FEDERAL COLUMBIA RIVER POWER SYSTEM IMPROVEMENTS AND OPERATIONS UNDER THE ENDANGERED SPECIES ACT – A PROGRESS REPORT

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EXECUTIVE SUMMARY

The 2008 Biological Opinion (BiOp) calls for improving juvenile and adult fish passage survival through the Federal Columbia River Power System (FCRPS). Implementing the actions specified in the BiOp and evaluating their effects on Pacific salmon and steelhead listed under the Endangered Species Act are high priority objectives for the Action Agencies (AA), which include the Bonneville Power Administration, U.S. Army Corps of Engineers (Corps) and U.S. Bureau of Reclamation. This paper assesses and discusses the results, which include quantitative analyses of fish passage and survival. Monitoring results and performance tests indicate that the new configuration and operation of dams have improved juvenile fish survival through the FCRPS to levels roughly comparable to those realized decades ago, when fewer dams were in place. Annual estimates indicate an upward trend in survival of juvenile steelhead and yearling Chinook salmon migrating through the Snake and Columbia rivers over the last two decades, as described later in this report. Analyses indicate that this is a result of collective management actions implemented at individual dams and system-wide, as described and documented in this report.

The increases in juvenile survival are the result of a science-based system overhaul that began in the 1990s and has continued and expanded in recent years. A key strategy has been to increase the survival of smolts through all passage routes at each dam. In pursuit of that goal, all Lower Snake and Columbia dams now feature surface passage systems such as spillway weirs and voluntary spill[1] programs. These systems are generally the safest routes for fish and increase passage efficiency through routes near the surface, where smolts naturally migrate. Surface passage systems situated in or near spillways improve the effectiveness of the spill by attracting smolts to that area, using less water and yet generally achieving better attraction and survival than conventional spill, which requires smolts to dive in search of spillway openings. These passage routes also reduce forebay residence time, thereby contributing to faster migration though the entire FCRPS, reducing exposure time to predators. Other actions work in concert with these passage routes to improve overall dam survival; these actions include improved turbine survival, improving screened bypass

[1] Voluntary spill refers to spill provided to promote juvenile fish passage, while involuntary spill is forced spill caused by large volumes of water in the river.

systems, relocating outfalls, and providing conventional spill. Results of performance testing indicate that overall juvenile fish survival is now on track to meet survival performance standards for dam passage (96% and 93%, for spring and summer migrants, respectively) prescribed by NOAA in the 2008 BiOp.

Other actions have been implemented to improve survival through the FCRPS. Many are system-wide in scope and include providing flow augmentation from storage reservoirs and controlling predator-related mortality from fish, birds and marine mammals. Flow augmentation increases water velocity and smolt migration speed, reducing travel time through the system of dams and thereby reducing exposure to predators.

Juvenile survival through the FCRPS represents only one piece of the picture. The biological opinion also provides for the transportation of some juvenile fish on barges past dams, which can promote survival relative to in river migration. Broad improvements in the survival of juvenile salmon through the FCRPS have reduced, but not eliminated, the relative benefit of barge transportation. Recent analyses of adult returns indicates that during most of the year, spring-migrating Snake River Chinook salmon and steelhead that are transported as juveniles return at higher rates as adults than their counterparts that migrated through the FCRPS. This indicates that transportation can be tailored to the times of the year when it most benefits migrating stocks, especially steelhead. Whether this pattern persists in light of the recent completion of surface passage systems at all dam remains to be determined through future analyses of PIT tagged fish that have not yet returned.

While the 2008 BiOp calls for substantial volumes of spill, success should not be measured according to the spilled volume alone, but also by how effectively it increases the number of juvenile fish safely passing dams through non-turbine routes and through the system as a whole. In addition, excessive spill levels can also have detrimental effects, such as elevating dissolved gas to levels that can harm fish. It can also delay adult migration timing by affecting hydraulic conditions and potentially increasing the number of adults that fall back over some dams, requiring fish to ascend ladders a second time.

The BiOp also includes performance standards for survival of adult fish migrating upstream. While the survival of Snake River fall Chinook salmon and upper Columbia River Chinook

salmon and steelhead are near or at the BiOp performance standards, the survival of Snake River spring-summer Chinook salmon, steelhead, and sockeye salmon have fallen below the standard in recent years. It is not clear what is causing this shortfall, particularly since survival had been higher in previous years. The Action Agencies have installed additional PIT tag detectors at strategic locations to help identify the location, timing and reasons for the decline in adult survival, which could include adult fallback, harvest, or other factors.

1 PURPOSE AND SCOPE

This report summarizes the results of actions taken under the 2008 Federal Columbia River Power System (FCRPS) Biological Opinion (BiOp) to improve survival of juvenile and adult Pacific salmon and steelhead (*Oncorhynchus* spp.) through federal dams in the Snake-Columbia River basin. These management actions and evaluations are the responsibility of three federal Action Agencies (AAs): the U.S. Army Corps of Engineers, Bureau of Reclamation and Bonneville Power Administration. This report focuses on how the eight FCRPS dams in the lower Snake and Columbia Rivers are configured and operated and examines the associated effects on smolt and adult life stages and the effects of smolt transportation. Two appendices are included, one providing additional details on the methodology for assessing the effectiveness of summer spill and a second appendix providing more detailed discussion of delayed or latent mortality, including an assessment of recent research on the topic.

2 BACKGROUND

Prior to European settlement of the Pacific Northwest, 7.5 to 10 million adult salmon and steelhead were estimated to have returned to the Columbia River annually, although the numbers undoubtedly fluctuated from year to year (Chapman 1986; NRC 1996). Extensive harvest by Euro-Americans in the mainstem Columbia River began after the first salmon cannery was built in 1866. Harvest peaked at approximately 23,000 metric tons in 1917, and declined thereafter due to overfishing, tributary habitat degradation, blocked access to spawning habitats from dams and other obstacles, and mortality during passage at mainstem dams (NRC 1996; Lichatowich 1999). Overharvest, dam construction, water management, and habitat destruction, all within a backdrop of long-term environmental variability in ocean productivity, have impacted anadromous salmon and steelhead populations. As a result, 13 distinct species or evolutionarily significant units (ESUs) of salmon and steelhead from the Columbia River were listed under the Endangered Species Act (ESA) starting in 1991.

Improving migration conditions for juvenile salmon became a focus of a series of BiOps once stocks were listed under the ESA. In May 2008, NOAA Fisheries issued the most recent BiOp for the FCRPS. NOAA Fisheries then issued a Supplemental BiOp in May 2010 that formally integrated an Adaptive Management Implementation Plan into, and further supplemented and reaffirmed, the 2008 FCRPS BiOp. Hereafter we refer to the 2008 BiOp and the 2010 Supplemental BiOp jointly as the 2008 BiOp.

The 2008 BiOp is broad in scope and calls for a variety of actions affecting salmon and steelhead throughout their life cycle, with the goal of improving the survival and productivity of each ESU. Actions include improving habitat conditions, updating hatchery practices, better management of harvest, and improving passage conditions through the Federal Columbia River Power System (Figure 1). Actions to improve passage survival at individual dams and through the entire FCRPS represent a key objective of the 2008 BiOp. Strategies to improve juvenile (smolt) and adult survival fall into two general categories: 1) improve migratory conditions (at dams and in reservoirs) for juveniles and adults migrating in-river; or 2) strategically provide transportation of juveniles to below Bonneville Dam, bypassing the series of dams at opportune times to promote fish survival. Identifying the

appropriate balance between these two strategies is a subject of ongoing discussion and evaluation.

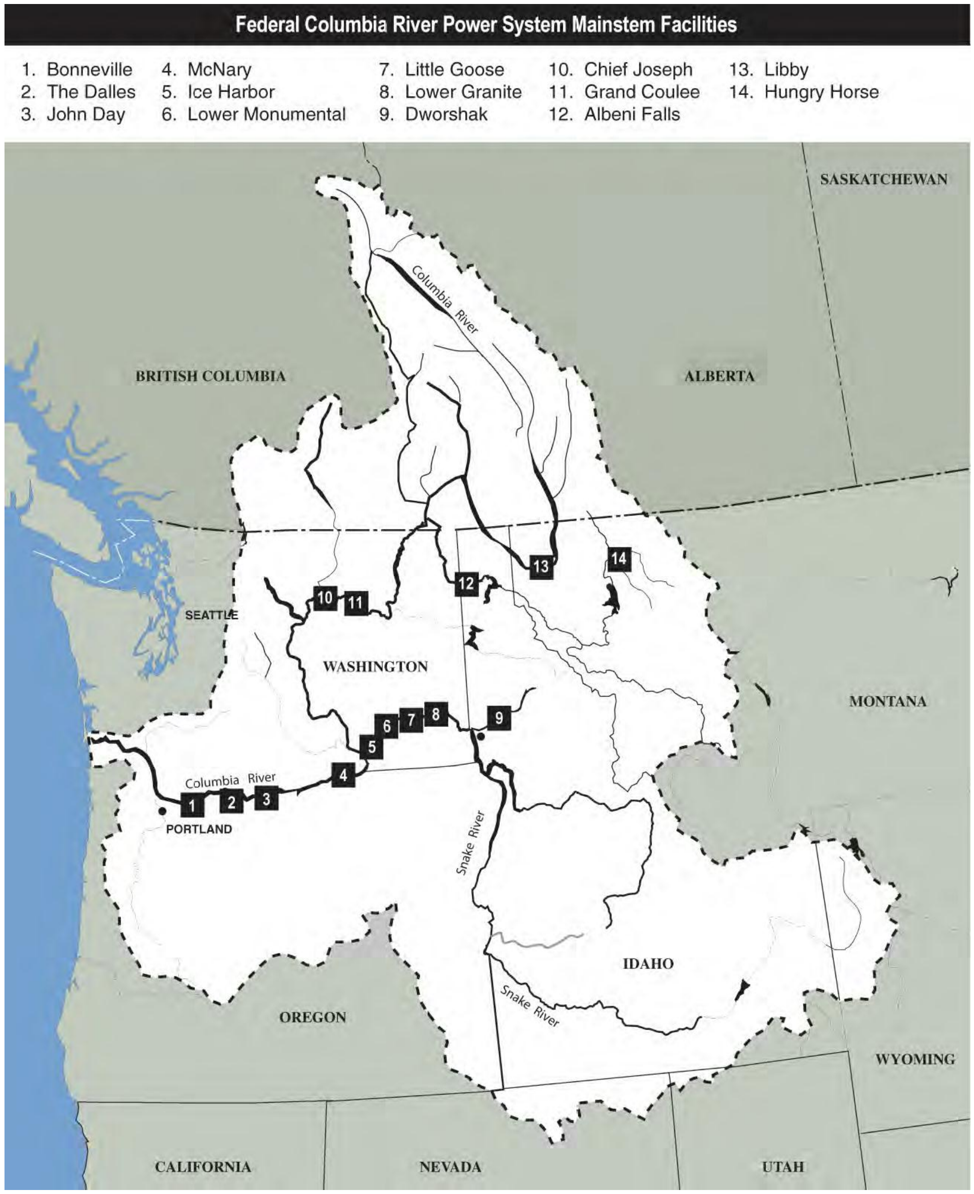

Figure 1. Federal Columbia Power System dams.

Note: Mainstem Snake and Columbia River dams are numbered 1 to 8 and are operated as run-of-river dams. The primary water storage dams include dams numbered 9 to 14, which store water and are managed to provide flows and meet water quality criteria to improve juvenile and adult salmon survival through the FCRPS.

The Action Agencies (AAs) pursued the key objective of improving juvenile and adult survival through the FCRPS through several strategies: 1) structural modifications of dams to

provide safer fish passage; 2) implementation of spill and selective use of juvenile transportation; and 3) operations that result in flows more closely approximating the shape of the natural hydrograph, enhanced river flows, and improved water quality.

Dam passage survival standards prescribed in the 2008 BiOp require that 96% and 93% of spring- and summer-migrating juveniles, respectively, survive passage at each of the eight FCRPS dams on the lower Columbia and Snake Rivers. Actions to accomplish this have included conventional spill, installation of surface passage systems, improved turbine designs and upgrades of screened bypass systems to improve how and where fish are returned to the river below dams. Most of these modifications have now been designed, installed or implemented, and tested, such that their overall impact can be evaluated.

2.1 Benefits of surface passage

Compared to historical levels, the 2008 BiOp provides for increased spill volumes at all Lower Snake and Lower Columbia dams during the juvenile salmon migration. In recent years, surface passage systems were incorporated into some spillways to make spill more effective, providing an alternative passage route that uses less water and facilitates the attraction of juvenile fish to the spillway. This type of surface passage provides a shallow, spill-based route at the water surface (Figures 2 and 3). At some sites surface passage routes use existing ice and trash sluiceways rather than spillways. Importantly, the selection of appropriate locations for surface passage was based on detailed evaluations involving hydraulic modeling and site-specific fish monitoring studies.

The Corps of Engineers installed the first spillway weir at Lower Granite Dam in 2001 and in early 2003 it was named the nation's top engineering achievement of the year by the American Council of Engineering Companies. The award cited tests showing improved juvenile fish passage and described the weir as an innovative "engineering marvel" that was chosen for the ACEC's Grand Conceptor Award over other major engineering projects such as new museums and bridges.

Surface passage structures and related surface spill operations are now in place at all eight mainstem dams and are a key element in achieving performance standards. Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, and John Day dams have spillway weirs. Both The Dalles Dam and Bonneville Dam have surface passage systems (in the form of sluiceways) associated with the powerhouses. Surface-oriented passage structures provide more natural passage conditions for juvenile salmon and steelhead and are designed to improve survival, reduce dam-passage time, and use water more efficiently by passing more fish through a given unit of water.

Figure 2. A spillway weir provides surface passage for fish at McNary Dam.

Furthermore, with the addition of spillway weirs and other improvements, new spill patterns have been developed at the eight Lower Columbia and Snake river dams to improve conditions leading to and exiting the spillways. As discussed below, this shift in the distribution of fish passing dams (away from turbines and bypass systems and to spillways

and surface routes) has increased the proportion of fish passing dams through non-turbine routes and reduced the proportion of Snake River fish that are transported.

Spill levels are tailored based on the test results to optimize fish passage given the configuration of each dam. The measure of effectiveness is not necessarily the volume of water spilled, but rather the proportion of fish using the safest passage routes (i.e., the spillway, surface passage systems, and screened bypass systems). Determining the appropriate spill level and pattern at dams can involve balancing competing objectives. For example, high spill volumes can in some cases delay the migration of adult fish moving upstream, and increase dissolved gas levels. Spilling high volumes near adult fish ladder exits can increase the number of adults that fall back over a dam (Reischel and Bjornn 2003). This forces fish to locate fish ladders again, increasing dam passage times. Fish that take longer to pass dams are less likely to successfully complete their migration to their final spawning locations (Caudill et al. 2007). Also, the effects of gas supersaturation caused by spill on juvenile and adult salmon has been a concern since the mid-1960s (Ebel and Raymond 1976). Today the U.S. Environmental Protection Agency provides that total dissolved gas (TDG) saturation be limited to 110%. However, state regulatory agencies issue waivers or criteria adjustments allowing higher gas levels when associated with spill to facilitate passage of juvenile salmon, and spill levels and patterns are managed consistent with state requirements. Excessive spill also creates currents that can draw fish away from the most effective surface passage routes, depending on conditions.

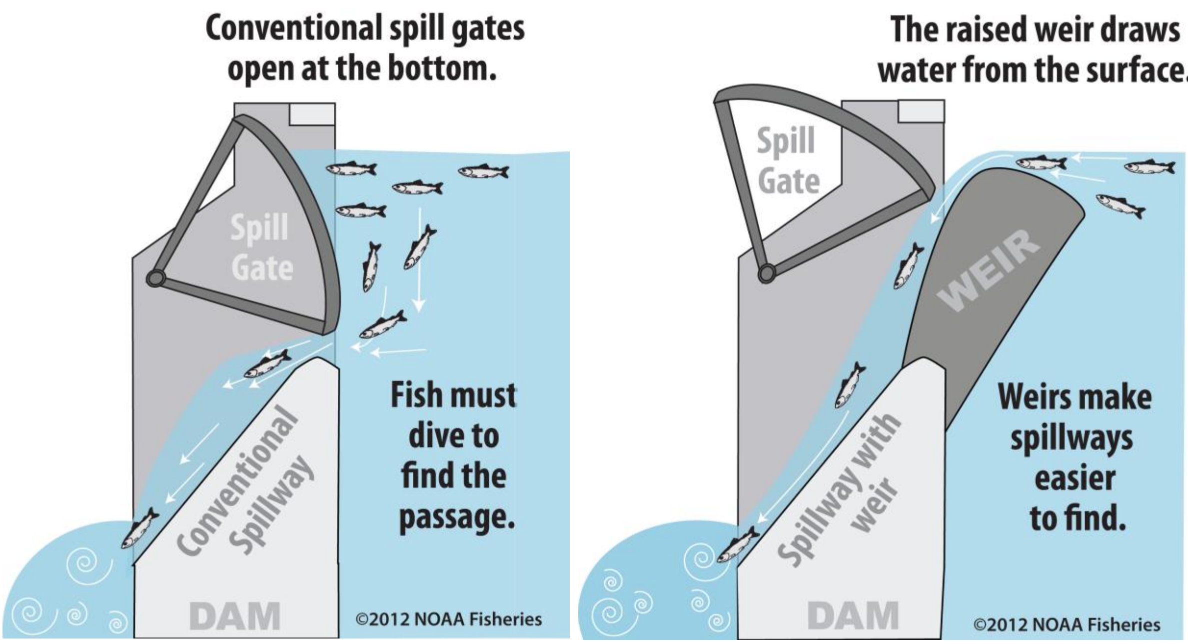

Figure 3

Surface passage weirs allow fish to pass dams at the surface, where they naturally travel.

Screened bypass systems are incorporated into powerhouses at seven FCRPS dams to guide fish away from turbine intakes. Several such systems can be operated in either bypass mode where they augment spillway and surface passage systems by returning fish to the river or collection mode so that fish can be collected and released downstream or in some cases transported. Under the 2008 BiOp, screened bypass/collection systems have also undergone substantial modifications, including modifications to divert fish away from turbine intakes and increase survival by relocating bypass exits at McNary, Lower Monumental and Little Goose dams to reduce predation.

Although a goal of the 2008 BiOp is to increase dam passage survival by reducing the proportion of fish passing dams through turbines, the turbine routes have also been modified to improve survival for fish that still pass dams through this route. Turbines designed to pass fish more safely were installed at the Bonneville Dam first powerhouse, where all 10 units were replaced, with additional turbine replacements expected at Ice Harbor Dam. Under the 2008 BiOp, turbine operations were optimized at McNary Dam and Ice Harbor Dam and all turbines at FCRPS dams are operated within 1% of peak unit efficiency. These operations

reduce hydraulic turbulence within turbines, improving conditions for the small proportion of fish that still pass through them.

Under the 2008 BiOp, structural modifications at the dams were completed in tailrace zones immediately below dams to reduce losses from predation. A concrete wall was installed below The Dalles Dam to keep smolts in the main river channel and away from shallow areas where predation was a concern. Below The Dalles and John Day dams, aerial wire arrays were installed to reduce losses to avian predators. Also, deflectors have now been installed in most spill bays at the federal dams to improve hydraulic conditions for juvenile fish and speed their egress from the area below each dam.

Additionally, a variety of actions have been adopted to improve conditions smolts experience when passing through FCRPS reservoirs. First, flow augmentation is employed to increase water velocity and speed the migration of fish seaward. Flow augmentation involves the strategic release of water from storage reservoirs in the upper reaches of the Snake and Columbia rivers at specific times to increase water velocity through the FCRPS or modify water temperature in the lower Snake River. The magnitude and timing of water releases must be balanced with system requirements, including the needs of other fish listed under the ESA, flood control, irrigation, recreation, and hydroelectric generation. Second, surface passage systems were installed and operated in combination with spill to avoid delaying smolts in areas immediately upstream of dams. This reduces the time that juvenile salmon are exposed to predators when passing dams, reduces losses to predation and, by narrowing the breadth of the river, improves travel time through the FCRPS. That results in earlier arrival in the ocean that generally promotes improved adult returns (Scheuerell et al. 2009). Finally, actions to deter or control the number of fish and bird predators have been implemented at individual dams, as described above, to reduce impacts from predation.

3 JUVENILE FISH RESPONSE – SPRING MIGRANTS

3.1 Survival

Extensive testing has demonstrated that yearling Chinook salmon and steelhead survival rates past dams are near the BiOp performance standard of 96% survival through each of the six dams tested to date (Figures 4 and 5). Steelhead survival was generally highest and exceeded 98% during at least one test at five of the six dams tested from 2010 to 2012. Dam passage survival is defined as survival from the upstream face of a dam to a standardized reference point in the tailrace immediately below the dam. Successful performance tests for two years are required to meet the BiOp performance standards, but have not yet been completed at the remaining two dams. While the process will include discussion of the results with state, tribal and federal biologists, the performance standard data collected thus far is considered solid and final reports will be forthcoming.

Monitoring protocols developed by the AAs in consultation with the fishery resource agencies to estimate dam passage are standardized and systematic. They are based on state-of-the-art experimental designs, fish tag technologies, analytical frameworks and employ standardized fish handling and marking procedures across test sites. The protocols are used to develop annual estimates of survival, which are compared against the 96% performance standard specified in the BiOp. The Northwest Power and Conservation Council's Independent Scientific Review Panel called the testing design "well-reasoned, justified and described" and said the testing would provide important information on how fish pass dams and help assess the benefits of structural changes made at dams (ISRP 2009).

> **Performance standards and SARs**
>
> Salmon survival can be measured over different distances and periods. Survival from the smolt life stage to adulthood encompasses most of the salmon life cycle over a period of years and is often referred to as smolt-to-adult returns or SARs. This can reflect the influence of many factors, most notably ocean conditions that may dramatically increase or reduce returns. To provide a clear measure of improvements in dam passage, the Action Agencies track fish survival past each dam. Performance standards use this dam survival measure.

Prior to the 2008 BiOp, testing focused on evaluating specific configurations and operations. The tests

conducted were statistically rigorous and provided extremely valuable information. Although dam passage survival research was conducted at most dams in the FCRPS, researchers used a variety of tagging and mark-recapture experimental designs that varied across years and among dams. Early evaluations focused on testing specific configurations and operations. However, once the structural and operational improvements identified in the 2008 BiOp were in place, performance tests using standardized methods and techniques were required to estimate survival in a consistent manner across years and sites. Additionally, to further ensure consistency, a single research team has monitored survival at FCRPS dams. Performance testing using the new methods began in 2010.

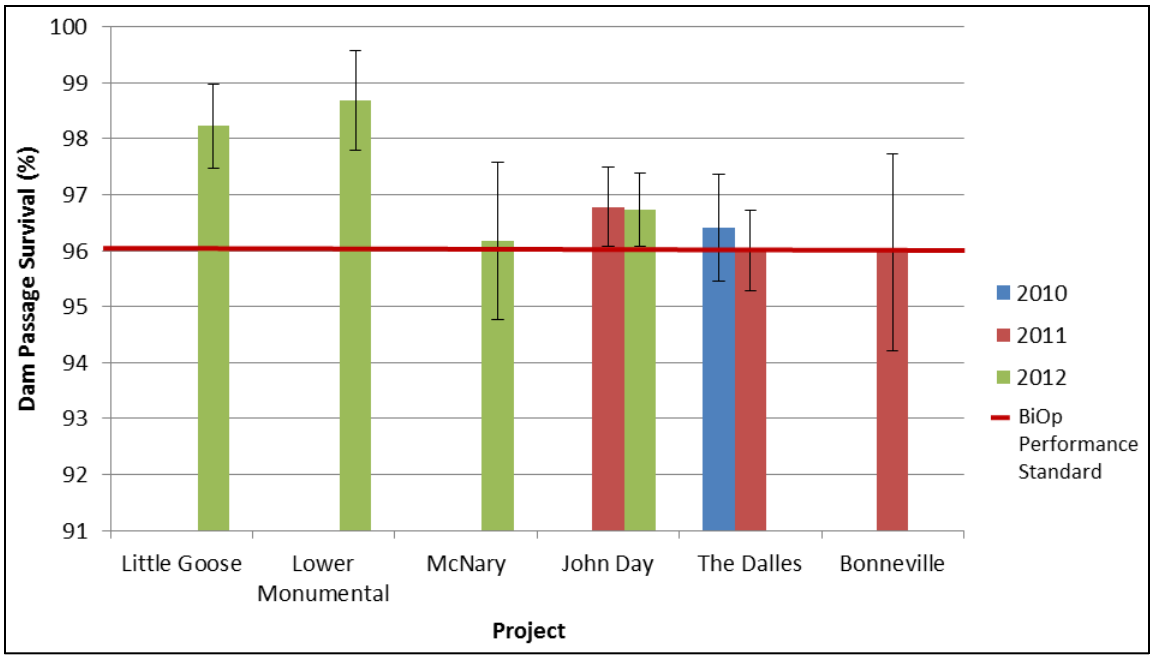

Figure 4

Estimated dam passage survival for yearling Chinook salmon.

Notes: The BiOp performance standard for yearling Chinook salmon is 96%. Bars represent annual mean survival based on testing. Whisker plots represent standard error.

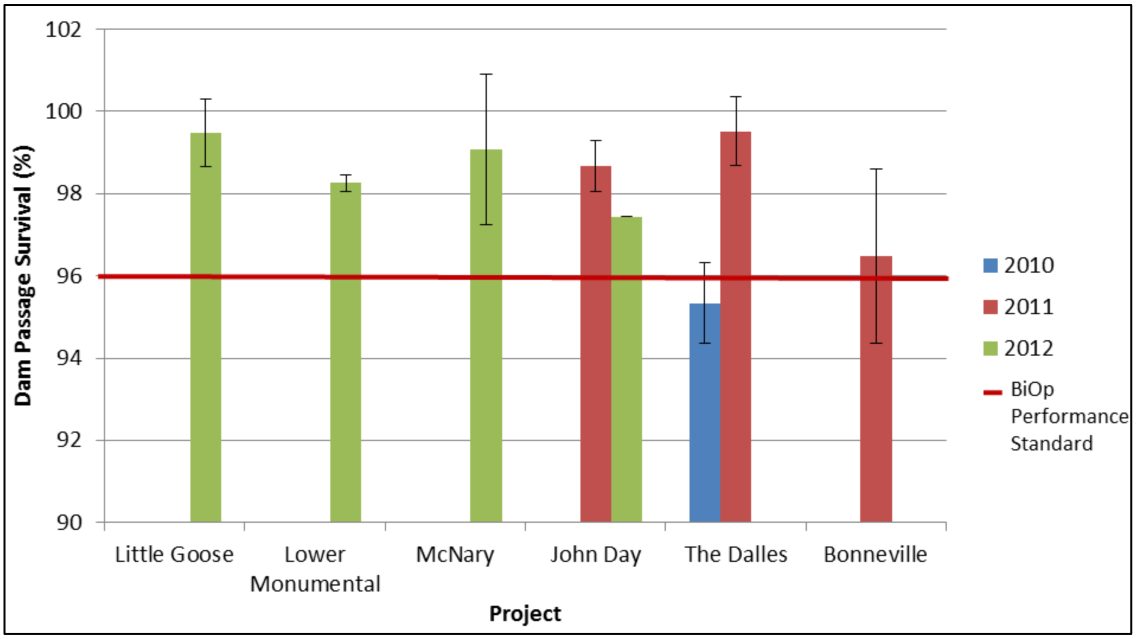

Figure 5

Estimated dam passage survival for steelhead.
Notes: The BiOp performance standard for steelhead is 96%. Bars represent annual mean survival based on testing. Whisker plots represent standard error.

3.2 Dam Passage Time

The installation and operation of surface passage systems combined with spill have resulted in rapid passage of juvenile fish past dams, reducing their exposure to predators. Tagged fish are released during performance tests to monitor the transit time of juvenile salmon through the forebays at Bonneville, The Dalles, John Day, McNary, Lower Monumental and Little Goose dams. Forebays are the portion of reservoirs located immediately upstream from dams. Prior to the installation of surface passage, fish might require several hours to find their way through forebays and standard spillway outlets or screened bypass systems that are 40 or more feet underwater. This was especially true under conditions of no spill and low river flow and exposed the fish to predators (Ferguson et al. 2005). Results of recent testing indicate that median forebay passage times for yearling Chinook salmon were short and ranged from 0.6 hour at Bonneville Dam (Skalski et al. 2012b) to 2.4 hours at Lower Monumental Dam (Skalski et al. 2013a) and were typically less than two hours. The 2.4 hour

passage time at Lower Monumental was down more than 30% from 3.6 hours in the year prior to the installation of surface passage (Absolon et al. 2008). Median forebay passage times for steelhead were also short and ranged from 0.8 hour at The Dalles Dam (Skalski et al. 2012a) to 2.7 hours at Little Goose Dam (Skalski et al. 2013b).

3.3 Turbine and Bypass Passage

The suite of 2008 BiOp actions implemented to date has reduced the proportion of fish passing through turbines and bypass systems, and shifted their passage to routes such as spillways and surface passage. The proportion of juvenile fish passing through non-turbine routes is known as fish passage efficiency (FPE) and has increased from the era prior to the 2008 BiOp era. Based on the most recent year of testing, FPE is now typically above 87% for spring migrants and 70% for summer migrants at all dams (Table 1). FPE estimates are generally higher at Snake River dams than those in the Columbia River. With the installation of spillway weirs and other surface passage devices plus increased spill volumes, more juvenile fish are using spillway passage routes. As a consequence, the proportion of fish passing dams through screen bypass systems has decreased from pre-BiOp levels and is currently at or below 41% at all dams, and is typically less than 25%. Only five percent of fish pass through screen bypass systems at Bonneville Dam, which has numerous alternate passage routes for juvenile fish (Table 2).

Table 1

Estimated Proportion (%) of Juvenile Fish Migrating Through Non-turbine Routes at Mainstem Columbia and Snake River Dams

Location	Year of Testing	Yearling Chinook Salmon (%)	Steelhead (%)	Subyearling Chinook Salmon (%)
Bonneville Dam[1]	2012	-	-	69.7
The Dalles[1]	2012	-	-	78.4
John Day[1]	2012	92.7	97.0	85.8
McNary[1]	2012	96.8	87.7	90.9
Lower Monumental[2]	2012	94.8	96.5	92.4
Little Goose[3]	2012	96.3	98.0	95.1

1. Source: Results from U.S. Army Corps of Engineers, Anadromous Fish Evaluation Program Studies Review Work Group special meeting to present results of 2008 BiOp Performance Standard Studies, April 16, 2013.
2. Source: Skalski et al. (2013a)
3. Source: Skalski et al. (2013b)

Table 2
Estimated Proportion (%) of Juvenile Fish Migrating Through Screened Bypass Systems at Mainstem Columbia and Snake River Dams[1]

Location[1]	Year of Testing	Yearling Chinook Salmon (%)	Steelhead (%)	Subyearling Chinook Salmon (%)
Bonneville Dam	2011	5	2	-
	2010	-	-	3
John Day	2011	25	33	-
	2010	-	-	11
McNary	2012	24	-	-
Ice Harbor	2008	14	22	21
Lower Monumental	2009	20	29	30
Little Goose	2009	24	41	24

1. Source: Data provided in the draft Comprehensive Evaluation report developed by the AAs.

3.4 The question of delayed mortality

Some analyses suggest that juvenile fish passing through the FCRPS can experience stress or other effects that result in mortality at some point after they exit the system, a concept that has been termed "delayed" or "latent" mortality. The effect is often assessed by comparing the survival of groups of fish that experience different passage conditions. The comparisons can be complicated by other variables, such as ocean conditions, that also influence life-cycle survival. The existence and extent of delayed mortality have been analyzed and debated for years with conflicting results. In 2007 the ISAB strongly advised against continuing to try to measure absolute latent mortality and instead called for focusing on the total mortality of in-river migrants and transported fish, which the ISAB described as "the critical issue for recovery of listed salmonids."

Investigations have often focused on the impacts of screened bypass systems designed to divert fish away from turbines. Sandford et al. (2012) held juvenile fish in tanks for approximately seven months following their downstream migration through the FCRPS but

did not detect higher mortality among fish that had passed through more bypass systems. However, an analysis of 11 years of PIT-tag data by Buchanan et al. (2011) found that the more bypass systems Chinook smolts passed through, the lower the rate they returned as adults. Steelhead smolts showed similarly reduced returns after passing through two or more bypass systems. Another published zanalysis by Rechisky et al. (2012) used acoustic tags to track two groups of hatchery fish through their downstream migration and their first month in the ocean. They found no difference in survival between juvenile fish that migrated through eight dams and others that migrated through only four. Some have questioned the validity of comparisons between different hatchery stocks and the limited period the fish were monitored in the ocean.

In 2012 the ISAB concluded that bypass systems are associated with some mortality, but cautioned that "the factors responsible for latent mortality remain poorly understood and inadequately evaluated." The ISAB said the mortality may reflect a tendency for smaller and more vulnerable fish to pass through bypass systems, in which case the mortality could be related to fish condition rather than the effects of bypass systems themselves.

Either way, however, BiOp spill and surface passage improvements have simultaneously reduced the proportions of fish transiting bypass systems, as described in the previous section. This should reduce delayed mortality effects, if they exist. The Action Agencies have focused on improving overall survival of juvenile fish during their downstream migration, as the ISAB recommended.

3.5 Spill and survival

Another recent investigation by Haeseker et al. (2012) identified correlations between spill and water travel time through the FCRPS and the rate of adult returns, as measured by SARs. They also found that higher juvenile fish survival through the FCRPS was associated with higher ocean survival. They suggested that increased spill and reduced water travel time through the FCRPS could provide more favorable river conditions that could further improve life-cycle survival.

However, the analysis by Haeseker et al. (2012) examined fish passage data and average FCRPS spill from 1998 to 2006, before the installation of many of the surface passage systems that have reduced travel time and made spill more efficient. The period was also prior to the implementation of the 2008 BiOp spill program. Given those improvements, the spill levels examined by Haeseker et al. do not accurately reflect the proportion of fish that benefit from today's more efficient spill in conjunction with surface passage. In addition, averaging spill across the system does not accurately reflect the specific configuration and conditions at each dam and the spill regime individually tailored to those circumstances.

Haeseker et al. (2012) also projected spill recommendations beyond the range of observed data, raising the possibility that high spill levels could be accompanied by unforeseen consequences. These may include elevated levels of total dissolved gas (TDG) and interference with upstream passage of returning adult salmon and steelhead.

A more complete discussion of the Haeseker et al. (2012) proposals and associated issues of delayed mortality is included in Appendix B.

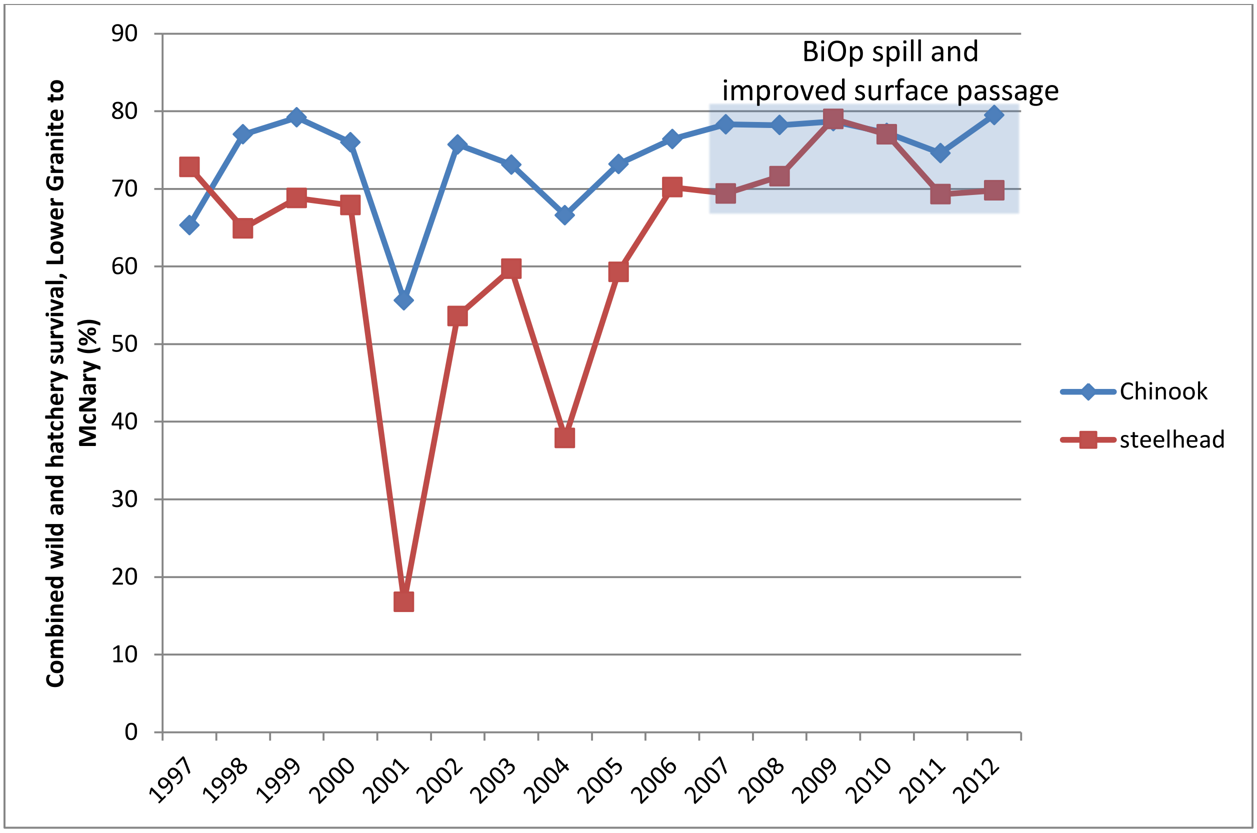

Figure 6. Juvenile fish survival through the lower Snake River, from Lower Granite to McNary dam, has remained more consistent since the installation of surface passage systems and implementation of the BiOp spill program. Data from Zabel (2012).

3.6 Smolt Survival through River Reaches

Improvements in dam passage survival and reductions in the time it takes juvenile fish to pass dams should result in observable changes in survival detectable at the reach scale. This depends on whether the change is large enough to be detected relative to other factors that may affect survival each year, such as fish size and condition. Starting in 1964, the survival of yearling migrants through the FCRPS was estimated using a variety of mark-recapture methods. Since 1993, the availability of passive integrated transponder (PIT) tags, mass tagging of representative fish, installation of multiple detection systems, and the development of statistical models have enabled juvenile fish survival through the FCRPS reach to be standardized and estimated with greater precision.

While estimated survival varied among years and species, important patterns in the data stand out for both species (Figure 7). First, the severe downward trend in survival observed in earlier decades has been arrested. Also, survival through the river reaches has generally increased since ESA listing began in the early 1990s. Finally, survival today is higher than it was in the 1970s. The 1970s represent a period when most dams were completed and operating, but significant improvements in passage conditions at FCRPS dams had not been initiated (Lower Granite Dam was the last dam installed and was completed in 1975). It is important to recognize that any change in juvenile fish survival through the FCRPS is the result of the overall migratory conditions encountered, including the volume and timing of runoff, the suite of management actions implemented under the 2008 BiOp, the condition of wild fish and those released from hatcheries, and the degree of predation fish are exposed to each year.

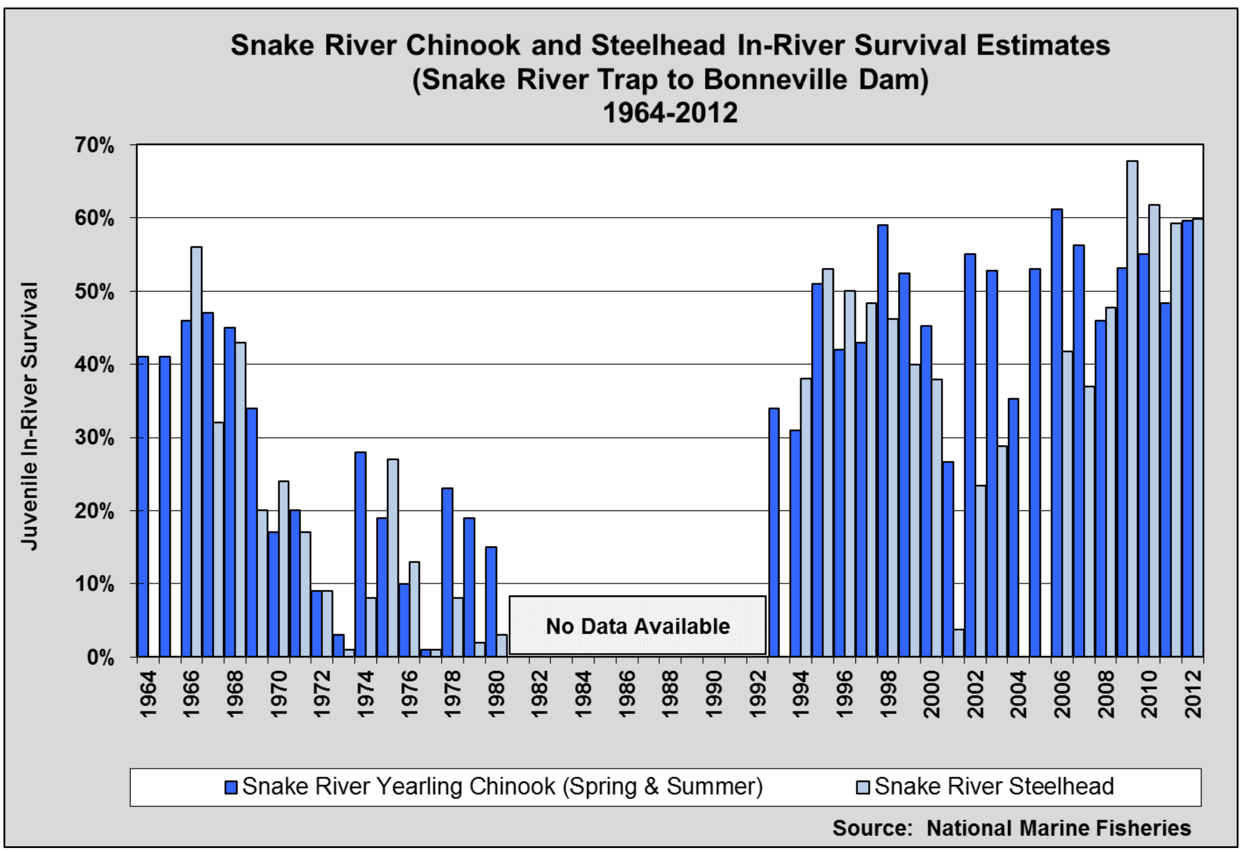

Figure 7

In-river Survival of Juvenile Chinook Salmon and Steelhead from the Snake River to Bonneville Dam from 1964 to 2012. Note: Data represent wild and hatchery fish combined.

Two independent research groups estimate juvenile fish survival through dams and reservoirs on the lower Snake and Columbia rivers: NOAA's Northwest Fisheries Science Center (e.g., Faulkner et al. 2012) and the Comparative Survival Study (CSS) program (www.fpc.org; e.g., Tuomikoski et al. 2012). Estimates by both groups are based on PIT-tagged fish released from hatcheries throughout the basin or at traps at key locations in the migration corridor, and subsequently detected at one or more receivers while migrating downstream. PIT tag data are archived and made available to the research groups through the PIT Tag Information System.

The analyses generated by each group have different purposes and use different aggregates of fish groups in the estimates. In general, CSS estimates focus on results related to both hatchery and wild-origin fish marked above Lower Granite Dam while the NOAA estimates focus on the composite population and includes fish marked at Lower Granite Dam. Since this review focused on survival trends for the composite population, the analysis was based on NOAA estimates of reach survival from Faulkner et al. (2012) and Zabel (2012).

For yearling Chinook salmon, steelhead, and sockeye salmon migrating from the Snake River through the FCRPS the trend in survival since 1997, 1998, or 1999 (depending on the data available for each species) was positive for all three species (Figures 5, 6, and 7). The increase in steelhead survival since 2001, a severe drought year, is notable. In 2001 most fish were transported around dams and the few fish remaining in the river were likely preyed upon heavily. Steelhead survival through the eight dams of the FCRPS was approximately 4% that year (Figure 6). Autocorrelation, or correlation between survival estimates at different points in time, was observed in these results. Therefore, this analysis did not use standard linear regression techniques to test for statistical significance.

Since the 2008 BiOp, annual survival estimates of wild- and hatchery-origin juvenile salmon from the Snake River through eight reservoirs and dams ranged from approximately 46 to 60% for yearling Chinook salmon, from 48 to 68% for steelhead, and from 40 to 57% for sockeye salmon. Comparing annual estimated survival during the post-BiOp period (2008-2012) to the pre-BiOp period (beginning in either 1997, 1998 or 1999, depending on the species, through 2007) indicated that median survival during the post-BiOp period increased

over the pre-BiOp period for sockeye salmon (a 65.5% relative increase) and steelhead (a 57.8% increase) more than for Chinook salmon (a 0.6% increase; Figures 5, 6, and 7). Likewise, mean estimated annual survival also rose for all three species during the post-BiOp period (2008-2012), with relative increases ranging from 7.6% for Chinook salmon to 73.9% for steelhead (Figure 8). The median and mean survival figures reflect different statistical strengths, with the mean more heavily influenced by outliers in the data, so each is noteworthy. The statistical significance of the survival increases will become more apparent as more data under the 2008 BiOp become available.

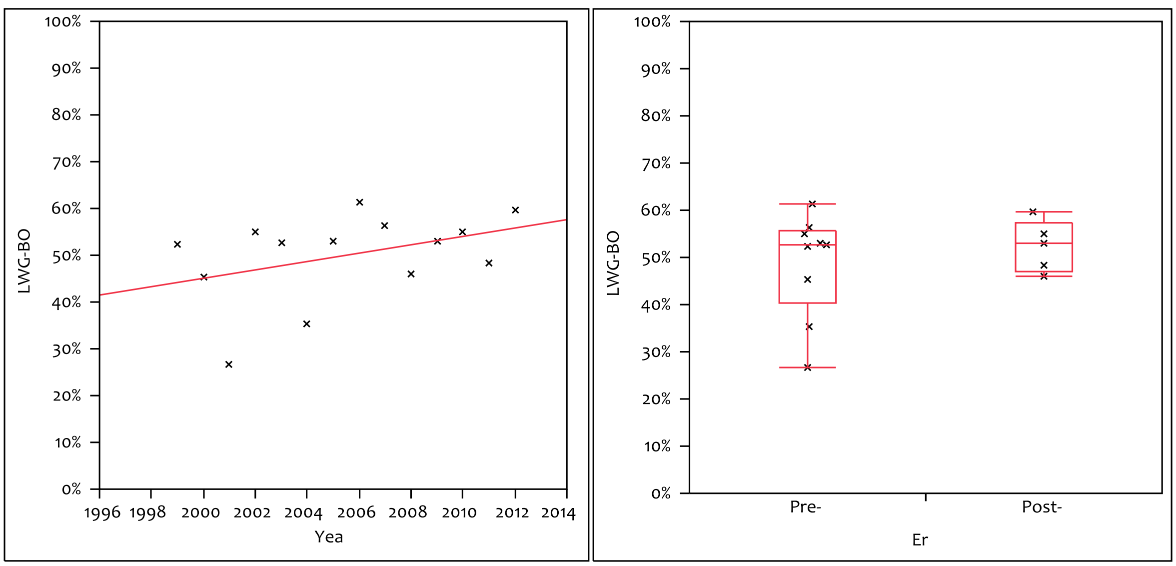

Figure 8

Estimated Snake River yearling Chinook salmon survival from Lower Granite trap through the FCRPS, 1999 to 2012, with trend line (left panel); and box plots of survival data distributions from pre- and post-BiOp periods (right panel). In box plots, central horizontal line represents the median, with box enclosing the middle 50% of data and whiskers representing data outside the middle 50%.

Notes: Data were obtained from Faulkner et al. (2012) and Zabel (2012); estimated survival for 2012 (Zabel 2012) is preliminary. Data include wild and hatchery salmon.

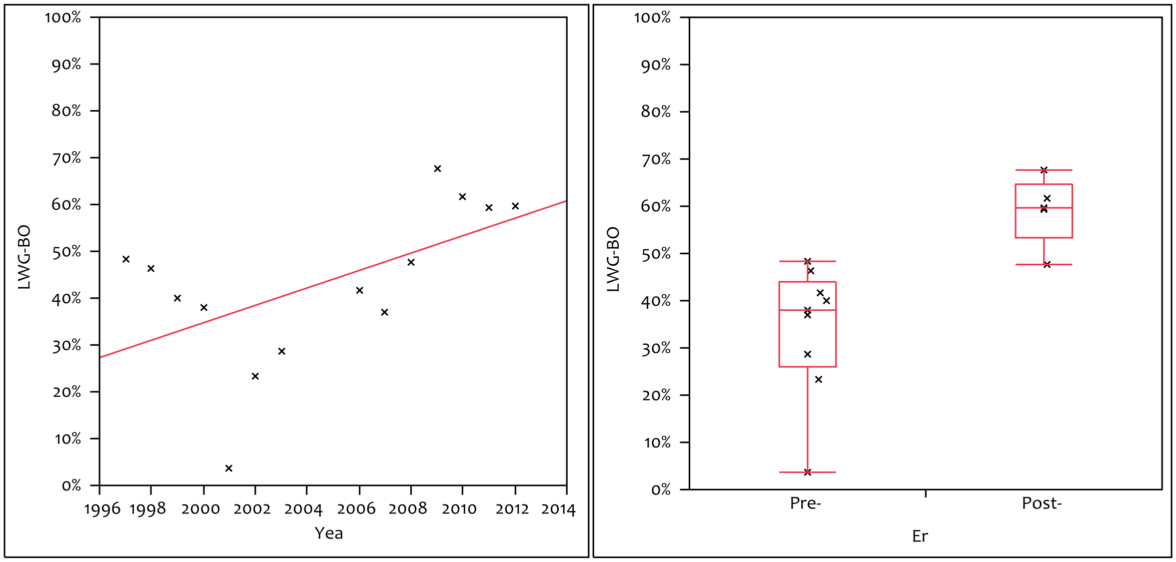

Figure 9

Estimated Snake River steelhead survival from Lower Granite trap through the FCRPS, 1997 to 2012, with trend line (left panel); and box plots of survival data distributions from pre- and post-BiOp periods (right panel). In box plots, central horizontal line represents the median, with box enclosing the middle 50% of data and whiskers representing data outside the middle 50%.

Notes: Data were obtained from Faulkner et al. (2012) and Zabel (2012); estimated survival for 2012 (Zabel 2012) is preliminary. Data include wild and hatchery fish. Data for 2004 and 2005 not available.

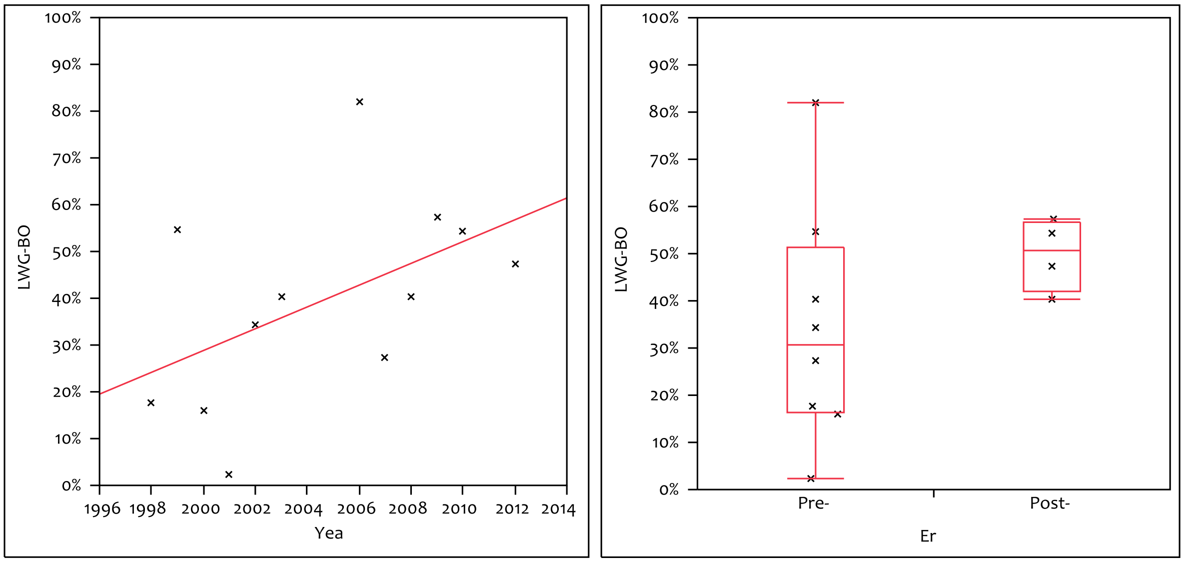

Figure 10

Estimated Snake River sockeye survival from Lower Granite dam through the FCRPS, 1998 to 2012, with trend line (left panel); and box plots of survival data distributions from pre- and post-BiOp periods (right panel). In box plots, central horizontal line represents the median, with box enclosing the middle 50% of data and whiskers representing data outside the middle 50%.

Notes: Data were obtained from Faulkner et al. (2012) and Zabel (2012); estimated survival for 2012 from Zabel 2012 is preliminary. Data include wild and hatchery sockeye. Data for 2004, 2005 and 2011 not available.

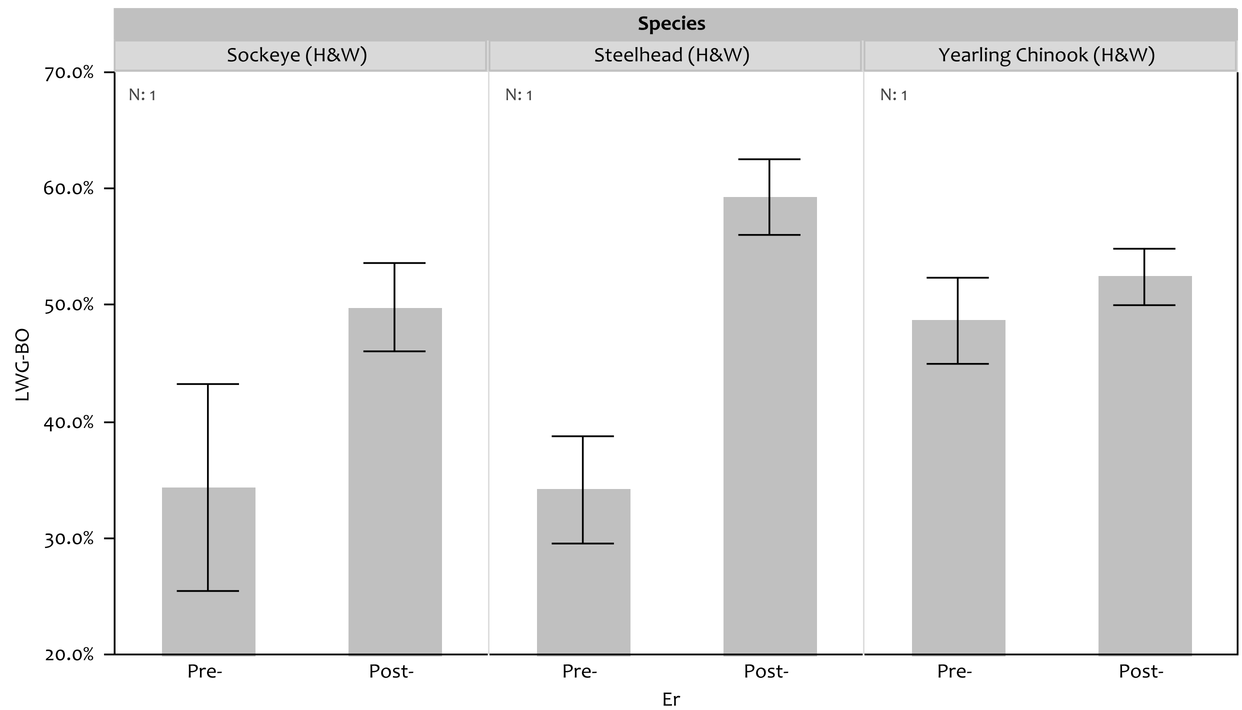

Figure 11. Mean annual survival (with whiskers representing standard error) from Lower Granite Trap through the FCRPS in pre-and post-BiOp periods.

Notes: Data were obtained from Faulkner et al. 2012 and Zabel 2012; estimated survival for 2012 (Zabel 2012) is preliminary. Data include hatchery and wild fish.

Faulkner et al. (2012) and Zabel (2012) also provide annual estimates of survival for wild-origin yearling Chinook salmon and steelhead migrating from the Snake River through the FCRPS. The patterns in survival were similar to those reported above for the composite population of wild- and hatchery-origin fish combined.

Starting in the late 1990s, NOAA also estimated the survival of hatchery-origin yearling Chinook salmon, sockeye salmon, and steelhead emigrating from the upper Columbia River through the four lower Columbia River dams (Faulkner et al. 2012; Zabel 2012). No survival trend was apparent for the three species. Annual estimated survival of hatchery-origin yearling Chinook salmon between McNary Dam and Bonneville Dam ranged from approximately 63 to 90% and averaged approximately 76% since 1999. Annual survival of hatchery-origin steelhead ranged from approximately 59 to 100% and averaged

approximately 75% since 2003. Annual survival of hatchery-origin sockeye salmon was highly variable and averaged approximately 71% during the 1999 to 2012 period.

In contrast, the trend in survival for wild- and hatchery-origin yearling Chinook salmon, steelhead, and sockeye salmon from the Snake River between McNary Dam and Bonneville Dam was generally positive. Annual estimated survival of yearling Chinook salmon ranged from approximately 50 to 84% and averaged approximately 70% since 1999. Annual survival of steelhead ranged from approximately 25 to 87% and averaged approximately 64% since 1997. Annual estimated survival of sockeye salmon was also highly variable, ranging from approximately 11 to 111% (the high estimate above 100% is likely the statistical result of small sample size) and averaging approximately 55% since 1998. Potential explanations as to why survival trends for Snake River and Columbia River fish migrating through the lower Columbia River differed were not apparent in the data, and ascertaining causation will require additional analysis.

3.7 Columbia and Snake River Reach Survival Comparisons to COMPASS and other rivers

The FCRPS BiOp also includes a performance target for inriver reach survival for Snake River and upper Columbia River Chinook and steelhead. The BiOp calls for the Action Agencies to empirically measure inriver survival over two reaches: Lower Granite to Bonneville and McNary to Bonneville. The results are then compared with the survival estimates derived from COMPASS modeling that incorporates improvements implemented under the BiOp. COMPASS is a Comprehensive Passage model developed under NOAA's leadership to predict the effect of alternative dam operations on salmon survival rates. The model is designed to simulate survival and travel time through the FCRPS under various river and operational conditions and can simulate the effects of different management actions, producing results that agree with available data.

For the most recent comparison (see figure 12), the COMPASS model was run for the actions implemented at the start of the 2011 migration season using 2011 river conditions, fish

migration patterns, and dam and transport operations. Results indicate that the benefits from the operational and passage improvements and predator-deterrent actions implemented to date are generally accruing as expected in the FCRPS BiOp analysis.

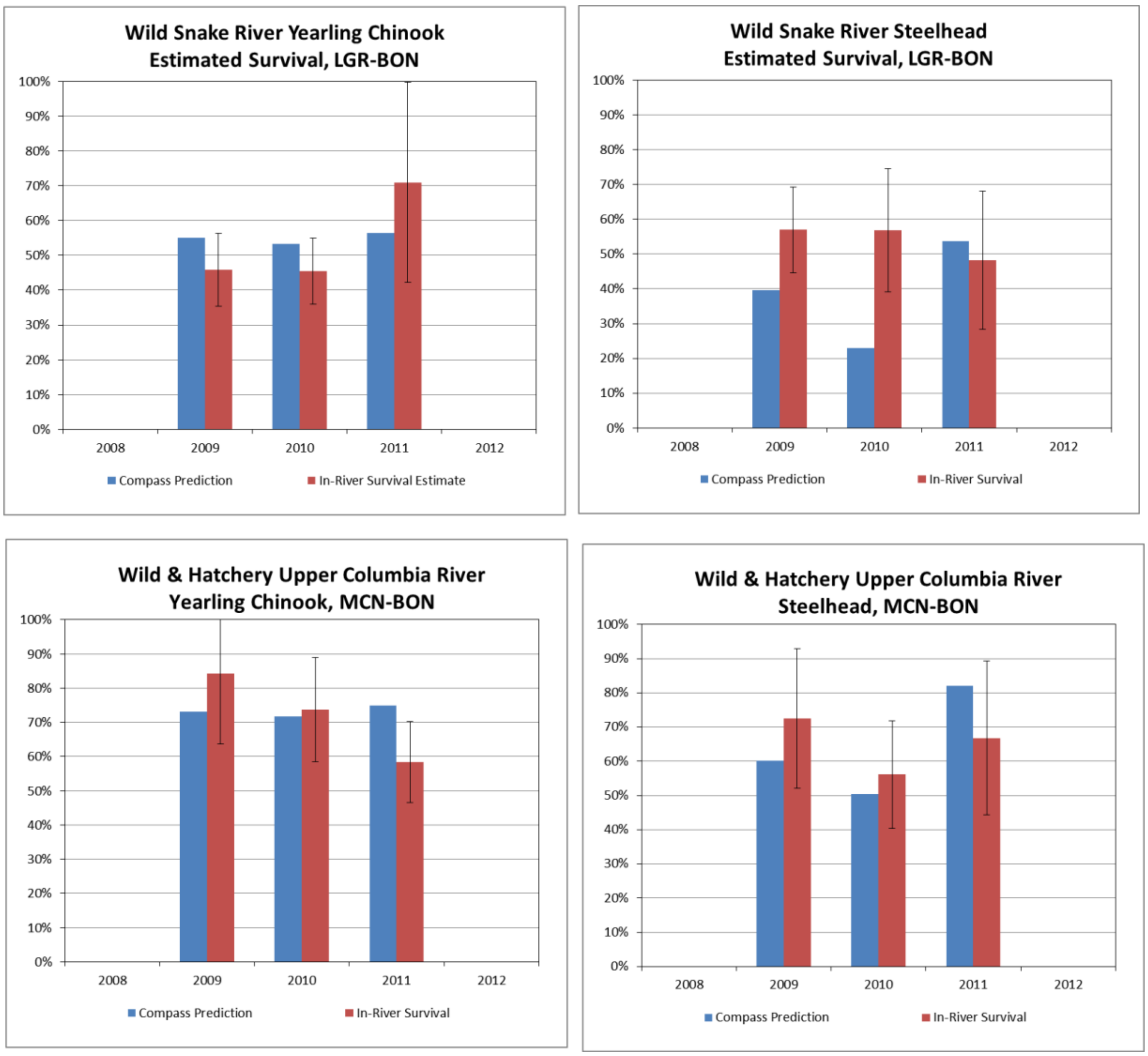

Figure 11. Mean annual survival (with whiskers representing standard error) from Lower Granite Trap through the FCRPS in pre-and post-BiOp periods.

An analysis by Welch et al. (2008) also compared survival of juvenile hatchery fish through the FCRPS and the undammed section of the Columbia River below Bonneville Dam with survival of juvenile fish through the undammed Fraser River in Canada. Welch et al. concluded that overall survival of spring Chinook was statistically indistinguishable between the two rivers and was slightly higher in the Fraser for steelhead. Although the two river

systems are different and critics have questioned the value of comparisons between the two, the results indicate that fish in rivers without dams remain vulnerable to substantial sources of mortality and that improved fish survival through the FCRPS may be approaching that of some less developed river reaches and systems.

3.8 Water Management and Flow

In addition to dam-passage improvements discussed above, system-wide actions to improve conditions in the migration corridor have been implemented. These include flow augmentation and water management actions to reshape the hydrograph to more closely resemble the natural runoff patterns fish experienced historically. These actions were designed to move fish downstream faster and limit their exposure to instream predators. This is also important because it assists juvenile fish in reaching marine waters when they can take advantage of optimum forage conditions and best avoid ocean predators. The benefit may be substantial. Scheuerell et al. (2009) analyzed data from more than 40,000 individually tagged yearling Chinook salmon and steelhead detected at Bonneville Dam on their downstream migration and at Lower Granite Dam when they returned as adults. Scheuerell et al. found that juveniles migrating from early to mid-May survived to return as adults at rates four to 50 times greater than those migrating in mid-June. They also found that the precise peak in smolt-to-adult survival varied among years, presumably reflecting variations in ocean conditions from year to year.

While the primary water management action in the basin is to reduce flood risk, flow augmentation to enhance migratory conditions for juvenile and adult salmonids in the mainstem Snake and Columbia rivers is also important. Water provided to the upper Columbia River (downstream from Chief Joseph Dam) comes from large storage reservoirs such as Grand Coulee Dam and a complex of storage reservoirs that supply runoff from Canada and Montana. Water provided to the Snake River comes from Dworshak Dam and through the Hells Canyon Complex in Idaho. The foundation for prescribing flow augmentation measures is based on the following two premises (Giorgi et al. 2002):

1. Increased water velocity → increases migration speed of smolts → increases survival.

2. Lowering water temperature (summer) → improves migratory and rearing conditions for both juvenile and adult salmonids → improves survival.

Flow augmentation actions are complex and strive to meet multiple environmental objectives, including: improved flows for fish under the 2008 BiOp, state and federal water quality standards that currently limit TDG concentrations, flow needs for other listed fish and resident fish such as Kootenai white sturgeon and bull trout, state and federal water temperature standards, and reservoir refill for flow augmentation in subsequent years. Water management actions must also balance environmental needs against other uses including flood control, irrigation, recreation, and power generation.

Hydrologic conditions in the Columbia River basin vary among and within years, and are primarily driven by the total amount and form of precipitation and the runoff pattern. This variability greatly influences FCRPS operations and requires a process for coordinating pre- and in-season water management decisions. The FCRPS storage projects are operated in conjunction with Canadian projects to provide flows that balance the available stored volume and predicted runoff among the competing needs discussed above (Figure 13).

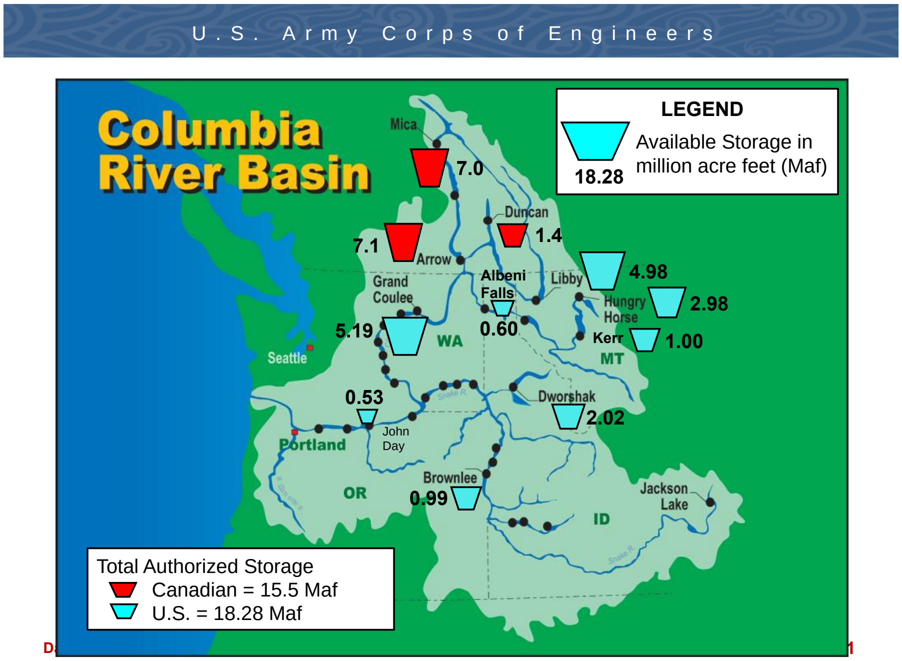

Figure 123

Source: Figure provided by U.S. Army Corps of Engineers.

Active Storage Volumes at Reservoirs in the Columbia River Basin

The seasonal flow objectives identified in the 2008 BiOp are designed to improve juvenile fish survival and expose juvenile salmon to peak flows with a hydrograph that more closely resembles conditions prior to development of the FCRPS. The flow targets are not performance standards and they cannot physically be met every year. However, they are benchmarks that are used to guide real-time water management decisions and maximize benefits for migrating salmon given annual conditions and stored water volumes.

During late summer when ambient river temperatures can be excessive, flow augmentation is also used to moderate temperatures in the upper reach of the Snake River near Lower Granite Dam. Cool water is released from Dworshak Reservoir on the Clearwater River. The action primarily benefits juvenile fall Chinook salmon that rear and migrate in the Snake River during summer. These actions also benefit adult steelhead and fall Chinook migrating during summer.

In addition to flow augmentation, the Corps also operates mainstem Snake River dams to increase water velocity by reducing reservoir volume, further expediting juvenile migration. Since 1995, Snake River projects have been operated within 1 foot of minimum operating pool (MOP) and John Day Dam has been operated within 1.5 feet of minimum irrigation pool (MIP) to reduce the volume of these reservoirs so water and fish move more quickly through them. Minimum Operating Pool refers to a project's lower operating range while Minimum Irrigation Pool refers to the minimum level at which irrigation systems can effectively access water. An exception has been Lower Granite Reservoir, which has been held within 2 feet of MOP because of sedimentation in the reservoir and the need to maintain minimum depths in the federal navigation channel.

The rationale for increasing flow and water velocity in the FCRPS dates back to the 1970s when the Snake River dams were being constructed (Raymond 1979, Sims and Ossiander 1981, Giorgi et al. 2002). This more contemporary review of conditions relies on the most recent published data and analyses by NOAA (Faulkner et al. 2012) and the CSS (Tuomikoski et al. 2011) of the time fish take to travel through the FCRPS.

Faulkner et al. (2012) evaluated fish travel time patterns within the outmigration season each year and concluded that the observed decreases in travel times for yearling Chinook salmon and steelhead later in the season generally coincided with increases in flow, and presumably with increased levels of smoltification (Figure 14). For example, Faulkner et al. (2012) found that travel time through the hydropower system during 2011 was among the fastest of all years studied for both yearling Chinook salmon and steelhead. Flows at Snake River dams were above the historic average (1994-2010) and increased to high levels during May. The high flows resulted in increased water velocity and relatively high spill percentages. Travel time was likely shortened by these high levels of flow and spill and by the use of surface bypass structures at most projects during 2011. Travel time generally decreases as flow increases over the course of each year.

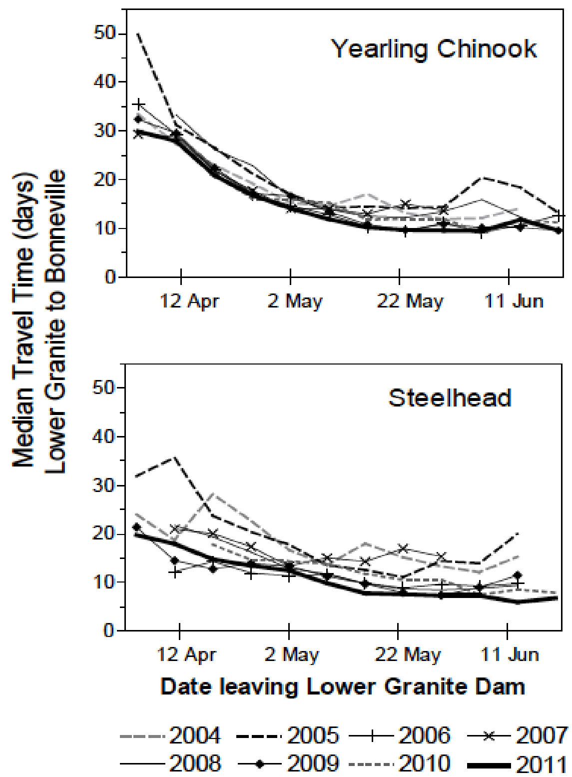

Figure 14

Source: Faulkner et al. 2012

Median Travel Time (Days) for Weekly Release Groups of Snake River Yearling Chinook Salmon and Steelhead from Lower Granite Dam to Bonneville, 2004-2011

Tuomikoski et al. (2011) used a model-based approach because benefits of flow augmentation alone cannot be estimated empirically, since juvenile fish migrations are affected by multiple factors simultaneously (e.g., climate, hydrology, and smolt characteristics such as the degree of smoltification and fish size). They assessed the effects of environmental variables such as flow and spill and found that fish travel time was related to flow-based water travel time (WTT) and spill. They posit "the effect of WTT most likely influences the amount of time required to transit the reservoirs, with faster WTT resulting in faster fish travel time through the reservoirs."

In summary, both groups that have investigated relationships between flow and fish travel time indicate that targeted flow augmentation contributed to increased smolt migration speed in recent years since the implementation of the 2008 BiOp. However, available studies do not clearly quantify the changes in water velocity, smolt speed, or survival above base conditions that are attributable to flow augmentation alone. Changes in FCRPS fish travel time are also associated with actions apart from flow augmentation, particularly dam passage improvements such as surface passage and spill-related effects designed to achieve dam passage performance standards, addressed later in this paper. Even in light of these analytical limitations, the combined actions to manage flows for fish and improve passage conditions at dams and reservoirs appear to have contributed to improved migratory conditions through the FCRPS, resulting in shorter smolt travel times compared to pre-2008 BiOp operations.

4 JUVENILE FISH – SUMMER MIGRANTS

The dam passage survival performance testing that began in 2010 includes estimating survival for ocean-type, subyearling Chinook salmon, the majority of which typically migrate through the FCRPS during the late spring and summer. Initial results are positive, and estimated survival has exceeded the 93% BiOp survival standard at each dam evaluated to date (Figure 15). This indicates that passage improvements implemented at FCRPS dams under the 2008 BiOp are reducing smolt mortality by providing safe, effective passage routes in the form of surface passage and conventional spill.

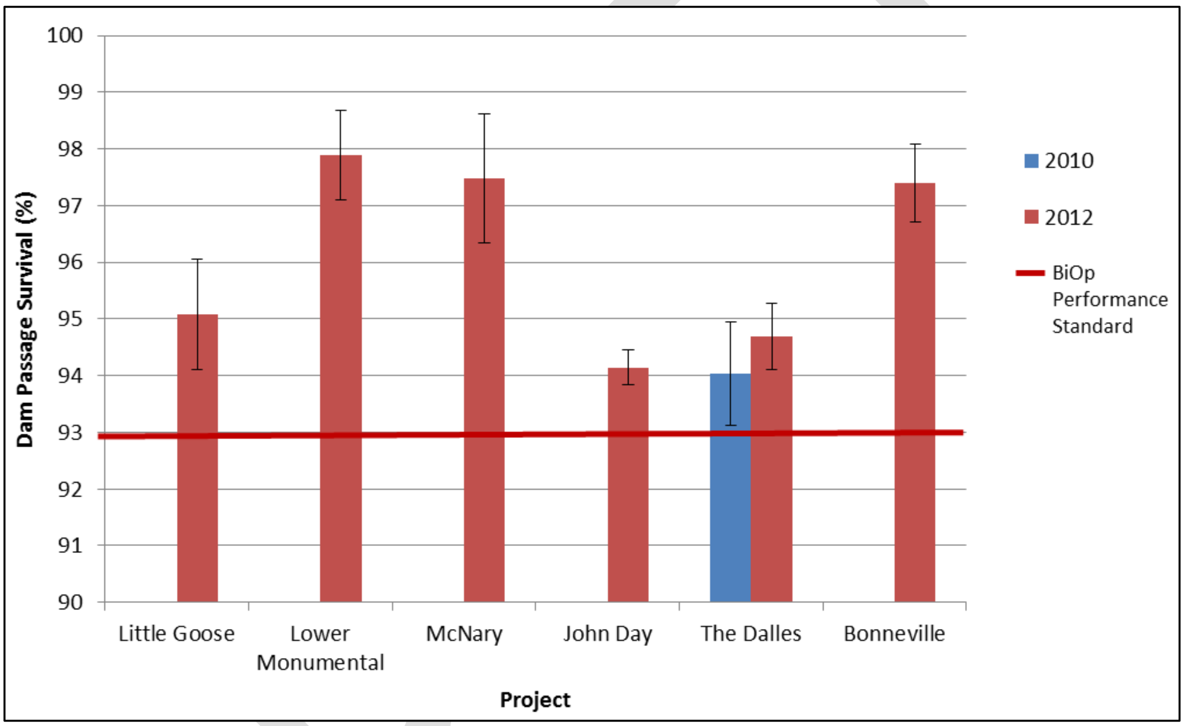

Figure 13

Estimated dam passage survival for subyearling Chinook salmon.

Note: The 2008 BiOp spring performance standard is 93% for subyearling Chinook salmon. Bars represent annual mean survival. Whisker plots represent standard error.

Unlike the situation for spring migrants, direct estimates of survival through the FCRPS reach for summer migrants such as Snake River fall Chinook salmon are limited. This is the result of complications associated with accurately estimating survival, given the complex life history strategies of subyearling Chinook. Some members of the population exhibit protracted migrations and rear as they slowly migrate downstream. Others hold over in reservoirs and continue their migration into the fall and winter, or even the following year (Connor et al. 2005). This complex pattern has been recognized more recently, and violates one of the standard assumptions of the statistical model used to estimate survival over extended river reaches.

Performance standard testing conducted by the Corps does provide estimates of fish residence time in dam forebays. Test results indicate that subyearling Chinook salmon spend a relatively brief period searching for passage routes. The median elapsed time from first arrival at the dam to passage has ranged from about one hour at The Dalles (Skalski et al. 2012c) to 2.6 hours at Lower Monumental (Skalski et al. 2013a).

Tuomikoski et al. (2011) compared travel times of subyearling Snake River fall Chinook salmon from Lower Granite to McNary Dams between two different passage eras. For the period from 2005 to2010 mean fish travel time was 11.2 days, compared to 21.3 days for the same reach during preceding era from 1998 to 2004. They attributed the reduction in travel time to the implementation of summer spill, which began in 2005. However, system monitoring also indicates that the faster migration of juvenile fish through the FCRPS reflects the combined effects of flow augmentation, spill, and recently installed surface passage systems. But this is complicated by the apparent life history change in which some subyearling Chinook salmon cease active migration in midsummer and hold over in reservoirs. Operations designed to facilitate migration during this time may instead simply redistribute these fish within the system.

5 SUMMER SPILL

The 2008 BiOp calls for summer spill to be provided at all lower Snake River and Columbia River dams, generally beginning in mid-June. While summer spill continues at the four lower Columbia River dams through the end of August, there is a spill cessation criteria associated with the end date of summer spill at the Snake River dams. Summer spill cessation generally refers to spill at Snake River dams in the late summer, most notably in the month of August. The current timing of the Snake River fall Chinook migration is such that few fish migrate past Snake River Dams during August (Fig. 16). Consequently, a small percentage of the population encounters August spill and the effects on the ESU remain unclear.

The rearing and migratory behavior of fish is relevant when evaluating the effectiveness of operations to improve their passage through the FCRPS. Fall Chinook salmon from the Snake River are believed to have historically migrated in summer as subyearlings and have generally been considered in that context. However, research over the last decade has found that this ESU now exhibits a variety of rearing/migratory forms including subyearling, yearling, and reservoir-type patterns (Connor et al. 2005). This complexity likely benefits the population by increasing diversity that enables the fish to be productive across a broad range of environmental conditions. It results from complex interactions between the thermal regimes fish are exposed to during incubation and rearing each year, as well as dams and reservoirs in their migration corridor (Waples et al. 2007) and hatchery practices.

Investigations indicate that fall Chinook salmon that do not actively migrate downstream beyond July hold over in reservoirs or other parts of the river, feeding and growing before continuing their downstream migration later in the year or even the following year. Zabel et al. (2012) found that a majority of yearling fish overwinter in the Snake River, with a small fraction potentially moving downstream to the Columbia River. Zabel et al. also reported that 62% of returning adult fall Chinook had followed a yearling life history as juveniles and proposed that the high percentage provides circumstantial evidence of a survival advantage associated with the delayed migration. This is a consideration in terms of spill operations. In light of this behavior, spill operations designed to facilitate migration in late summer may

simply redistribute these fish within the system and perhaps affect or interrupt this potentially advantageous rearing behavior.

The 2008 BiOp, in Reasonable and Prudent Alternative (RPA) 29, adjusts summer spill based on the presence of fish by specifying that spill will continue at the four lower Snake River dams until daily passage counts of subyearling Chinook salmon fall below 300 fish for three consecutive days after August 1. The RPA also calls for restarting spill if fish numbers later increase. This concept was further refined in the 2008 Columbia Basin Fish Accords (Accords), which specified that if the trigger was met spill would end at the four dams on a staggered basis, continuing longer at dams farther downstream to support fish migrating toward the ocean. To further enhance the summer spill program, the AAs developed a safeguard based on adult returns, whereby low abundance of naturally produced Snake River fall Chinook would trigger spill through August at Snake River projects the following year, regardless of the number of juveniles migrating downstream. Although these safeguards remain in place, court-ordered operations since 2005 have required spill through August each year regardless of daily juvenile fish counts (Figure 16). Thus, RPA 29 has not been implemented, nor has the site-specific staggered spill curtailment operation that was negotiated under the Accords.

Based on the most recent five-year period, the timing of the Snake River fall Chinook salmon migration was such that few fish migrated past Snake River dams during August (Figure 11). Since 2005, the proportion of the annual outmigration passing the three uppermost Snake River dams during August ranged from 0.23 to 5.28% and was less than 2% in most cases (Table 3; see Appendix A for methods used to develop Table 3). The release of hatchery fish that are part of the Snake River fall Chinook ESU has left a smaller percentage of fish migrating in August, which is why the threshold for continuing spill in August is based on the specific number of 300 fish and not a percentage of the migration. If spill had ended when fish numbers declined as described in the 2008 BiOp and Accords guidelines, the ending date would have varied each year but could have occurred as early as August 1. An analysis shows that from 0.0 to 1.2% of the outmigrating fall Chinook would have migrated past the Snake River dams after spill ended each year (Table 3). Since 2005, those percentages would have translated into 0 to 12,369 fish passing Snake River dams after the spill cessation dates based on the 2008 BiOp and Accords (Table 3).

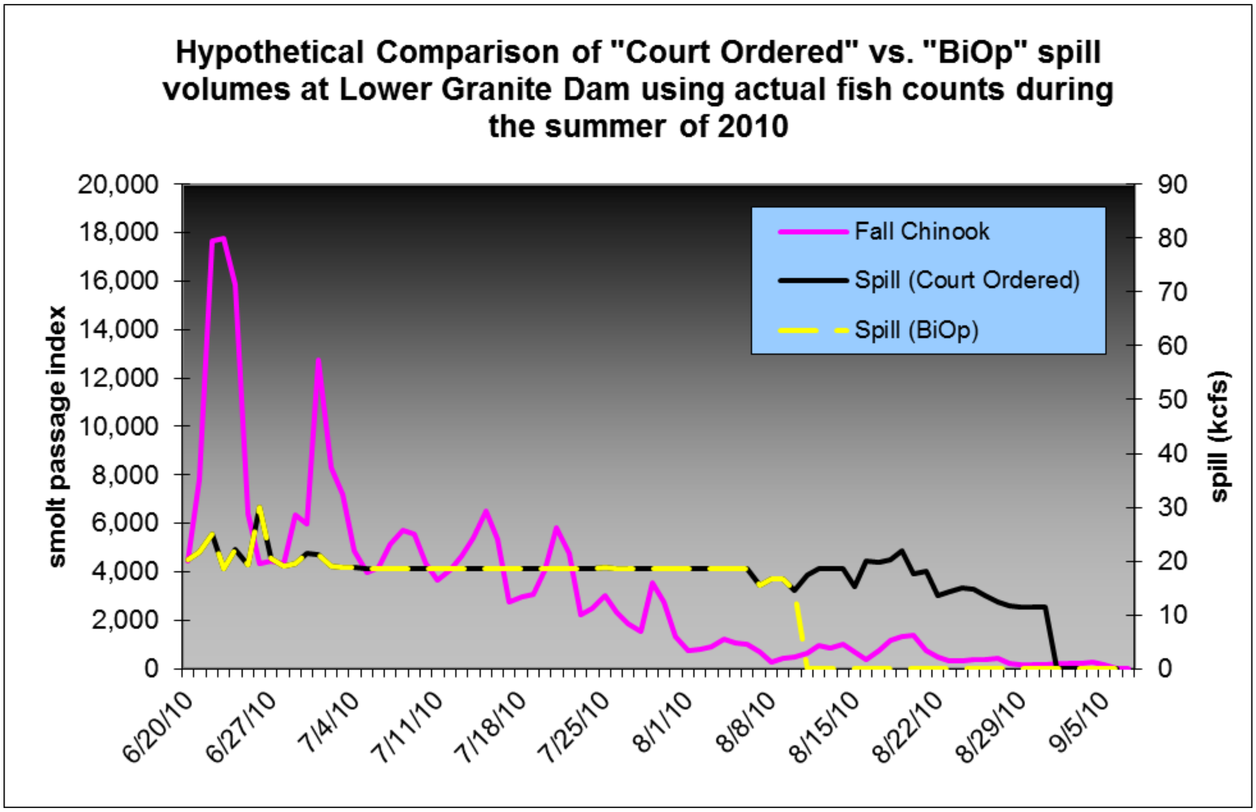

Figure 14

Under the BiOp and Fish Accords, spill (dashed yellow line) would continue at Snake River dams until the number of migrating fall Chinook (pink line) falls below a predetermined threshold, which in the above example year of 2010 occurred in mid-August. Court-ordered spill continues through August irrespective of the number of migrating fish.

These data indicate that if the 2008 BiOp provisions for coordinating summer spill with the fish migration were implemented, dam operations and spill would have been provided for at least 98.8% of all fish since 2005. Conversely, extending spill at Snake River dams through the month of August as mandated has provided spillway passage for 0.0 to 1.2% of the intended population since 2005, depending on dam location and year. The actual effects on fish are unclear because the effects of spill during August have not been analyzed in the context of fall Chinook salmon rearing behavior, survival, and adult returns. A key question is whether summer spill supports or hinders the diversity in life history strategies expressed

by this ESU, and adult returns based on these strategies. This is because certain life history strategies represented in a juvenile outmigration can contribute disproportionately to adult returns (Reimers 1973). Diversity in such strategies has been shown to promote productivity, despite changes in freshwater and marine climatic conditions over the course of a century (Hilborn et al. 2003). This leads some to argue that management and recovery efforts should focus on maintaining life-history variation rather than promoting of a particular phenotype (Miller et al. 2010).

Table 3

Proportion of Summer Migrants Passing Snake River Dams, 2005-2012

Year	Project	Proportion of Annual Outmigration Passing the Dam During August	Spill Cessation Date Based on BiOp Criteria (RPA 29)	Proportion of Annual Outmigration Past the Dam by BiOp Spill Cessation Date
2005	Lower Granite	0.39%	Aug. 1	99.24%
	Little Goose	0.44%	Aug. 4	99.46%
	Lower Monumental	0.50%	Aug. 7	99.35%
2006	Lower Granite	0.58%	Aug. 1	98.63%
	Little Goose	0.31%	Aug. 4	99.65%
	Lower Monumental	0.23%	Aug. 7	99.72%
2007	Lower Granite	1.27%	Aug. 1	95.49%
	Little Goose	1.03%	Aug. 6	99.17%
	Lower Monumental	0.98%	Aug. 9	99.27%
2008	Lower Granite	5.28%	Aug. 31	97.69%
	Little Goose	4.82%	Aug. 31	99.26%
	Lower Monumental	2.95%	Aug. 31	99.69%
2009	Lower Granite	0.65%	Aug. 3	98.45%
	Little Goose	0.82%	Aug. 12	99.64%
	Lower Monumental	0.92%	Aug. 15	99.74%
2010	Lower Granite	2.00%	Aug. 11	96.88%
	Little Goose	2.40%	Aug. 24	99.45%
	Lower Monumental	1.02%	Aug. 27	99.92%
2011	Lower Granite	1.77%	Aug. 6	97.46%
	Little Goose	2.06%	Aug. 15	99.06%
	Lower Monumental	4.89%	Aug. 18	98.10%
2012	Lower Granite	1.65%	Aug. 20	98.06%
	Little Goose	2.11%	Aug. 23	99.52%
	Lower Monumental	1.45%	Aug. 26	99.37%

6 ADULT FISH

Many BiOp actions have also been directed at improving migration conditions for returning adult fish, which are especially valuable to their populations because they have survived difficult years at sea and are nearly at the point of spawning and giving rise to successive generations. The 2008 BiOp specifies performance standards for adult survival for most species/races, and includes provisions for annually monitoring survival through the FCRPS. Adult passage survival was consistently high through the mid-2000s and remains so for several species. However, adult passage survival has unexpectedly declined in recent years for certain Snake River species. Recent and planned improvements in PIT tag monitoring capabilities will help identify the location and potential causes, which could include high flows and spill leading to adult fallback, straying and effects of harvest. That should inform the development of possible solutions.

Once past Bonneville Dam, the ability of adult fish to reach their natal streams is influenced by many factors including their successful migration through additional FCRPS dams via fish ladders. The 2008 BiOp identifies performance standards for adult passage through selected FCRPS reaches (Table 4). NOAA Fisheries calculates adult survival through these reaches each year and provided these data (Bellerud 2013). These data are based on known source, PIT-tagged adults detected at Bonneville Dam and subsequently detected (or not) at McNary Dam and Lower Granite Dam. NOAA calculates the annual point estimates and rolling five-year averages for each ESU and applicable river reach. NOAA adjusts the rates of conversion between dams for estimated harvest and straying. In 2013, a new detector will be installed at The Dalles Dam to provide improved spatial resolution of adult survival in the FCRPS and further inform analysis of adult survival.

Based on NOAA's data, adult survival relative to the BiOp performance standards has been mixed (Table 4). In general, survival of Snake River fall Chinook salmon, upper Columbia River spring Chinook salmon, and upper Columbia River steelhead are near the survival standards. In contrast, the survival of adult Snake River spring-summer Chinook salmon and steelhead has declined in recent years to the point where they are currently below the adult performance standard. This suggests some adverse change in migration conditions. Data from

NOAA suggests that this unknown impact may be occurring in the lower Columbia River between Bonneville and McNary Dams, since survival through the upper Columbia and the Snake River appears to be comparable to previous years.

Table 4
FCRPS Biological Opinion Adult Performance Standards by ESU for Hatchery and Wild Fish Combined and Current Estimates of Passage Success, as provided by NOAA Fisheries, April 2013

ESU[1]	Adult Passage Standard	River Reach[2]	Passage Success
SR Fall Chinook	81.2%	BON to LGR	87.4[3]
SR Spring-summer Chinook	91.0%	BON to LGR	81.7[4]
SR Sockeye	Surrogate; develop in future if data is sufficient	BON to LGR	72.2[4]
SR Steelhead	90.1%	BON to LGR	81.6[3]
UCR Spring Chinook	90.1%	BON to MCN	90.7[4]
UCR Steelhead	84.5%	BON to MCN	87.8[3]

1. The acronyms represent Snake River (SR) Upper Columbia River (UCR), Middle Columbia River (MCR); Columbia River (CR) and the Upper Willamette River (UWR).
2. BON stands for Bonneville Dam; MCN stands for McNary Dam; and LGR stands for Lower Granite Dam.
3. Average for the period from 2007 to 2011 for adults that migrated in-river as juveniles (were not transported).
4. Average for the period from 2008 to 2012 for adults that migrated in-river as juveniles (were not transported).

A performance standard specifically for Snake River sockeye salmon has not been developed. However, the 2008 BiOp considers that sockeye survival is adequate if the survival standards for Snake River spring-summer Chinook salmon and steelhead from Bonneville Dam to Lower Granite Dam are being met. Based on the NMFS data reported above, this is not the case. NOAA estimated that survival of sockeye salmon through the reach ranged from 57.0 to 82.8% the past 5 years (Bellerud 2013).

6.1 BiOp Actions for Adult Passage

Under the 2008 BiOp many actions have been or will soon be implemented to improve adult passage survival. At John Day Dam modifications to the adult passage systems were

completed in 2011. At Lower Granite Dam in 2011, prototype adult fishway modifications were tested to improve upstream adult passage conditions impaired by temperature differentials. In 2012, the use of additional auxiliary water supply for the new adult trap was investigated so the trap could be operated at full capacity when the forebay is at minimum operating pool. Beginning in 2014, the east ladder emergency auxiliary water supply system at The Dalles Dam will be modified to improve passage conditions.

These improvements notwithstanding, the recent drop in adult survival for three Snake River species is a concern that warrants further investigation. Unfortunately, NOAA's estimates cannot be partitioned further to identify the mortality attributable to various potential sources. Candidate sources of mortality could include natural causes, impaired passage through the FCRPS because of high flow or spill, direct and indirect effects of harvest, increased straying, and delayed effects of marine mammal attacks incurred below Bonneville Dam. Recent and planned improvements in PIT tag monitoring capabilities in the FCRPS will help identify the location and potential causes of the loss, and additional research or monitoring will likely be required to inform the formulation of solutions.

7 JUVENILE TRANSPORTATION

The transportation program has been operational in the lower Snake River for more than three decades. It involves diverting migrating smolts from turbine intakes at specially designed collector dams and transporting the fish, primarily by barge, to release sites downstream from Bonneville Dam. The uppermost dams (Lower Granite, Little Goose, and Lower Monumental) are the primary transport facilities, but fish can also be transported from McNary Dam during summer. These collector dams are fitted with turbine intake screens that guide a large portion of the turbine-routed fish into a collection system, where they are loaded into specially designed barges supplied with circulating river water. The collection systems can also be operated in a bypass mode when transport is not warranted, returning fish directly to the river to continue their migration. In the Snake River there are two general passage options for smolts: 1) collection and transport from dams fitted with screened collection/bypass systems, or 2) in-river migration to the ocean via some

combination of routes including conventional spillways, surface passage, screened bypasses or turbines.

The goal of the transportation program is to increase the proportion of fish that return as adults to spawn. The objective of the program is to improve smolt survival by avoiding the hazards associated with passing multiple hydroelectric projects. Research has also indicated potential benefits associated with arrival of fish in the lower Columbia River and estuary when increased productivity makes more food resources available (Scheuerell et al. 2009). The timing and conditions for transport are empirically based, relying on recent data indicating that adult return rates are higher for juveniles that are transported at certain times than for their counterparts that migrate in the river through the FCRPS. For example, results have shown that transportation in early April is not beneficial, while transportation in early May has shown consistent improvement compared with in-river migration. The result is that transportation in early April has been curtailed in recent years.

Key metrics used in these comparisons include the proportion of smolts that return through adulthood or the smolt-to-adult return rate (SAR) for each treatment group, and various ratios derived from the SAR estimates that are generally referred to as the transport to in-river migrant ratio (TIR). This ratio and variants thereof as described in Smith et al. (2013) are used to assess the effectiveness of transporting smolts, where:

- TIR > 1.0 indicates that transported fish survive to returning adult at rates exceeding in-river migrants.
- TIR < 1.0 indicates that in-river fish survive to returning adult at higher rates than those transported.

7.1 Spring Migrants

Spring-summer Chinook salmon, steelhead, sockeye and lamprey migrate through the Snake River during the spring migration period, primarily April through early June. Their migration timing overlaps at varying degrees each year. Thus, the decision to transport, or not, affects all species present. These issues are discussed in the following sections by

examining broad scale, species-specific annual responses to transport, as well as within-year variation in responses.

7.1.1 Transportation Evaluations

Two analytical groups regularly evaluate the effectiveness of transportation: the Fish Passage Center (FPC), which coordinates the CSS study, and NOAA's Northwest Fisheries Science Center. For the years 1994 to 2009, results from the CSS indicate that transported and in-river migrating wild Chinook salmon smolts have nearly equal probabilities of surviving to return as adults. Hatchery-origin smolts showed similar patterns, but with more variability among hatcheries and across years.

Analyses of annual performance indices for more than a decade ending in 2008 conducted by NOAA Fisheries (2010) indicate that depending on the baseline used, transported wild spring Chinook salmon survived at about the same, or slightly higher rates than in-river migrants. In contrast, transported hatchery-origin yearling Chinook salmon exhibited transport-to-migrant (T:M) ratios that were typically greater than 1.0, regardless of the baseline examined. The T:M ratio is a variant of TIR, discussed earlier.

Separately, Holsman et al. (2012) analyzed PIT-tag data from 1998-2006 and found that considering the marine component of the life cycle yielded very different results among rearing histories that were not apparent in the T:M ratio. The survival of transported wild Chinook salmon in the marine environment was about two-thirds less than that of counterparts migrating in-river. In contrast, transported hatchery Chinook survived their marine residence at approximately twice the rate of in-river migrants. The two studies conducted by NOAA investigators characterize wild Chinook responses to transportation somewhat differently, ranging from negative to slightly positive. This apparent discrepancy may depend in part on the different timeframes (years) included in the separate analyses.

For the last decade ending in 2009, both wild- and hatchery-origin steelhead that were transported survived to return as adults at higher rates than cohorts migrating through the FCRPS (NOAA 2010). The results of CSS analysis are generally consistent with NOAA's

observations. In most years, transported wild and hatchery origin steelhead survived to return as adults at appreciably higher rates than in-river migrants, as evidenced by the TIR estimates well above 1.0. (Figure 13; Tuomikoski et al. 2011). But in four of the 12 years, transported fish survived at about the same or lower rates than in-river migrating counterparts. In terms of SAR magnitude, the CSS 12-year average for transported fish was 2.16 and 1.62 for transported wild and hatchery origin steelhead, respectively. These values are 2 to 3 times higher than observed for either group (bypassed or not) that migrated in-river, showing a definite benefit for steelhead from transportation, even with in-river survival improving in recent years.

Retrospective analyses conducted by different analytical teams indicate that on average across more than a decade (ending in 2008 or 2009), the proportion of transported yearling Chinook salmon and steelhead surviving to return as adults varied by species and natal origin (hatchery or wild). Regardless of those factors, transported steelhead generally survived at higher rates than in-river migrants. Wild and hatchery yearling Chinook displayed different patterns in survival, where transported hatchery fish generally returned as adults at higher rates than in-river migrants. In contrast, wild yearling Chinook salmon survived at about the same or lower rates than their counterparts migrating in-river.

Other considerations also inform decisions on transportation. For instance in 2010 the Northwest Power and Conservation Council's Independent Scientific Advisory Board reviewed a proposal for transporting fish in low flow conditions and noted that combinations of transport and in-river migration supported by spill help spread the risk across species, stocks and the ecosystem (ISAB 2010). The ISAB also noted questions about potential for increased straying by steelhead and uncertainties about the effects of transportation on sockeye and lamprey migration.

The most relevant and instructive information on the effects of transportation on survival is from the most recent years, when all of the dams in the FCRPS had been fitted with surface bypass systems and additional spill had been integrated into the BiOp. Those actions appear to have substantially improved passage conditions for in-river migrants, thereby providing the most current comparison with transportation. Importantly, adult returns from the recent 2009-2012 migration years may offer the best assessment in this regard, since all surface

passage systems were in place during this period. However, the adult returns for those years are incomplete and a more definitive evaluation will be possible in 2015 or beyond.

For Snake River sockeye salmon, there are too few data to adequately evaluate transportation effects. A pilot study has been initiated to examine the relative survival of sockeye experiencing either transport or in-river migration conditions. For that study, sockeye salmon smolts were PIT tagged at the Sawtooth Hatchery in Idaho, and Oxbow Hatchery in Oregon. Initial results from 2009 suggest that transport is neutral for Sawtooth Hatchery-reared sockeye, but beneficial for Oxbow Hatchery-reared sockeye, which were larger than Sawtooth Hatchery fish (Biomark and Quantitative 2012). However, fish from each hatchery were also released at different sites, which could have influenced these results. Importantly, data from a single year is inadequate to provide a definitive evaluation of transportation for this species.

7.1.2 Intra-annual Variation in Survival (SAR)

Broad annual indices of transportation effects do not fully inform decisions facing fishery and hydropower system managers. This is because within-year variation in survival provides a more complicated picture that should be considered when crafting a transport program Management decisions involve identifying when within a year, and at which sites, transportation provides benefits. The decisions are complicated by the presence of three salmon and steelhead species during the spring migration period, each of which responded differently to transportation as noted previously. Recent analyses by NOAA provide information useful for exploring these issues.

A recently published report by NOAA (Smith et al. 2013) analyzed seasonal (intra-annual) patterns in SAR for various classes of transported and in-river migrating Snake River steelhead and spring-summer Chinook salmon. The NOAA results for 2006 to 2009 suggest that postponing transport until late April or the first week of May should improve survival for wild Chinook, hatchery steelhead and perhaps hatchery Chinook salmon. Findings by Holsman et al. (2012) support the decision to delay the onset of transportation until later in the spring migration, at least as a benefit for wild Chinook salmon. But the outcome is less

certain for wild steelhead that generally survive better when transported anytime during the spring migration.

With respect to transporting smolts after the first week in May, the data are convincingly clear. Overall, in the vast majority of years included in the NOAA analyses, yearling Chinook salmon and steelhead that were transported from Lower Granite Dam survived at rates higher (often significantly so), or no different, than their counterparts migrating in the river through the FCRPS. This is evident regardless of natal origin, even for the most recent years (2006 to 2009) under the current spill program and reconfigured system.

Unintended consequences of barging smolts are also of concern when crafting a transportation program. Recently, the effect of barging on adult straying rates has received increased attention (Keefer and Caudill 2012). It remains unclear whether increased stray rates associated with transportation have been excessive.

For more than a decade the region has explored ways to balance transportation and in-river migration to increase SARs for listed ESUs and minimize the risk of unforeseen negative conditions/effects in any particular year, given the vagaries of environmental conditions or unexpected hydrosystem operations. This balance is often referred to a "spread-the-risk" operation in the hydrosystem. It involves distributing the population between transportation and in-river migration, by tailoring operations between spill, surface bypasses, and screened bypass systems. A "spread-the-risk" operation presumes an approximate balance between the fish left to migrate in the river, and those that are transported. However, in recent years the majority of fish have remained in-river to migrate through the FCRPS. The Action Agencies are taking steps to more closely achieve an even balance between the number of fish transported and those left to migrate in the river, primarily by beginning transportation slightly earlier in the spring.

The collective analyses indicate that over most of the past decade, Snake River steelhead and spring Chinook salmon transported after about May 1 survived to return as adults at rates higher than, or equivalent to, their counterparts migrating in-river. Thus, in terms of maximizing the number of adults returning to these populations, transportation appears to have offered the best option for maximizing survival for both species across a broad spectrum

of water years, at least after about the first week of May. Even so, recent improvements in dam operations and configurations have increased the survival of smolts migrating through the FCRPS. The outcome of these improvements measured over an adequate number of years (more than three) as reflected in adult returns will not be in hand until at least 2015. A re-evaluation at that time could take into account contemporary passage conditions.

7.2 Summer Migrants (Early and Late Fall Chinook)

Subyearling fall Chinook salmon from the Snake River are regularly transported, although a thorough evaluation of the mitigation action has yet to be completed. However, a decade-long, multi-agency investigation has been initiated. That study is designed to determine the best passage options for optimizing the survival of juvenile fall Chinook salmon through the FCRPS. The complex life history of fall Chinook salmon has complicated investigations in previous decades. Those complications will be considered in the ongoing study.

Snake River fall Chinook salmon are regularly transported from dams in the FCRPS, while also affected by the summer spill program. Upcoming results from the decade-long, multi-agency investigation will provide information regarding the merits of these passage strategies. Until those results are in hand, the policy of "spread-the-risk" by using a blend of both strategies remains prudent for this ESU.

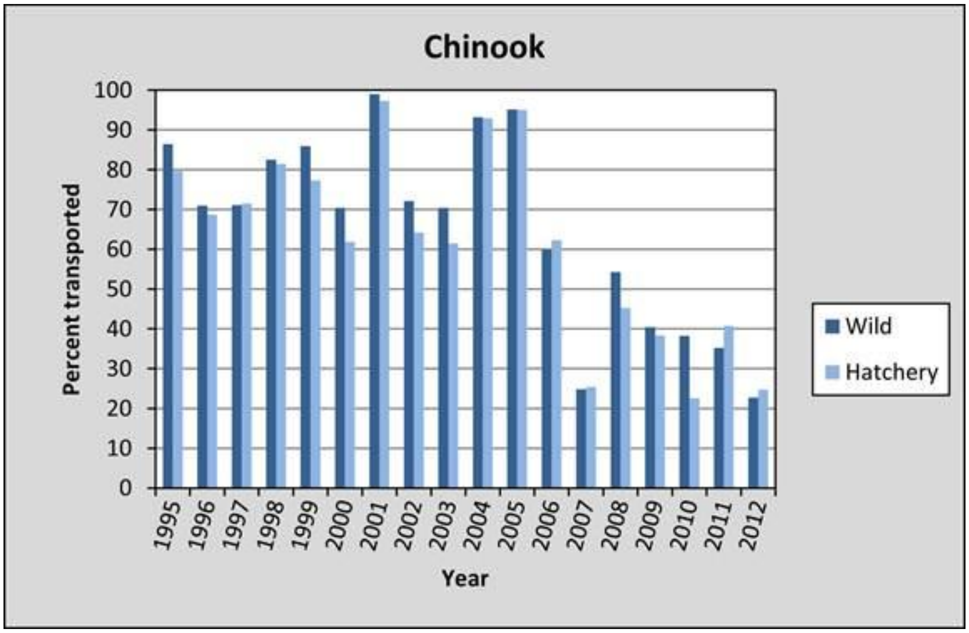

Figure 17

Estimated Percentage of Wild- and Hatchery-origin Yearling Chinook Salmon Smolts Arriving at Lower Granite Dam that were Transported from all Collector Dams on the Snake River, 1995-2012.

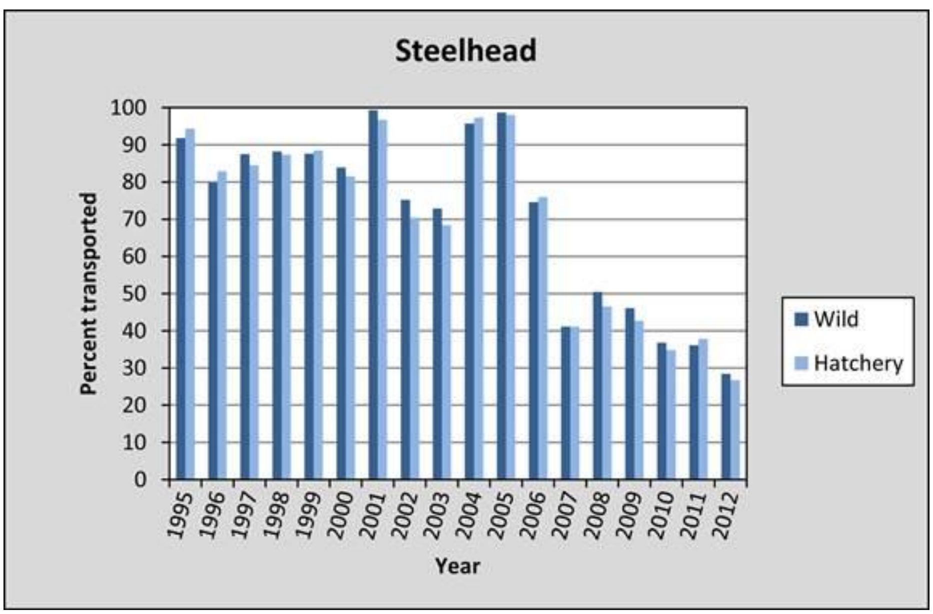

Figure 18

Estimated Percentage of Wild- and Hatchery-origin Steelhead Smolts Arriving at Lower Granite Dam that were Transported from all Collector Dams on the Snake River, 1995-2012.

The current practice of postponing transport until the first week of May appears to be advantageous to some, but not necessarily all Snake River ESUs. Responses vary by species and natal origin (wild or hatchery). This suggests that inter-species tradeoffs between Chinook salmon and steelhead may be in play during April. Managers may need to consider which ESUs are in most need of protection, given the current status of the ESU or sub-populations and their migration timing through the system.

Importantly, over the last decade the increased use of spill to route fish safely past dams in the Snake River has resulted in lower numbers of fish available for collection at transport dams. This has translated into fewer yearling Chinook salmon (Fig. 14) and steelhead (Fig. 15) transported each year. It would be instructive if the role and objectives of "spread-the-risk" were formally described in quantitative terms.

8 SUMMARY AND CONCLUSIONS

The suite of BiOp actions directed at improving smolt survival while passing dams in the FCRPS has been successful. The installation of surface passage systems, in concert with spill operations and improvements to screened bypass systems, has resulted in high survival at sites where compliance testing has been initiated. In nearly all instances empirical estimates of smolt survival equal or exceed the stated performance standards for dam passage survival. This is true for all three species/races tested thus far: steelhead, and both yearling and subyearling Chinook salmon.

The benefits of these passage improvements are evident system-wide. The survival of juvenile salmon from the Snake River through the entire FCRPS has increased over the last 15 years, and is now at levels that prevailed prior to the installation of most Snake River dams. System-wide actions such as flow augmentation and an aggressive predator control/deterrent program have made migratory conditions through reservoirs less hazardous

for juvenile salmonids, and likely contributed to the high system-wide survival realized in recent years. Even so it is difficult to ascertain survival improvements that are directly attributable to flow augmentation.

Surface passage and increased spill levels have contributed to high proportions of juvenile fish passing through non-turbine routes, high dam passage survivals, short forebay residence times, and faster travel times through the FCRPS. This indicates that the judicious use of spill to improve passage conditions and survival has merit. But when few fish are in-river to encounter the spill operation, which is the case at Snake River dams during the month of August when fewer than 2% of the population of Snake River fall Chinook salmon are still migrating downriver, its effectiveness may be questionable. Furthermore, water temperatures in the Snake River peak well above 20 degrees C from mid-July through August. However, the consequences associated with promoting in-river migration through spill and surface passage during this thermally inhospitable period are unclear.

For adult fish, recent estimates of passage survival for three Snake River ESUs have been of concern because they have not met the survival standards specified in the 2008 BiOp. At this juncture, the causes and specific location of the adult losses within the FCRPS are not clear, and scheduled improvements to PIT-tag monitoring capabilities in the FCRPS will provide the improved spatial resolution required to pinpoint zones where fish are not successfully migrating, when this occurs, and river conditions at that time. This information will help identify causal agents and potential solutions. The improvements include the installation of detectors in ladders at The Dalles Dam beginning in 2013, and the expansion of the stream-based detectors in major tributaries to the lower Columbia River.

Another key issue is the transportation of juvenile salmon and steelhead from collector dams. The analyses described indicate that over most of the past decade, Snake River steelhead and spring Chinook salmon transported after about May 1 have survived to return as adults at rates higher than, or equivalent to, their counterparts migrating in-river. Thus, in terms of maximizing the number of adults returning to these populations, transportation appears to have offered the best option for maximizing survival for both species across a broad spectrum of water years. Even so, recent improvements in dam operations and configurations have increased the survival of smolts migrating through the FCRPS. The outcome of these

improvements in comparison to the benefits provided by transportation will not be fully apparent until adult returns through 2015 are in hand.

The current practice of postponing transport until the first week of May appears to be advantageous to some, but not necessarily all Snake River ESUs. Wild steelhead would survive at higher rates if they were transported throughout the entire spring. Over the last decade the increased use of spill to route fish safely past dams in the Snake River has resulted in lower numbers of fish available for collection and transport. This has decreased the proportion of yearling Chinook salmon and steelhead transported each year over time, in contrast to the intent of the "spread the risk" policy.

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10 APPENDIX A: METHODOLOGY FOR ASSESSING SUMMER SPILL

To explore the proportion of the Snake River subyearling Chinook salmon outmigration potentially affected by this operational variance from the 2008 BiOp, we downloaded daily subyearling Chinook salmon indices of passage for 2005 to 2012 from Columbia River DART (http://www.cbr.washington.edu/dart). The data are provided to DART via a link to the Fish Passage Center's smolt passage database. Indices are available at three Snake River dams: Lower Granite, Little Goose, and Lower Monumental.

According to Fish Passage Center's 2011 annual report (FPC 2012) "The daily passage index is computed by dividing the daily collection by the proportion of water passing through the powerhouse where the sampling takes place. The daily passage indices adjust for daily changes in spill proportion under the conservative assumption that the proportion of fish passing through spill will be close to the proportion of water being spilled. Estimates of fish guidance efficiency of the screens or of spill efficiency (proportion of fish passing through spill) are not necessary using this method. As long as the daily passage index remains highly correlated to daily population abundance at each site, the passage index remains useful for gauging passage timing and magnitude of passage." The daily collection estimates are the total number of juvenile salmonids calculated to have entered the juvenile fish bypass system at each dam that day. The collection estimate is derived from timed sub-samples taken at intervals throughout a daily twenty-four hour period, where the timed sub-sample is adjusted each day to meet the sample rate required for smolt monitoring purposes that day.

While the daily passage indices are not daily population estimates, they provide the most accurate and standardized information on daily passage available across dams and years. Daily indices are based on smolt monitoring at each dam, which is conducted throughout the entire bypass period and generally extends from late March through October. Annual Fish Passage Center reports provide annual estimates of the number of subyearling Chinook salmon passing Snake River dams each year, but not daily estimates.

Next, we calculated three metrics for each dam and year:

- The proportion of the annual number of subyearling Chinook salmon that passed each dam during August. Since spill ceases on August 31st each year regardless of the daily index number, this represents the maximum proportion of the outmigrant population that would be affected by spill being curtailed per RPA 29 and the Accords.
- The proportion of the annual subyearling Chinook salmon outmigration that passed each dam after the date spill would have been curtailed based on the criteria identified in RPA 29 and the Accords. Spill curtailment dates were provided by the Action Agencies. They were calculated based on RPA 29 criteria, the stagger negotiated in the Accords, and daily dam collection counts.
- The number of subyearling Chinook salmon that passed each dam from the time spill would have been curtailed according to RPA 29 and the Accords through the end of August that year, and the proportion of the total outmigration this represents.

11 APPENDIX B: DELAYED OR LATENT MORTALITY

The terms "delayed" or "latent" mortality are used to describe the loss of smolts believed to be related to passage through the FCRPS but which does not become apparent until after the smolts exit the system. Comparisons of SAR among smolt cohorts that experience different passage events, or conditions, are used to identify and attempt to quantify the existence and magnitude of such effects. This section expands on the contents of the preceding report and reviews the latest research examining the question of delayed mortality and related issues of river and ocean fish survival.

There are two general categories of delayed mortality. One, the differential delayed mortality, is the relative survival between transported and in-river migrating smolts that is calculated once PIT-tagged adults return to the Snake River. The second category, referred to as latent mortality, is associated with non-transported fish that migrate through the FCRPS to the estuary and beyond. It can be expressed as the differential mortality detected among various groups of smolts that experience different passage histories.

The existence, magnitude, and factors affecting latent mortality have been debated for at least two decades as investigations have produced conflicting results. In 2006, NOAA requested that the ISAB review a number of hypotheses explaining the effect, and causative factors thereof. The ISAB concluded that the hydrosystem causes some latent mortality, but strongly advised against continuing to try to measure absolute latent mortality, since it is not measurable relative to a pre-dam reference condition. Instead, they suggested the focus should be on the total mortality of in-river migrants and transported fish, which is the critical issue for recovery of listed salmonids (ISAB 2007).

Since the ISAB first offered their recommendations several research groups have continued to delve into aspects of delayed mortality associated with in-river migration. Focal topics have included the effects of screened bypass systems, general migratory conditions in the FCRPS, and the number of hydroelectric projects encountered.

11.1 Screened bypass systems

Recently, the ISAB reviewed regional analyses that examined latent mortality associated with different routes of passage through the FCRPS (ISAB 2012). The ISAB noted:

> *" The ISAB finds that collectively these analyses demonstrate that fish bypass systems are associated with some latent mortality, but the factors responsible for latent mortality remain poorly understood and inadequately evaluated. The significant association between fish bypass and latent mortality might only reflect a non-random sampling of smolts at the bypass collectors (the selection hypothesis) rather than injury or stress caused by the bypass event (the damage hypothesis). Because these hypotheses have very different implications for hydrosystem operations, FPC and CSS conclusions should be re-examined to consider alternative explanations discussed in this review. Further research will be needed to resolve this issue."*

Sandford et al. (2012) conducted an experiment in an attempt to disentangle some of the confounding factors associated with latent mortality. They conducted experiments with Chinook salmon to assess the magnitude of latent mortality from two sources: passage through juvenile bypass structures at dams, and transportation with larger juvenile steelhead comingled in barges. Chinook salmon were exposed to different treatment conditions during downstream migration. Study fish were then held in seawater tanks for up to 223 days, and time-to-mortality was noted for each individual that died. They found evidence that juvenile Chinook transported with steelhead exhibited higher latent mortality that those transported alone. However, the number of times that individuals encountered bypass system did not appear to affect survival. These survival results span about a seven-month observation period for fish held in tanks and not the entire life cycle through to returning adult. Thus, they may not reflect longer-term effects associated with the treatments. Even so, the results provide a foundation for future investigations.

Separate analyses by Smith et al. (2013) focused on delayed effects associated with transportation. In contrast with Sandford et al. (2012), there were implications regarding latent effects associated with encountering screen bypass systems. The investigators identified two sets of standards for examining transport effects. According to the authors:

> *" The first used the traditional standard where a T:B ratio exceeding 1.0 indicated that transported fish returned at a rate greater than bypassed fish (vice versa, if < 1.0, bypassed fish returned at rates greater than transported fish). The second standard for T:B was set higher than 1.0 – in order to provide evidence that the SAR for transported fish exceeded that for the in-river-migrant population at large, the T:B ratio must be greater than this higher standard, because the population at large included never-bypassed fish which likely returned at a higher rate than bypassed fish."*

Adoption of this more stringent standard implies that these authors recognize that some delayed effects are associated with smolt passage through screened bypass systems.

Buchannan et al. (2011) analyzed 11 years (1996-2006) of PIT tag data and also found evidence for delayed effects of bypass systems. For yearling Chinook salmon, smolts with one or more bypass events tended to have lower adult return rates than non-bypassed smolts. With multiple bypass events, the adult return rate of yearling Chinook salmon declined further. Steelhead smolts that were bypassed at only a single dam exhibited no noticeable decrease in adult returns. However, two or more bypass events for steelhead smolts reduced the rate of adult returns. In addition to simple perceived effects of bypass at individual dams, some pairs of dams appeared to have synergistic effects, where the effect on adult returns from joint detection at the two dams was more than the sum of the perceived effects of bypass at the two dams separately. At some dams they found evidence for size selectivity, but its role in delayed effects remains unclear.

The PIT tag analyses conducted by two separate research groups, Smith et al (2013) and Buchanan et al. (2011), identified delayed effects associated with smolt passage through screened bypass systems. A shorter-term experiment observed no effects being expressed during a relatively brief observation period (several months), while fish were held in captivity. Given the overall weight of evidence, the 2012 position from the ISAB remains relevant:

" The ISAB finds that collectively these analyses demonstrate that fish bypass systems are associated with some latent mortality, but the factors responsible for latent mortality remain poorly understood and inadequately evaluated…".

11.2 Migratory conditions

Apart from the specific passage route encountered by smolts, broader processes such as reservoir conditions and collective dam operations might also influence delayed mortality. In recent years, investigators have explored the potential effects of migratory experience on delayed mortality. Two lines of investigation have received focused discussion and debate.

Haeseker et al. (2012) calculated life-stage-specific survival probability estimates for cohorts of Snake River spring–summer Chinook salmon and steelhead using PIT tag data from migration years 1998-2006. They analyzed freshwater and marine environmental factors associated with survival at each life stage. They found that for in-river variables, the average percentage of river flow spilled at dams and water transit time were correlated with survival rates from the smolt stage through returning adult. They also noted that the effect of marine conditions were influential, as reflected in the Pacific Decadal Oscillation index. They found a positive correlation between smolt survival through the FCRPS and subsequent adult survival during marine residence, and found that higher volumes of spill were associated with higher survival in the FCRPS and during ocean residence, for both species. They concluded that improvements in life cycle survival (SAR) may be achievable by increasing spill percentages and reducing water transit times during juvenile salmon out-migration.

However, the authors did not delve into some matters that are both instructive and important in formulating future passage alternatives and operations. Reviews of the methods and assumptions of the Haeseker et. al paper, commissioned by the Action Agencies (Skalski et al, in prep and Manly, 2011), pointed out several issues that should be considered when correlating SARs to in-river passage conditions as presented in the Haeseker paper. One consideration is that the Haeseker data set terminates in the 2006 migration year, when surface bypasses systems were still being installed at dams in the FCRPS. These devices are

often situated in or near spillways, thereby enhancing smolt passage through both non-turbine routes. The central issue for fish is not how much water is spilled, but what proportion of the smolt population uses the combined non-turbine passage routes that typically have the highest survival rates. As such, the described relationships lose relevance after 2006. The performance indices of spill passage efficiency (SPE) and fish passage efficiency (FPE) called for in the Fish Accords provide more meaningful measures of passage success in today's FCRPS because they track not just the volume of water spilled but how effective the spill is at moving fish through the passage routes with high survival.

Another aspect of the analyses by Haeseker et al. (2012) requires some discussion. They predicted changes in survival associated with additional spill, which were extrapolated beyond the range of observed data. At spill levels beyond the observed range, additional limiting factors can arise, such as total dissolved gas (TDG) effects. These conditions could potentially be hazardous and harmful to both juvenile and adult life stages. Furthermore, excessive spill, or mismanaged spill patterns can interfere with adult passage at ladder entrances in the tailrace. These mechanisms point to practical upper limits for suitable spill volumes. In part, it was such concerns that led to the accelerated installation of surface bypass systems in the FCRPS over the last decade.

Water particle travel time (an index of river flow) was another key predictor variable in the Haeseker et al. (2012) analysis. They noted that lower SARs were associated with higher WTT indices and projected that reduced WTT would promote higher SARs. However, it is not clear what incremental changes in WTT are possible within any given water year, given water management operations that need to balance across sometimes competing demands including flood control, irrigation, recreation, water quality (total dissolved gas limits under the Clean Water Act), and international water treaties, as well as fish resources.

The Haeseker et al. (2012) analyses indicate potential delayed effects associated with smolt migratory conditions, at least for the era they investigated. But the solutions and direction suggested to improve in-river migratory conditions beyond 2006 do not reflect the current state of the FCRPS. With surface bypasses now in place, the usefulness of average spill volume as a meaningful index is greatly diminished and their request for high spill levels today has questionable relevance, given the high FPE observed in recent years (Table 1).

In another project under the NPPC's Fish and Wildlife Program, investigators explored a related aspect concerning delayed mortality. Rechisky et al. (2012) hypothesized that if in-river migration conditions affect survival after smolts exit the FCRPS, then the effect should be evident during the sensitive early ocean entry period of the life cycle. They contend that adult returns are too coarse an index spanning too much of the life cycle and affected by too many variables to be very instructive.

Monitoring smolts with acoustic tags, they analyzed three years (2006, 2008, and 2009) of data using two different hatchery populations of spring Chinook salmon. Snake River smolts released from Dworshak Hatchery traversed eight hydroelectric projects during the seaward migration. Fish released from Yakima Hatchery migrated through only the four dams on the Columbia River, the river segment common to both populations. Rechisky et al. (2012) compared survival of the two populations through the common migratory corridor, from the vicinity of McNary Dam to Willapa Bay on the Washington Coast. They observed no difference in survival between the two groups despite the fact the Snake River population encountered four additional hydroelectric projects. Some critics have cautioned that upstream-downstream comparisons may be inappropriate and misleading, particularly when different stocks are employed, such as in this case. Furthermore, it is possible that the theoretical delayed effect was simply not expressed during the first month of marine residence, but later in the life cycle.

To summarize, two different lines of investigation using different methods and addressing different stages of the salmon life cycle came to different conclusions regarding the existence of delayed/latent mortality associated with migratory experience.

11.3 Conclusions

The debate regarding delayed effects accompanying the migratory experience through the FCRPS continues, fueled by seemingly contradictory analyses exploring different lines of evidence. Definitive research and analyses have been elusive since enactment of the current

BiOp. In part this is due to inherent limitations with such studies. In a system such as the FCRPS where operations have changed substantially over the years to maximize in-river survival, analyses from a previous operational era may lose relevance. In other studies, the response window may not be long enough to observe a delayed effect expressed later in the life cycle.

For these and other reasons, it appears that the earlier observations and recommendations of the ISAB (2007) still ring clear today. The ISAB strongly advised against continuing to try to measure absolute latent mortality, since it is not measurable relative to a pre-dam reference condition. Instead, they suggested the focus should be on the total mortality of in-river migrants and transported fish, which is the critical issue for recovery of listed salmonids. That guidance still holds. The fact is, AAs and fishery resource agencies have reconfigured and operated the FCRPS to improve smolt survival during in-river migration. That goal has been, and remains, the beacon for guiding effective management actions that yield tangible results. A continuing question in terms of improving adult returns for Snake River ESUs is how to identify and implement the correct balance between the timing and proportion of each ESU to be either transported or remain in-river.

The advice of the ISAB is one of the reasons that the performance based construct of the 2008 Biological Opinion focuses on improving survival past the dams and through the reservoirs, rather than using SAR. By implementing strategies to improve the survival through all routes at the dams, and by speeding fish more quickly past the dams and through the reservoirs, the impacts of any latent effects of the FCRPS will be reduced. Those affects will also continue to be balanced in the context of transportation based returns and operational constraints at each dam.