the run becomes the norm.

Alternatively, balancing transportation such that no segment is consistently influenced in one way might reduce directional selective pressures. Further exploration of the tradeoffs and implications from an evolutionary perspective could be useful, but at present it seems virtually impossible to do more than speculate on the net effects of selection associated with transportation. Given this uncertainty, a strategy of balancing risks still seems most likely to conserve diversity and future potential. Heavily favoring transport in a single year may not be particularly problematic, but consistent strong selection for a narrow window of short-term biological success is likely to be problematic.

Holling and Meffe (1996) and others (e.g., Ludwig et al. 1993; Bernhardt et al. 1996; Lichatowich 1999; Williams et al. 2006; Waples et al. 2009) have commented on the long history of human engineering in response to environmental problems, the tendency to favor technological solutions, and the often unintended or unanticipated results. There is no question that the Columbia River has been massively altered by hydrosystem development and changing land use, and that technological solutions will necessarily be part of the response if we are to conserve salmon stocks that serve a diversity of natural functions and human values. The call for conservation of natural processes, minimizing the effects of artificial selection, and maximizing the diversity within and among populations is common in the region (Williams 2006). A strategy that attempts to balance the risks and maintain as much diversity as possible is the strategy best supported by contemporary scientific understanding of ecosystem resilience and management under conditions of uncertainty.

Table 1: Comparison of river and marine environmental conditions, in-river migrant survival rates (SR) and smolt-to-adult survival rates (SARs) of several salmonid species for three recent low-flow years in the Snake River Basin.

Year	Water Supply (Rank)[1]	Spill %	Marine Conditions (Rank)[2]	Species (Origin)[3]	Transport proportion	S_R[4]	SARs[5] C_0 or C_1	T_0	T:M[6]
2001	46/49	1.2	Intermed. (5/12)	Chinook (W)	0.98	0.23	0.14	1.3	9.0
				Chinook (H)	0.98	0.33	0.05	1.1	22
				Steelhead (W)	0.99	0.04	0.07	2.5	37
				Steelhead (H)	0.99	0.04	0.02	0.94	60
				Sockeye	0.95	0.26	0.03	--	--
2005	41/49	28	**Poor** (12/12)	Chinook (W)	0.92	0.28	0.11	0.23	2.1
				Chinook (H)	0.92	0.54	0.12	0.27	2.4
				Steelhead (W)	0.94	0.25	0.17	0.84	4.9
				Steelhead (H)	0.94	0.36	0.24	2.03	8.4
				Sockeye	0.86	0.45	0.03	--	--
2007	39/49	38	Intermed. (6/12)	Chinook (W)	0.17	0.60	0.59	0.93	1.2
				Chinook (H)	0.24	0.63	0.25	0.45	1.8
				Steelhead (W)	0.44	0.38	--	--	--
				Steelhead (H)	0.47	0.49	--	--	--
				Sockeye	0.53	0.62	0.85	--	--
2010	43/49 (predicted)	?	**Poor** (predicted)						

[1]Ranking of water supply above Lower Granite Dam from highest to lowest over the past 49 years. Data obtained from the National Weather Service Northwest Forecast Center (http://www.nwrfc.noaa.gov). The 2010 forecast was issued April 1, 2010.

[2]Indices of physical and biological conditions in the NE Pacific Ocean are reported on the Ocean Ecosystem Indicators web page of NOAA's NW Fisheries Science Center (http://www.nwfsc.noaa.gov/research/divisions/fed/oeip/a-ecinhome.cfm) and the Multivariate ENSO Index web page of NOAA's Earth System Research Laboratory (http://www.esrl.noaa.gov/psd/people/klaus.wolter/MEI/).

[3]The Comparative Survival Study reports most data for hatchery Chinook salmon for individual hatcheries, rather than as composite data. Data for *only Rapid River Hatchery* fish are shown here as representative of hatchery Chinook salmon.

[4]S_R is in-river survival from Lower Granite Dam to Bonneville Dam for Chinook salmon and steelhead, from Lower Granite Dam to McNary Dam for sockeye.

[5]C_1 is the SAR for Chinook salmon or steelhead smolts that were detected in bypasses at one or more of the three uppermost Snake River dams and returned to the river, and C_0 is the SAR for smolts that migrated in-river but not detected in those bypasses (presumably passing over spillways or through powerhouses). Both smolts and returning adults were enumerated at Lower Granite Dam. Estimates of SARs for C_0 fish were not available in 2001 and 2005; C_1 values are shown. The numbers of never-detected fish were higher in 2007 as a consequence of higher spill levels; C_0 values are shown for that year. T_0 is the SAR for fish collected from bypasses at one of the three dams, transported through the hydropower system, and released below Bonneville Dam. The SAR values for sockeye salmon are for smolts migrating from the Sawtooth Valley (with adult returns enumerated at Lower Granite Dam); these fish had unknown passage histories (some were transported and some migrated in-river), and values are shown in the "C_0 or C_1" column only for convenience.

[6] T:M is the ratio of SAR for transported fish (T_0) to SAR for in-river fish (C_0 or C_1). Estimates of T_0, C_0, C_1, and T:M in this table were obtained from several sources.

VI. References and Reports Submitted for ISAB Review

In the list below, references cited in the main body of the report are intermixed with references to materials submitted for the ISAB review. Some of these submitted materials are not cited in the report, but all were reviewed. The materials submitted are followed by the statement "Available at www.nwcouncil.org/library/isab/2010-2."

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