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Supplemental Recovery Plan Module for Snake River Salmon and Steelhead Mainstem Columbia River Hydropower Projects

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Contents

1. Introduction

This document incorporates by reference and supplements NMFS' *Recovery Plan Module, Mainstem Columbia River Hydropower Projects* (Hydro Module, dated September 24, 2008) for Snake River anadromous fish species listed under the Federal Endangered Species Act (ESA): Snake River spring/summer and Chinook and Snake River fall Chinook salmon, Snake River steelhead, and Snake River sockeye salmon (NMFS 2008a).[1] NMFS prepared this module to assist in recovery planning for listed Columbia basin species. The 2008 Hydro Module overviews limiting factors and threats, summarizes current recovery strategies, and provides estimates of juvenile and adult survival rates associated with the Columbia and Snake River hydropower and water storage projects. This 2014 Supplemental Module (hereafter "Supplemental Module") updates the scientific and technical information relevant to the four Snake River species, including an updated discussion of "latent" and "differential delayed" mortality. The geographic area addressed in the Hydro Module and the Supplemental Module extends from the accessible mainstem habitat in the Snake River (i.e., to the tailrace of Hells Canyon Dam) downstream to the tailrace of Bonneville Dam (see Figure 1 below).[2]

This Supplemental Module, together with the 2008 Hydro Module, will comprise the "Hydro Module," an appendix to the ESA Snake River "roll-up" Recovery Plan. The Hydro Module provides consistent information on the general effects of Columbia River mainstem hydropower and water storage projects.

This Supplemental Module incorporates new scientific data that assesses the implementation of the Reasonable and Prudent Alternative (RPA) described in the 2008 Federal Columbia River Power System (FCRPS) Biological Opinion (NMFS 2008a) and the 2009 Adaptive Management Implementation Plan, which we incorporated into the 2010 and 2014 FCRPS Supplemental Biological Opinions (NMFS 2010, 2014). This new information includes:

- Post-2008 configuration changes at FCRPS mainstem dams;
- Recent (2008-2013) data on juvenile survival following the installation of surface bypass structures;
- Recent (2008-2013) information on juvenile fish transportation;
- Recent (2008-2010) data on latent mortality.

[1] This module is a supplement to the September 24, 2008 Hydro Module (*Recovery Plan Module, Mainstem Columbia River Hydropower Projects*; NMFS 2008b) in the sense that it updates the information in the 2008 module. The 2008 module and this supplement together serve as guidance for the recovery of the four Snake River salmon and steelhead species and the remaining nine listed salmonid species in the Columbia River.
[2] The *Columbia River Estuary ESA Recovery Plan Module for Salmon and Steelhead* (NMFS 2011) provides guidance for the recovery of all 13 listed species of salmon and steelhead in the Columbia basin based on limiting factors and threats in the lower Columbia River below Bonneville Dam.

We will continue to update this module in the future as emerging monitoring and research findings change our understanding of the ways that hydropower facilities in the Columbia basin affect the recovery of ESA-listed salmon and steelhead.

The new and updated information in this Supplemental Module is arranged in the following order:

- Hydropower System Overview
    - Limiting Factors & Threats
    - Recent Hydrosystem Improvements
- Adult and Juvenile Management Actions & Survival Rates
    - Adult Passage Management Actions & Conversion Rates
    - Kelt Management Actions & Survival Rates
    - Juvenile Passage Management Actions & Survival Rates
- Smolt to Adult Returns
- Key Uncertainties

2. Hydropower System Overview

Historically, the Snake River species traveled through a free-flowing river system as they migrated from their freshwater natal streams to the Pacific Ocean, and again as they returned as adults to spawn. Many dams were constructed by the Corps of Engineers, Bureau of Reclamation, and Idaho Power Company in the Snake River basin during the 20th century beginning with the construction of Swan Falls Dam and its hydroelectric plant in 1901. The reservoirs behind these dams inundated habitat, blocked access to upstream spawning and rearing areas, altered the natural hydrograph, and affected water quality (temperature, turbidity, etc.) and sediment transport processes. The construction of these water storage and hydro generating projects affected the ecological functions necessary for fish growth and survival. In the following paragraphs we describe the past and continuing effects of these dams and their operations on the four listed Snake River species and their designated critical habitat.

2.1 Limiting Factors & Threats

The reasons for a species' decline are generally described in terms of limiting factors and threats. Limiting factors are the biological, physical or chemical conditions and associated ecological processes and interactions that limit a species' viability. Threats are human activities or natural events, such as floodplain development or drought that cause or contribute to limiting factors.[3] The most dramatic effect of dams is blocked access to important historical production areas for salmon and steelhead. For example, prior to dam development the great majority of Snake River fall Chinook spawned primarily in the Thousand Springs and Marsing reaches of the Snake River, near Hagerman and Marsing, Idaho. Today, fall Chinook occupy the area downstream of the tailrace of Hells Canyon Dam, which represents approximately 18 percent of the historical range of this ESU (Groves and Chandler 2005, Williams et al. 2007). Those projects on the mainstem Snake and Columbia Rivers where fish passage has been provided affect salmonids in the following ways (Williams et al. 2005; Ferguson et al. 2005):

- Inundated mainstem spawning and shallow-water rearing areas (loss of spawning gravels and access to spawning and rearing habitat);
- Altered riparian vegetation;
- Altered water quality (reduced spring turbidity levels);
- Altered water quantity (seasonal changes in flows and consumptive losses resulting from use of stored water for agricultural, industrial, or municipal purposes);
- Influenced natural regulation of water temperature (including generally warmer minimum winter temperatures, cooler maximum summer temperatures, and delayed fall cooling);

[3] The term "threats" carries a negative connotation; however, they are often legitimate and necessary activities that at times may have unintended negative consequences on fish populations. These activities can be managed to minimize or eliminate the negative impacts.

- Altered water velocity (reduced spring flows, decreased channel gradient, and increased cross-sectional areas of the river channel);
- Altered habitat for predators in the reservoirs and in the tailrace of each mainstem dam
- Changed food webs (including the type and abundance of prey species [both native and non-native]); and
- Reduced or delayed safe fish passage.

Together these factors affect all Snake River species as they migrate through the Columbia and Snake River systems. The effects on fall Chinook salmon include changes in their spawning and rearing habitat because they use the mainstem river environment for these functions as well. In addition to access, important features of spawning and rearing habitat include spawning gravel, water quality, water quantity, water temperature, food, and riparian vegetation.

Detailed descriptions of the effects of the Columbia basin hydropower system on salmon and steelhead are provided in Williams et al. (2005) and Ferguson et al. (2005) and summarized in the 2008 Hydro Module and in Section 5.1 of NMFS (2008a).

In the following sections we provide new information on configuration and operational changes at the eight mainstem FCRPS projects; the five FCRPS reservoir storage projects; and Idaho Power Company’s three-project Hells Canyon Complex on the Snake River.

2.2 Federal Columbia River Power System

The FCRPS has been the subject of two supplemental biological opinions since 2008:

- 2010 FCRPS Supplemental Biological Opinion (NMFS 2010), which amended the RPA to incorporate the 2009 Adaptive Management Implementation Plan (BPA et al. 2009)
- 2014 FCRPS Supplemental Biological Opinion (NMFS 2014), which made some modifications to the RPA

The following descriptions of recent hydrosystem improvements (and monitoring data on juvenile and adult survival rates) include the measures described in the 2008 RPA and in these two supplemental biological opinions.

2.2.1 Recent Changes to FCRPS Project Configurations and Operations

Most of the mainstem project configuration and operational improvements required by the 2008 FCRPS RPA (as amended in the 2010 Supplemental BiOp) were in place by 2012. All eight run-of-river dams on the lower Snake and lower Columbia rivers now have a surface oriented passage route (spillway weirs at six dams, a corner collector at Bonneville Dam, and an ice and trash sluiceway at The Dalles Dam). These facilities were designed to improve passage conditions for juvenile and adult salmon and steelhead. The most significant changes made during 2008 to 2013 were:

- In 2008, the U.S. Army Corps of Engineers (Corps) installed a spillway weir at Lower Monumental Dam and two spillway weirs at John Day Dam to provide surface oriented passage routes for downstream migrants.
- In 2009, the Corps installed a spillway weir at Little Goose Dam and increased summer spill levels at McNary Dam to 50 percent of total river flow, following several years of testing alternative operations.[4]
- In 2010, the Corps rebuilt the John Day Dam north adult fish ladder's flow control section, installing redesigned weirs to improve passage conditions for adult salmon and steelhead.
- In 2010, the Corps completed construction of a spillway wall at The Dalles Dam. This structure, along with improved avian predator deterrents (wire arrays), has substantially increased the survival of juvenile salmon passing the dam by about 2 to 4 percent. Wire arrays were also installed in the tailrace of John Day Dam. The Corps discontinued the use of the temporary spillway weirs (TSW) at McNary Dam during the summer migration period because survival rates for subyearling fall Chinook were lower than through standard spillbays at this dam.

[4] Before 2005, no spill was provided after June 30. A determination of when to begin transporting juvenile fish reaching this project was made by the Technical Management Team based on their assessment of in-river migration conditions. Spring migrants have not been transported from McNary Dam since 1994.

- In 2012, the Corps relocated the juvenile bypass outfalls at Lower Monumental and McNary dams. In both cases, the old outfalls released fish into the slower-moving water close to the shoreline, exposing them to concentrations of predatory fish and birds. The new outfalls are further downstream and further from shore, where higher velocities prevent predatory fishes from maintaining their positions. This has increased the survival of juvenile salmon and steelhead passing each dam via the turbine bypass system.
- In 2013, the Corps installed adult PIT tag detectors in the ladders at The Dalles Dam, which will help fisheries managers identify adult losses or passage delays in the lower Columbia River.
- The Corps is planning to install adult PIT tag detectors in the ladders at Lower Monumental and Little Goose dams in 2014, which will help fisheries managers identify adult losses or passage delays in the lower Snake River.

2.2.2 Adult Management Actions & Conversion Rate (Minimum Survival) Estimates

The duration of the upstream migration of adults through the mainstem FCRPS projects is relatively unchanged compared to an undammed river. While adults are delayed as they search for fishway entrances and navigate through the fishways themselves, they migrate faster through the relatively low velocity reservoir environments. Water management operations at large upstream flood control storage projects in the United States and Canada, mainstem run-of-river reservoirs, and changing climate patterns have altered the thermal regime of the Snake and Columbia Rivers compared to the predevelopment period. In general, the mainstem Snake and Columbia Rivers now have higher minimum winter temperatures and lower maximum summer temperatures, and are cooler later in the spring and warmer later in the fall. The combined effects of these alterations could benefit adults that migrate during the spring and much of the summer (spring and summer Chinook salmon and early migrating sockeye salmon and steelhead), but could increase the exposure of fall Chinook salmon and later migrating sockeye and steelhead (which migrate in the late summer and fall) to elevated temperatures. The Corps operates Dworshak Dam, on the North Fork Clearwater River, during July, August, and September to maintain cooler summer temperatures in the lower Snake River to benefit summer migrating adult salmon and steelhead and juvenile fall Chinook salmon.

Adult salmon and steelhead can pass each of the eight mainstem dams in the lower Snake and Columbia rivers volitionally at fish ladders. In general, we consider these adult passage facilities to be highly effective. For example, the current estimate of average adult Snake River spring/summer Chinook salmon survival (conversion rate estimates using known-origin adult fish after accounting for “natural straying” and mainstem harvest) between Bonneville and Lower Granite dams (2008-2012) is approximately 82.4 percent (Table 1).[5,6] Prior to 2010 there

[5] These adult survival estimates capture all sources of mortality within the Bonneville to Lower Granite dam reach, including those resulting from the existence and operation of the FCRPS, unquantified levels of mortality from other potential sources (e.g., unreported or delayed mortality caused by fisheries, marine mammal attacks, etc.), and unquantified levels of “natural’ mortality (i.e., levels that would have occurred without the influence of human activities).

were not enough detections of PIT tagged adult SR sockeye in the system for assessing conversion rates. We therefore used PIT tag detections from upper Columbia River sockeye stocks as surrogates to assess survival rates in the lower Columbia River reach and extrapolated these to assess likely survival rates for the entire Bonneville to Lower Granite dam migration corridor. As the captive broodstock program is beginning to increase the number of adults returning to Bonneville Dam, we are now able to make direct estimates of survival to Lower Granite Dam. The average for the 2010 to 2012 migration years was 70.4 percent (Table 1).

Table 1. Adult salmon and steelhead survival estimates (adjusted for reported harvest and natural rates of straying) based on PIT tag conversion rate analysis for SR salmon ESUs and the steelhead DPS from Bonneville (BON) to McNary (MCN) dams, McNary to Lower Granite (LGR) dams, and Bonneville to Lower Granite dams. Sources: http://www.PTAGIS.org; WDFW and ODFW 2013, 2014; Appendix A in NMFS 2008c.

Species	Years	BON to MCN	MCN to LGR	BON to LGR
SR Fall Chinook	2008-2012 Avg	93.5%	96.9%	90.5%
SR Spr/Sum Chinook	2008-2012 Avg	87.6%	94.1%	82.4%
SR Sockeye	2010-2012 Avg[1]	75.7%	93.0%	70.4%
SR Steelhead	2008-2012 Avg	91.7%	88.7%	81.1%

[1] Only known origin SR sockeye salmon were used to assess adult reach survival from 2010 to 2012.

2.2.2.1 Adult passage blockages at Lower Granite Dam in 2013

Low summer flows, combined with high air temperatures and a period of little or no wind, created thermally stratified conditions in Lower Granite reservoir during late July 2013 such that the lens of warm surface water entered the adult ladder which disrupted fish passage for more than a week. The Corps pumped cooler water from deeper in the forebay into the ladder to enhance fishway entrance conditions. Modified operations, combined with cooler weather, allowed fish to resume passing the dam. Unadjusted PIT tag based conversion rates from Ice Harbor to Lower Granite Dam indicated that about 30 percent of the migrating sockeye salmon failed to pass Lower Granite Dam and most likely died without spawning. Fewer summer-run Chinook were affected (about 15 percent), but this is still a substantial effect.

A similar event occurred in September, blocking passage for fall Chinook salmon and for steelhead for about a week. The same combination of pumping cooler water from deeper in the forebay and modifying operations combined with more favorable weather conditions allowed adults to resume their migration, However, this event resulted in an estimated 7 percent of fall Chinook salmon and 12 percent of steelhead failed to pass Lower Granite Dam.

[6] Although NMFS believes this method provides the best scientific data available, it is possible that the harvest estimates – which were not generated specifically for PIT tagged fish – may be inaccurate for this purpose or biased in some other way. Further work is being done to assess this potential issue.

The Corps of Engineers is evaluating options to deliver cooler water into the ladder entrance and adult trap with the intent of designing and constructing the needed structures in time for the 2015 migration. In the event of this situation recurs in 2014, the Corps plans to employ the measures that were developed in 2013 and use pumps to draw additional cool water into the ladder entrances and adult trap to minimize the temperature effects and provide passage.

2.2.3 Snake River Steelhead Kelt Survival Rates

Unlike other Pacific salmonids, a large fraction of the adult steelhead do not die after spawning. Instead, these fish, termed “kelts,” migrate back to the ocean and then return in subsequent years as repeat spawners. Estimates of FCRPS kelt passage survival in the FCRPS have ranged from 4.1 to 6.0 percent in the low flow year 2001 to 15.6 percent in 2002 and 34 percent in 2003 (Boggs and Peery 2004; Wertheimer and Evans 2005). Although some portion of the implied mortality would occur in a free-flowing river, fisheries managers expect that survival is low because turbine bypass systems were not designed to safely pass adult fish. In addition to causing injury and mortality, the mainstem hydro projects delay kelt downstream migrations (Wertheimer and Evans 2005). Boggs and Peery (2004) and Wertheimer and Evans (2005) estimated that 17 to 25 percent of the steelhead that pass Lower Granite Dam return downstream as kelts. Thus, while there may be a relatively large number of kelts in Snake River, survival through the FCRPS may limit their contribution to the productivity of their respective populations.

BPA and the Corps have developed a Kelt Management Plan (BPA and USACE 2012) to improve the productivity of B-run Snake River steelhead populations by about 6 percent as required by the 2008 FCRPS BiOp (RPA 33). BPA and the Corps is pursuing three strategies for attaining the remaining survival improvements necessary to achieve this goal: implement measures to improve inriver survival of migrating kelts, collect and transport kelts to areas below Bonneville Dam to improve adult return rates, and long-term reconditioning to increase the number of viable females on the spawning grounds.

The Kelt Management Plan includes using surface passage routes at lower Columbia dams outside of the juvenile migration season to increase the survival of kelts moving back downstream. These include expanded operations at the ice and trash sluiceway at The Dalles Dam. Researchers are evaluating the behavior of adult steelhead at McNary Dam during winter 2012 and 2013 for modifications that could protect downstream migrants.

The installation of spill weirs and other surface passage routes at each of the mainstem FCRPS dams to improve juvenile passage has also benefited kelts. In 2012, Coleto et. al. (2013) estimated that about 40% of the kelts released at or above Lower Granite Dam survived to river kilometer 156 (downstream of Bonneville Dam); compared to estimated survival rates of about 4 to 16% in 2001 and 2002. The median travel time from Lower Granite to Bonneville Dam in 2012 was nine days compared with 27 days in 2001 (BPA and USACE 2013) and 19 days in 2002 (Wertheimer and Evans 2005). Although average Snake River flows were much higher in 2012 than in 2001 or 2002, which would be expected to reduce travel time, the scale of the improvement strongly suggests that improved surface passage routes are also a factor. Shorter travel times are likely to indirectly affect survival through the lower estuary and nearshore ocean environment by reducing stress and the amount of energy expended during the downstream migration.

The returns of transported kelts averaged 1.17%, compared to 0.68% for inriver migrating kelts over a 5-year period (BPA and USACE 2013b). However, until more good condition kelts are available, transportation will occur only after the capacity of the rehabilitation research facility at Dworshak Hatchery is exceeded.

Long-term reconditioning at the Dworshak Hatchery rehabilitation research facility continues to have potential for increasing kelt survival in the short term. To date, success rates have been somewhat inconsistent, but recent improvements to the facility should substantially increase the success rate of this program. (BPA and USACE 2013b) About 38% (10-year average) of the kelts in a similarYakima Basin program are being rehabilitated and released to spawn again (Hatch et al. 2013).

2.2.4 Juvenile Dam Passage Survival

Snake River juvenile migrants pass eight federal mainstem dams on their way to the ocean. They pass these mainstem dams via three potential routes: through turbines, by way of the spillway, or through the juvenile bypass system. Empirical studies indicate survival typically is highest through spillways, followed by bypass systems and then turbines (Muir et al. 2001). These studies have shown that juvenile salmon experience abut an 11 percent mortality rate per mainstem dam when they pass by way of turbines (Whitney et al. 1997). Mortality can be caused by striking the turbine runners, exposure to rapid and severe pressure changes that occur in the turbine environment, predation of fish emerging from the turbine tube into the project tailrace in a disoriented state, or other factors. The Corps has constructed juvenile bypass systems at the mainstem FCRPS dams to reduce the number of fish that pass through turbines. Large underwater screens partially cover the turbine intakes, creating a hydraulic field that guides the juvenile migrants into the bypass system. The juvenile fish then pass horizontally through the dam's interior through a series of galleries then through an outfall pipe to the tailrace. At some dams (Lower Granite, Little Goose, Lower Monumental, and McNary dams) the bypassed fish can be collected for barge or truck transport to below Bonneville Dam, but at the other four facilities they can only be discharged downstream into the river.

Fish can also pass the mainstem dams via spillways. All of the mainstem dams are equipped with spillways, which were designed to allow the controlled release of water from behind the dam when flow in the river would exceed the power house capacity or when there is no market for the energy that would otherwise be produced. Flow over the spillway is controlled by large gates, which must be raised to allow water to pass at a depth of 40 feet or more. Water spilled to provide a safer passage route for juvenile fish even when flows are below powerhouse capacity (rather than running the water through turbines to produce electricity) is called "voluntary" spill. Whether or not it is voluntary, as spill levels increase, the proportion of smolts passing through turbines (and bypass systems) generally decreases. The Corps has voluntarily spilled water as a means to increase the survival of smolts passing dams on the Snake and Columbia rivers since 1994, although the proportion of flow spilled for fish has increased over time.

Although spillways generally provide the highest survival rates for migrating juveniles, spillways were not designed for this purpose. Most yearling Chinook salmon migrate in the upper 10 to 20 feet of the water column (and steelhead are even shallower) and must dive 40 to 60 feet to take advantage of the spillway passage route. In addition, water plunging over the spillway increases the amount of total dissolved gas (TDG) in the water below the dams to levels that can injure or even kill fish. At present, spill levels that result in TDG levels in excess of the national water quality standard of 110% of saturation are allowed during the juvenile fish migration period (April through August) through “waivers” issued by the Oregon Department of Environmental Quality and Washington Department of Ecology. Because the effects of total dissolved gas on aquatic organisms are moderated by hydrostatic pressure—each meter of depth compensates for 10% of gas supersaturation as measured at the water surface—NOAA Fisheries has determined that as long as the water is deep enough for fish to migrate 2 meters below the surface, they will not be harmed. Thus, the waivers allow managers the ability to increase spill levels (beyond those that could occur without a waiver) to provide effective passage for juvenile migrants at the mainstem Columbia and Snake River dams.

During the early 2000s, hydrosystem biologists and engineers designed surface spillway weirs to capitalize on the natural tendency of juvenile salmonids to migrate at shallow depths (Beeman et al. 2006). Each spillway weir design is based on the concept of providing an overflow weir with a depth similar to the natural migration depths of juvenile Chinook and steelhead (Beeman et al. 2010). Empirical studies have shown that surface spillway weirs have guided enough fish away from the turbine and bypass system passage routes that total dam passage survival rates (for all routes combined) have increased (Beeman et al. 2010).

Fish passage operations including voluntary spill levels at lower Snake and Columbia River dams have been relatively stable since 2010 and the Corps of Engineers have made substantial progress during the past five years in implementing the structural improvements anticipated in the 2008 BiOp. Survival studies show that with few exceptions, these measures are performing as expected and are very close to achieving, or are already achieving, the juvenile dam passage survival objectives of 96 percent for yearling Chinook salmon and steelhead and 93 percent for subyearling Chinook salmon (in NMFS 2014). We expect the Action Agencies (U.S. Army Corps of Engineers, Bonneville Power Administration, and U.S. Bureau of Reclamation) to complete the remaining configuration and operational improvements and the associated juvenile performance standard testing by 2018.

2.2.4.1 Juvenile Inriver Reach Survival Estimates

Inriver reach survival estimates allow us to assess the combined effects of background environmental conditions, actions at the run-of-river projects within the lower Snake and Columbia River migration corridor, and water management operations at upstream storage projects on juvenile migrants. Because they estimate survival over distances of hundreds of miles and time periods of days to weeks, they are influenced by factors such as the condition and health of these fish when they first reach the mainstem and interactions between run timing and environmental conditions. To derive these estimates, thousands of juvenile salmon and steelhead are PIT tagged at or above Lower Granite Dam each year. Detections at mainstem dams (in juvenile bypass systems or the corner collector at Bonneville Dam) and in the estuary allow NMFS to estimate survival rates through the Lower Granite to Bonneville reach. We reported estimates of expected average annual juvenile survival rates in the 2008 Hydro Module derived from the COMPASS model, calibrated with the empirical data from wild (natural origin) migrants available at the time. We presented two scenarios, “Current” (survival through the hydrosystem under the operational and configuration changes at the mainstem hydroelectric projects through 2006) and “Prospective” (expected survival by 2014-2018, following implementation of key actions in the 2008 RPA). The 2008 to 2010 reach survival estimates for yearling Chinook salmon obtained from empirical PIT tag detections (Figure 1) were within the ranges of the “Current” survival rates considered in the 2008 BiOp (range = 33.9 to 60.8 percent, mean of 52.8 percent; see Appendix F, Inriver Juvenile Survival in NMFS 2008c). More recent (2011 to 2013) empirical estimates are consistent with, or slightly higher than, the “Prospective” survival rates (range = 46.7 to 67.8 percent, mean of 60.8 percent) expected in the 2008 BiOp.

Similar empirical (PIT tag) estimates for wild yearling SR steelhead ranged from about 42 to 57 percent during 2008-2013, about double the average survival rates estimated for the Base Period (26.5 percent) and higher than both the average Current survival rates (range = 3.3 to 56.9 percent, mean = 33.1 percent) and the Prospective survival rates (range = 4.0 to 64.4 percent, mean = 38.5 percent) in the 2008 BiOp (Figure 2). We do not report an empirical estimate for juvenile steelhead in 2012 because so few of the PIT tagged fish were detected at both Bonneville Dam and the estuary that the standard error was greater than 15%.

Increased smolt production from the SR sockeye captive broodstock program and the ability to tag and release larger groups for reach survival studies has substantially improved the accuracy of the empirical estimates for the Lower Granite to Bonneville Dam reach since 2008: 40.4 to 57.3 percent. These are higher than the average Current estimate derived from COMPASS modeling in the 2008 BiOp, and four of the five empirical estimates are higher than the average Prospective estimate in the 2008 BiOp (Figure 3). We do not present a survival estimate for SR sockeye salmon in 2011 because too few PIT-tagged fish were detected at both Bonneville dam and the downstream pair-trawl detector for adequate precision.

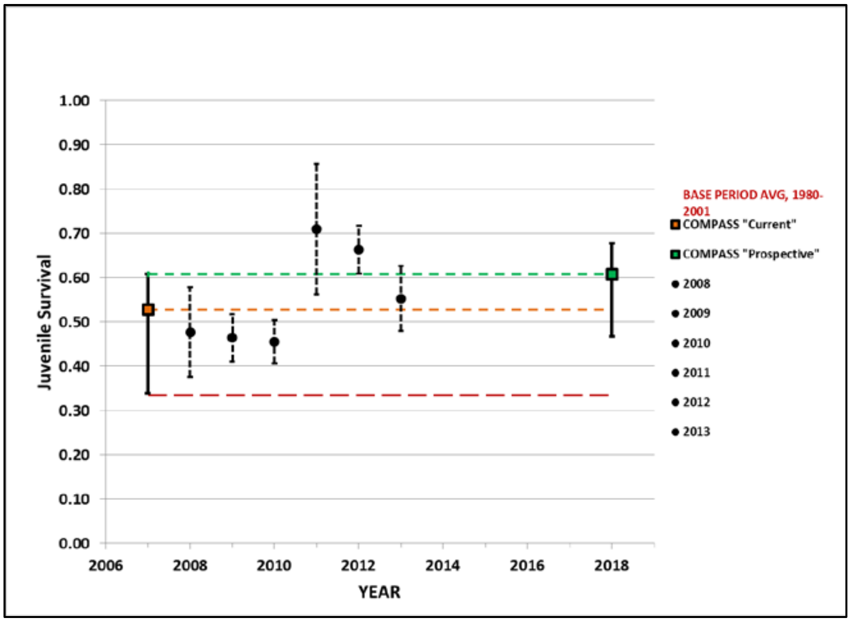

Figure 1. Lower Granite to Bonneville dam survival estimates (standard error) for wild SR spring/summer Chinook salmon (2008–2012) compared to Base Period (bottom horizontal dashed line), Current (middle horizontal dashed line), and Prospective (top horizontal dashed line) average estimates (ranges are indicated by vertical bars) in the 2008 BiOp.

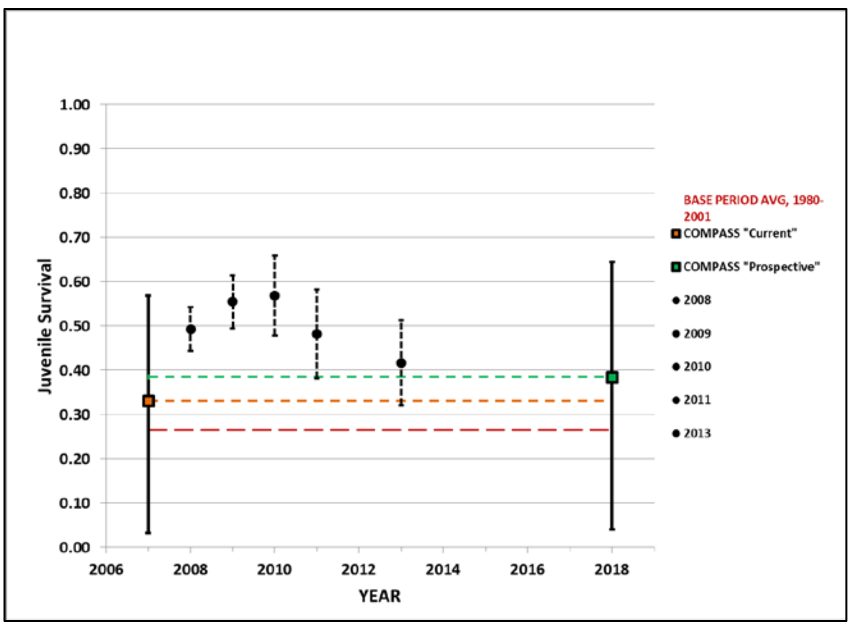

Figure 2. Lower Granite to Bonneville dam survival estimates (standard error) for wild SR steelhead (2008–2012) compared to Base Period (bottom horizontal dashed line), Current (middle horizontal dashed line), and Prospective (top horizontal dashed line) average estimates (ranges are indicated by vertical bars) in the 2008 BiOp.

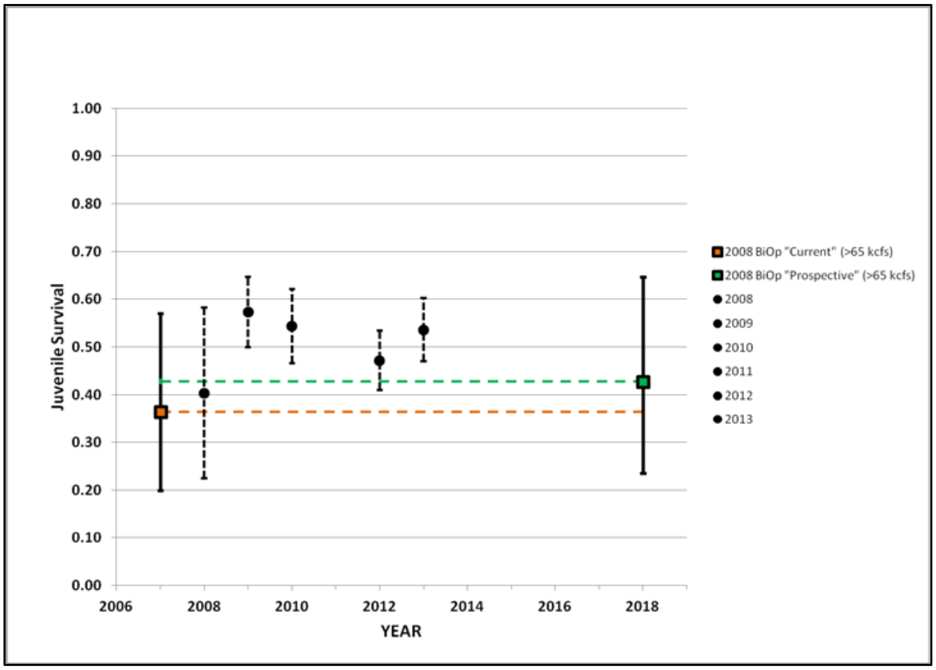

Figure 3. Lower Granite to Bonneville dam survival estimates (standard error) for wild SR sockeye salmon (2008–2012) compared to Current (bottom horizontal dashed line) and Prospective (top horizontal dashed line) average estimates (ranges are indicated by vertical bars) in the 2008 BiOp.

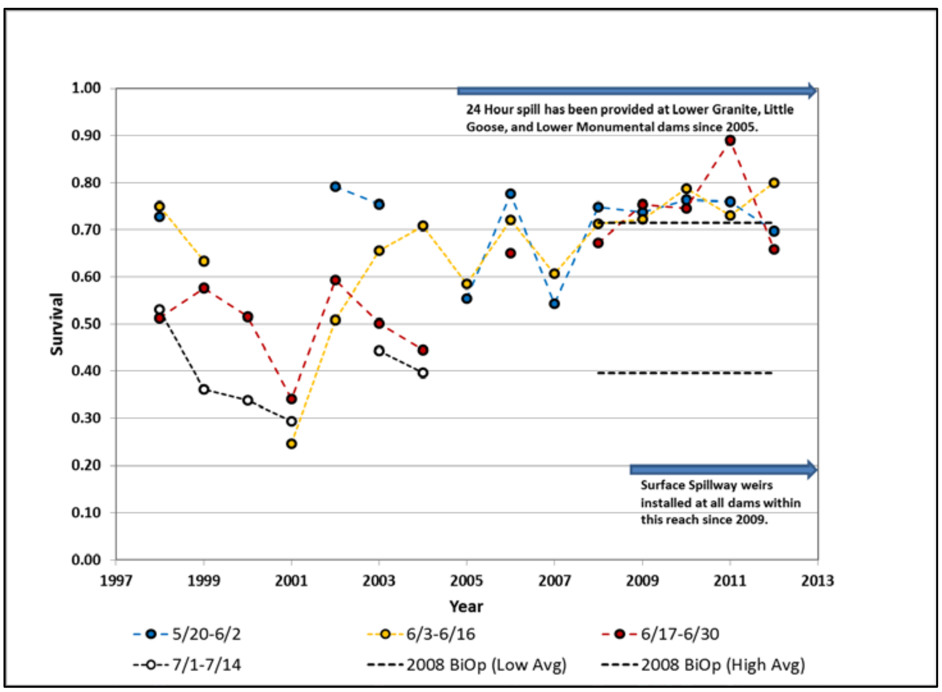

Figure 4. Estimated survival rates from two-week cohorts of juvenile subyearling SR fall Chinook salmon between Lower Granite and McNary Dams from 1998 to 2012. Black horizontal dashed lines denote Prospective minimum and maximum average survival rates estimated in the 2008 BiOp; blue arrows denote years in which Court Ordered summer spill occurred at the three Snake River transport projects (top) and years in which all dams in this reach were configured with surface passage routes (bottom).

The Action Agencies began providing summer spill at the three Snake River collector projects in 2005 in response to an order from a District Court.[7] Survival rates during the years affected by summer spill, prior to and including the installation of surface passage routes such as weirs at each of the five projects in the Lower Granite to McNary reach, are shown in Figure 4. Prior to 2005, survival estimates for subyearling SR fall Chinook between Lower Granite and McNary dams ranged from about 25 to nearly 80 percent, trending lower as the season progressed (i.e., groups passing later in the season typically had lower survival rates than those passing earlier). Between 2005 and 2008 (the last year before all of the new surface passage routes were installed), fish migrated earlier (i.e., there are now too few smolts passing Lower Granite Dam in the July 1 to July 14 period to make up a cohort for estimating survival) and survival rates were substantially higher, ranging from about 56 to 78 percent for individual cohorts.[8] From 2009-2012, years when both summer spill and surface passage routes were in effect, survival rates ranged from 66 to 89 percent for individual cohorts and all but two cohorts of fish tracked during this period exceeded the highest average survival rate expected (as a result of fully implementing the RPA) in the 2008 BiOp (71 percent).

In summary, reach survival estimates for subyearling SR fall Chinook salmon and yearling spring/summer Chinook salmon, sockeye salmon, steelhead, all appear to be meeting or, in the case of fall Chinook salmon, sockeye, and steelhead, substantially exceeding both Current and Prospective 2008 BiOp expectations for migrating smolts. As noted in the 2010 Supplemental BiOp (see Section 2.2.2.2), on a per-kilometer basis, these survival rates are approaching those estimated for several free-flowing river systems. In general, we expect these increased average survival rates for inriver migrating juveniles to result in increased adult returns.

Direct survival

Many juvenile salmon and steelhead do not survival their journey through the Columbia River to the ocean. Direct estimates of survival can be measured at a dam, through a reservoir, or past a series of dams and reservoirs using either passive (e.g., passive integrated transponder or “PIT”) or active (e.g., radio or acoustic) tags. In most studies, direct survival is measured from an upstream point to a location immediately below a dam or below a series of dams. The mortality rate can be calculated as 1 minus the observed survival rate (e.g., 1.00 – 0.98 survival rate = 0.02 or 2 percent mortality).

Latent Mortality

More complex is the concept of latent, or indirect, mortality. In terms of the Columbia River hydrosystem, it is defined as the mortality that occurs after a juvenile fish passes Bonneville Dam that would not occur in a free-flowing system of equal length (Williams et al. 2005). The concept assumes that juveniles passing through the FCRPS experience a certain degree of harm, which reduces the likelihood of that some proportion will survive to return as spawning adults. Potential causes of latent mortality include:

[7] NOAA Fisheries has since incorporated summer spill at these projects into the RPA.

[8] Researchers group the data for all juvenile migrants entering the hydrosystem within each 2-week block of time into a “cohort” in order to estimate any changes in survival rates across the season (i.e., within a migration year).

- Delayed arrival timing in the estuary and ocean (the series of dams and reservoirs increases juvenile travel time through the migration corridor);
- Sublethal injuries or stress incurred during migration through juvenile bypass systems, turbines, or spillways;
- Disease transmission or stress resulting from the artificial concentration of fish in bypass systems;
- Depletion of energy reserves from prolonged migrations;
- Altered conditions in the estuary and plume as a result of water management operations; and
- Disrupted homing ability in fish transported as juveniles.

Most researchers agree that some level of latent mortality exists. However, there are many opinions regarding what mechanisms are important and by extension, what managers can do to minimize or mitigate for these effects in the future. For example, Williams et al. (2005) posited that a major component of latent mortality was the disrupted migration timing of transported fish and inriver migrants and that the effect of interactions between latent mortality and ocean conditions was likely to vary seasonally. Schaller and Petrosky (2007) found that Snake River Chinook salmon adult return rates were substantially lower after construction of the four lower Snake River dams than during the years preceding their existence. More recently, the DeHart (2010) conducted a literature review and concluded that passage through turbines and bypass systems at the mainstem dams results in significant latent and differential delayed mortality of juvenile salmonids, which in turn reduces adult returns. Similarly, Buchanan et al. (2011) reviewed the effects of juvenile bypass systems and found that for some species, adult return rates were consistently lower for individuals that experienced bypass systems than for smolts that used turbines or spillways. They further noted that some pairs of dams had synergistic effects – where the experience of using two or more bypasses had a greater statistical effect on adult returns than the sum of the effect of each bypass individually.

The Independent Scientific Advisory Board (ISAB) reviewed a number of hypotheses relating causative factors for latent mortality. The panel noted that researchers have made estimates of latent mortality that range from 0.01 to 64 percent (ISAB 2007). The management implications of these vastly different estimates are substantial. If the 64 percent figure is accurate, then the adverse effects of FCRPS passage would be greater than currently known requiring consideration of commensurate reconfiguration actions to support recovery objectives. Conversely, if the 0.01 percent estimate is correct, mainstem passage would not play a significant role in post-Bonneville survival rates. The ISAB (2007) strongly advised against continuing efforts to measure absolute latent mortality because it requires a reference condition that does not exist: the Columbia and Snake River system with no dams. Instead, “the focus should be on the total mortality [direct and indirect] of in-river migrants and transported fish, which is the critical issue for recovery of listed salmonids,” and “research and monitoring [should] be used to further quantify biological factors[9] that contribute to variability in estimated post-Bonneville mortality" (ISAB 2007).

More recently, the ISAB (2011, 2012) was asked to review several Fish Passage Center documents relating to latent mortality of in-river migrants due to route of dam passage (spill passed fish versus bypassed fish). They concluded that "[b]ased, on our review, the studies and analyses cited in these technical memos do not provide an adequate base of reliable information to support a 'weight of evidence' conclusion on the strength of a relationship between multiple bypass passage and latent mortality of juvenile Chinook and steelhead. That is, the relationships observed between latent mortality and bypass passage are confounded with other factors that obscure unambiguous interpretation."

In summary, the experience of hydrosystem passage in the lower Snake and Columbia Rivers is likely to result in some latent mortality, but the specific mechanisms (e.g., altered migration timing, passage through bypass systems, etc.) and how these factors might interact with factors such as ocean productivity are poorly understood. Hopefully, continued monitoring of Smolt to Adult returns relating to hydrosystem improvements (juvenile bypass system outfall relocations, reduced travel times due to increased access to surface passage routes) and other ongoing research will shed additional light on this issue.

2.2.4.2 Juvenile Transportation

The Action Agencies, in cooperation with NMFS and other regional fish management agencies, developed the juvenile fish transportation system to mitigate for juvenile mortality incurred when passing through the mainstem Federal dams. Fish are collected at the uppermost mainstem dams and transported in barges (or trucks when numbers are very low) to a release point below Bonneville Dam. This is intended to eliminate the mortality juveniles would otherwise experience by passing multiple dams. Three of the four lower Snake River dams plus McNary Dam on the Columbia River are equipped with juvenile fish collection and transportation facilities that obtain fish from the bypass system discussed above.

The value of transportation as a strategy to improve juvenile survival is continuously evaluated. Studies have consistently shown that transportation results in a higher adult return rate for steelhead compared to in-river migrants (Marsh et al. 2005, 2006, 2007; Williams et al. 2005; Schaller et al. 2007). However, this is not true for wild (i.e., natural-origin) spring Chinook when measured as an annual average rate of return (Schaller et al. 2007). Williams et al. (2005) and Marmorek et al. (2004) have demonstrated a seasonal benefit from transport, generally beginning in early May. In addition, adult steelhead and to a lesser extent spring Chinook that were

[9] Identifiable factors that contribute to variability in post-Bonneville mortality may include: predation by birds; predation by fishes; increased vulnerability to predators because of size, stress, or disease; timing of ocean entry; ocean conditions; ocean interceptions and harvest of returning adults; and in-river adult pre-spawn mortalities. Source: ISAB (2007)

transported as juveniles tend to stray into non-natal spawning areas at higher rates than adults that out-migrated inriver as juveniles (cite NMFS 2008c and ISAB 2008).

Seasonal trends in the effectiveness of juvenile transport were reflected in the COMPASS model, which was used to evaluate proposed spill and transport operations and their likely effect on steelhead and spring/summer Chinook adult returns for the 2008 BiOp. As a result of this modeling effort, the 2008 BiOp called for two transportation operations, depending on the runoff volume forecast. In years when the Snake River spring flow was forecast to average less than 65 kcfs, no spill was to be provided at the three Snake River collector dams and all fish collected were to be transported beginning April 3. In years when the Snake River spring flow was forecast to exceed 65 kcfs, spill was to be provided and juvenile fish would be collected for transportation beginning April 21. The 2008 BiOp specified a spill cessation period from May 7 to May 20, with spill resuming May 21, to maximize transportation and to spread the risk between transport and inriver migration routes. However, the ISAB (2008) did not endorse NMFS' proposal to maximize transport even for the discreet periods proposed, citing a list of uncertainties with respect to this action including:

- The effects of recent configuration improvements (e.g., surface spillway weirs) at the dams
- Effects of transport on lamprey and sockeye
- Relative amounts of adult straying, and potential effects on genetic and life history diversity, for transported versus inriver fish.

Based on the COMPASS model, the 2008 BiOp had anticipated that the percentage of spring Chinook transported would range from about 40 to 96 percent (averaging 64 percent over the range of flow conditions analyzed). We expected a somewhat higher percentage of steelhead to be transported – from about 50 to 98 percent (averaging 74 percent). However, the actual percentage of spring yearlings transported has generally been less than 50 percent since 2008 (roughly 23 to 40 percent for natural-origin spring/summer Chinook salmon and 28 to 46 percent for natural-origin steelhead) because, based on the ISAB's advice, spill has been throughout the migration season and across all flow conditions. In addition, with the advice of regional fisheries managers, the Action Agencies have delayed the start of collection for transport until May 1 each year at Lower Granite and until May 8 at Lower Monumental Dam. Reduced transport rates should substantially reduce straying by SR spring/summer Chinook and steelhead into other basins.

Juvenile SR fall Chinook pass Lower Granite Dam in late May and June. Transportation operations begin in late April or early May at the three Snake River collector dams and continue through October. In the 2008 BiOp, we estimated that 52 percent of subyearling juvenile SR fall Chinook would be transported; the actual average during 2008-2011 was 52.8 percent (DeHart 2012).

Differential Delayed Mortality

"D" or differential delayed mortality is a specific type of latent mortality that is used to measure the relative effectiveness of transporting juvenile fish past the FCRPS dams compared to inriver migration. The direct survival rate of transported juveniles to below Bonneville Dam is estimated to be about 98%. However, average adult return rates are usually lower for transported fish than for fish that migrated through the hydrosystem in-river. "D" is defined as the ratio of post-Bonneville Dam survival for transported fish to that of in-river migrants. [10] When D = 1, the post-BON survival rates for transported and inriver migrating juveniles is equivalent, and when D is not equal to 1, there is a difference. Whether D is greater than or less than 1 indicates which type of hydrosystem passage results in higher relative post-BON survival rates. When D is greater than 1, transported fish survive at a higher rate post-BON, and when D is less than 1 inriver migrants survive at a higher rate. Transportation is beneficial when D exceeds the inriver survival rate. Differential delayed mortality is a ratio and not an absolute measure of survival (Anderson et al. 2012). Although there is regional consensus on the need to track "D" for Snake River salmon and steelhead, the mechanisms that produce the relative differences in post-Bonneville mortality are uncertain at this time. Candidates include:

- Arrival timing in the hydrosystem (i.e., from the spawning and rearing areas)
- Travel time through the hydrosystem (to below Bonneville)
- Fish size, physiological condition, and health
- Dam operations
- Barging conditions
- Environmental conditions and predators in the lower Columbia River
- Environmental conditions and predators (especially terns and cormorants) below Bonneville Dam
- Straying
- Survival estimation techniques

Calculated values of "D" vary by species and between years. The authors of the Comparative Survival Study (CSS, which is a collaborative effort by the U.S. Fish and Wildlife Service; the states of Washington, Oregon, and Idaho; and the Columbia River Intertribal Fish Commission) report average "D" values for spring Chinook and steelhead each year (Table 2; Tuomikoski et al. 2013).

Annual estimates of "D" remain one of the metrics that regional managers consider in evaluating trends in the effectiveness of transportation and its appropriate use as a mitigation strategy.

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[10] $D = (T: I) * S_{inriver}$ where D is differential delayed mortality, T is the SAR of transported juveniles and I is the SAR of inriver migrating juveniles (from Lower Granite Dam to the ocean and back to Lower Granite Dam for Snake River species), and $S_{inriver}$ is the estimated survival of inriver migrants from Lower Granite Dam to the Bonneville tailrace. Thus, unlike the TIR ratios discussed under "Effectiveness of Transport Operations," D takes into account the survival of inriver migrants to the tailrace of Bonneville Dam.

Table 2. Date at which transport started at Lower Granite Dam and D values reported by the CSS for natural origin SR spring Chinook and steelhead (Source: Tuomikoski et al. 2013).

Year	Transport Start Date at LGR	Spring Chinook D	Steelhead D
2006	April 20	0.47	0.52
2007	May 1	0.80	1.20
2008	May 1	0.82	0.60
2009	May 1	0.65	0.94
2010[1]	April 24	0.72[2]	0.93[1]
2011	May 1	0.41	

[1] Incomplete steelhead adult returns until 3-salt returns (if any) occur after June 27, 2013 at LGR.

[2] Incomplete adult return (only returning 2-salts as of July 18, 2013.

Note: "n-salt" refers to the number of years an adult has spent in the ocean prior to returning to freshwater to spawn. Most Chinook salmon return to freshwater after spending 1 to 3 years in the ocean (e.g., 1- to 3-salt returns).

Effectiveness of Transport Operations

We consider the smolt-to-adult return rates (SAR) of the juveniles that were transported (SAR_T), and the fish that migrated inriver (SAR_I) to assess the effectiveness of transportation. We use the ratio of SAR_T to SAR_I, referred to as the transport-to-inriver (TIR) ratio, to compare the two rates. A TIR greater than 1 indicates that transported fish survived to return as adults at a higher rate than inriver migrants. A TIR less than 1 indicates that inriver fish survived to return as adults at a higher rate than transported fish. The data used to calculate the inriver SARs are based on juveniles that were not detected at any of the Snake River collector projects (Tuomikoski et al. 2013). The TIRs for adults returning to Lower Granite Dam are available for the years 2006-2011for spring Chinook and 2006-2010 for steelhead (Table 3; Tuomikoski et al. 2013). The TIRs greater than 1 in Table 3.3-5 indicate that transport has returned more natural origin adult steelhead and spring Chinook for all years with the exception of 2006. The TIR for both steelhead and spring Chinook was less than 1 in 2006, which had an early transport start date at Lower Granite Dam (April 20) compared to April 24 to May 1 in subsequent years. The earlier transport start date in 2006 may explain the low TIR for that year.

Table 3. Initial date of transport for natural origin spring Chinook and steelhead at Lower Granite Dam. TIRs (Transport to Inriver ratios) from Tuomikoski et al. 2013.

Year	Transport Start Date at Lower Granite Dam	Spring Chinook TIR	Steelhead TIR
2006	April 20	0.78	0.85
2007	May 1	1.27	2.89
2008	May 1	1.19	1.16

2009	May 1	1.11	1.31
2010	April 24	1.21	1.47[1]
2011	May 1	0.64[2]	

[1]Incomplete adult returns for steelhead until 3-salt returns (if any) occur after June 27, 2013 at Lower Granite Dam.

[2]Incomplete adult return (only returning 2-salts as of July 18, 2013)

Note: "n-salt" refers to the number of years an adult has spent in the ocean prior to returning to freshwater to spawn. Most Chinook salmon return to freshwater after spending 1 to 3 years in the ocean (e.g., 1- to 3-salt returns).

As mentioned above, the NWFSC conducts a similar analysis of juvenile transportation effects, but focuses on within-season patterns in SARs relative to juvenile migration timing and changing environmental conditions. The metric used to report these results is the T:B ratio because the comparison is between transported (T) and bypassed (B) fish (i.e., bypassed, but returned to the river below the dam rather than transported). The average annual T:B ratios for juveniles that were PIT tagged upstream from Lower Granite Dam during 2006–2011 have ranged from 1.34 to 1.77 across the season for natural origin spring Chinook and 1.44 to 2.89 for steelhead (Smith et al. 2013). The seasonal benefit from transport is most prominent for natural origin spring Chinook; before May 1, there is almost no benefit from transport, but after May 1 transport is generally beneficial with the benefit increasing during the month of May (Williams et al. 2005; Smith et al. 2013). Steelhead typically show a benefit from transport during April and continuing through May.

To summarize, several different metrics have been developed to evaluate how juvenile fish transport affects adult returns: Transport to Inriver (TIR), Transport to Bypass (T:B), and Differential delayed mortality ("D"). "TIR" compares the relative success in terms of producing adult returns of juvenile fish that were transported versus those that migrated downstream "inriver" (i.e., fish that were never detected in a juvenile bypass system at any of the four dams on the Snake River or at McNary Dam on the Columbia River). Calculating this metric allows fish managers to assess of how the transport of juvenile fish affects adult returns in a given year. "T:B" compares the relative success in terms of adult returns of juveniles that were transported versus those that migrated inriver and were detected in one or more of the juvenile bypass systems on the Snake River or at McNary Dam. This metric, calculated daily, allows us to assess how transporting juveniles affects adult returns relative to juveniles that migrate inriver on the same day. "D" compares the relative success in terms of adult returns between fish that were either transported to below Bonneville Dam as juveniles or migrated inriver and survived to below Bonneville Dam.

2.2.5 Smolt-to-Adult Returns

Smolt-to-adult return ratios (SARs) represent the survival of salmon from the smolt stage at a particular location in the freshwater environment through adults returning to the same location (or to another useful location in the migration corridor). These estimates typically represent aggregate survival through a portion of the juvenile freshwater migration corridor, the estuary, the ocean, and a portion of the adult freshwater migration corridor. SARs therefore provide useful information to assess survival through the mainstem migration corridors and ocean-rearing environment. This section focuses on the SARs of all migrants (inriver and transported fish combined) rather than on the comparisons of these groups (see Section 2.2.4).

Estimated SARs (Lower Granite dam back to Lower Granite dam) for Snake River spring/summer Chinook and steelhead from the mid-1960s to mid-2000s are shown in Figures 5 and 6. The older (1960s to early 1990s) data were derived using run reconstruction techniques; the more recent data were generated using PIT tagged fish. In general, SARs for both Chinook salmon and steelhead have declined since the 1960s; but continue to be highly variable; ranging from about 0.5 to 4 percent in recent years. The exact causes are unknown, but several factors likely contributed including the construction of four dams in the late 1960s and early 1970s (John Day Dam on the Columbia River, and Lower Monumental, Little Goose, and Lower Granite dams on the Snake River); and a shift to generally less productive conditions in the northern Pacific Ocean (Mantua et al. 1997; Peterson and Schwing 2003; Scheuerell and Williams 2005; Petrosky and Schaller 2012; Haeseker et al. 2012; Burke et al. 2013). Other human factors, including increased hatchery production, and land use management activities (e.g., agriculture, forestry, and mining) could potentially affect the relative fitness (condition, size, or competiveness) of juvenile fish and so may also have contributed to a downward trend in SARs.

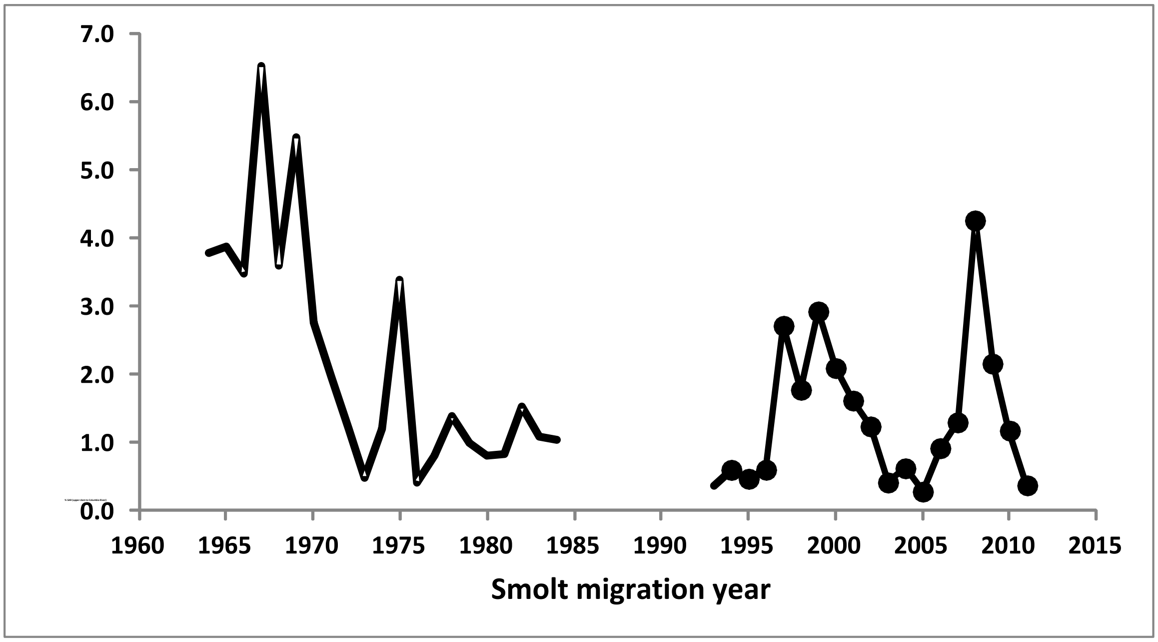


Figure 5. SARs from smolts at uppermost Snake River dam to Columbia River returns (including jacks) for wild Snake River spring/summer Chinook, 1964–2011. SARs based on run reconstruction (1964-1984 and 1993, solid line) and CSS PIT tags (1994-2001, dots and solid line). Smolt migration years are (brood year+2). The 2010 and 2011 estimates are derived from incomplete returns; SAR for 2011 is complete through 2-salt returns only. (Source: Figure 4.1 in Tuomikoski et al. 2013).

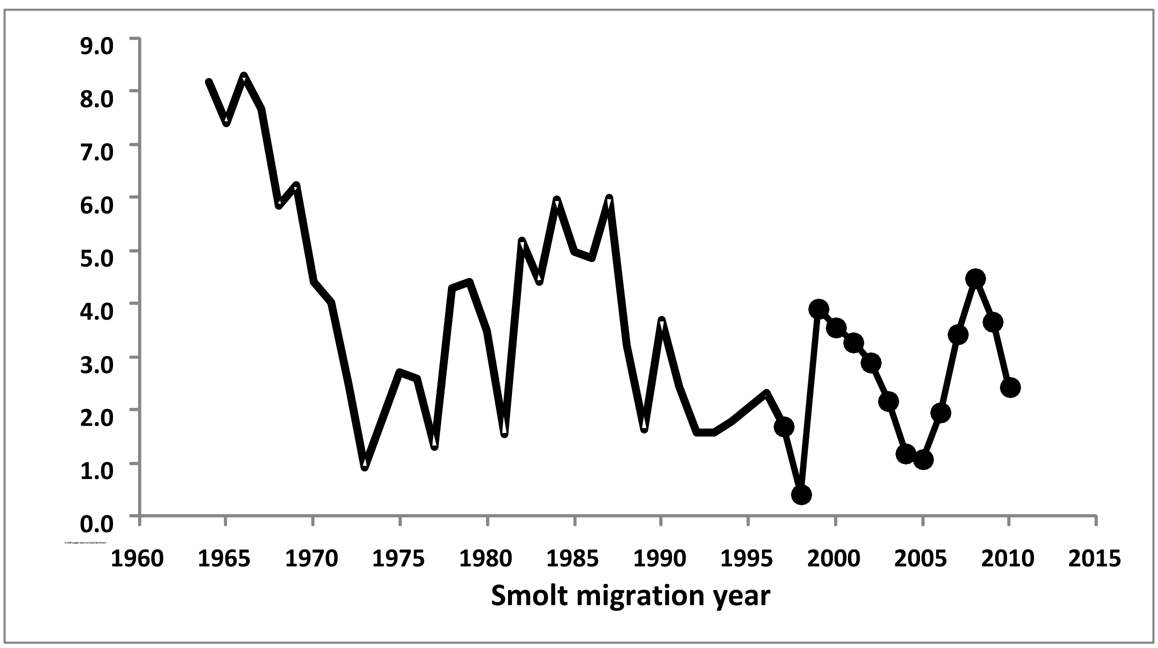
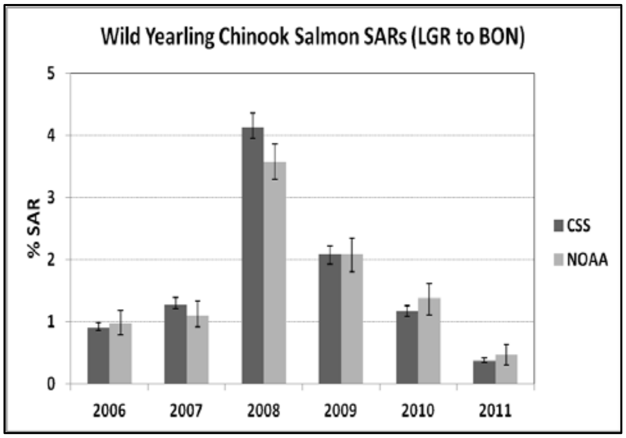


Figure 6. SARs from smolts at uppermost Snake River dam to Columbia River returns for wild Snake River steelhead, 1964-2010. SARs based on run reconstruction (1964-1996, solid line) and CSS PIT tags (1997-2010, dots and solid line). Smolt migration years are (brood year+2). The 2010 estimate is derived from incomplete returns. Source: Figure 4.5 in Tuomikoski et al. (2013).

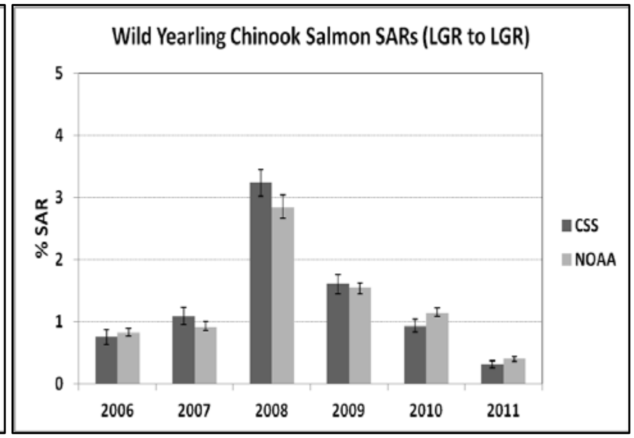
This remainder of this section summarizes recent SAR estimates for PIT tagged migrating smolts[11] that passed Lower Granite Dam from 2006 to 2011 (inriver and transported migrants combined). Figure 7 depicts SAR estimates (with 90% confidence intervals) for wild yearling Chinook salmon (including jacks) and steelhead smolts returning as adults to either Bonneville or Lower Granite Dam. Thus, the difference between these two estimates represents adult losses from Bonneville Dam to Lower Granite Dam from all sources (e.g., hydropower, harvest, injuries due to predation, natural mortalities, etc.). These graphics include estimates from the Comparative Survival Study (Tuomikoski et al. 2013) as well as the NOAA Fisheries' Northwest Fisheries Science Center (unpublished data) for juveniles tagged upstream of Lower Granite Dam.

There is substantial agreement in the SAR estimates made by CSS and NOAA. As expected, SAR estimates to Lower Granite Dam were consistently lower than SAR estimates to Bonneville Dam. Recent SARs peaked for both yearling Chinook salmon and steelhead smolts that outmigrated in 2008 with steelhead SARs exceeding 4 percent and yearling Chinook salmon SARs exceeding 3.5% back to Bonneville Dam. SARs estimates declined substantially to less than 0.5% in 2011 for spring/summer Chinook salmon (though relatively small numbers of 2-ocean and older fish have not returned and have not been included in this estimate).

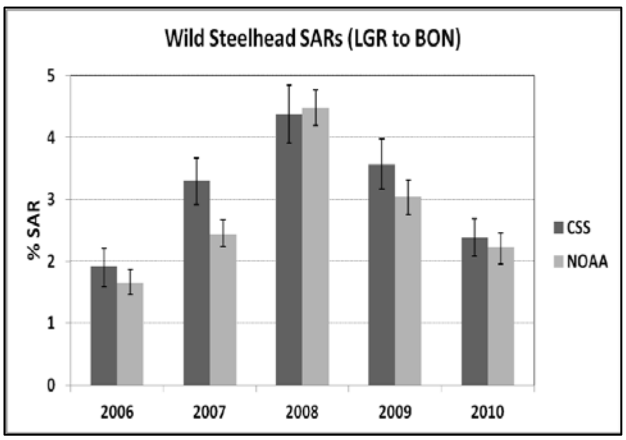
[11] There is evidence suggesting that PIT tagged juveniles return at lower rates (Knudsen et al. 2009) than untagged fish, although the magnitude and variability of this "handling effect" are poorly understood. Thus, PIT tag derived estimates should be interpreted as "minimum" SAR estimates for the run as a whole because they are likely lower (to an unknown degree) than those of untagged fish.



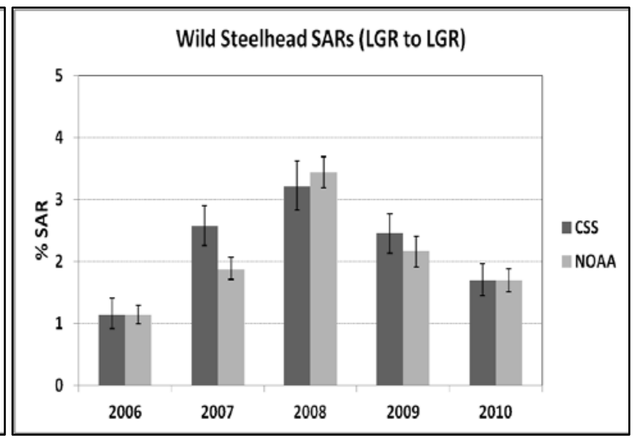
A.



B.



C.



D.

Figure 7. Smolt-to-Adult Return estimates (with 90% confidence intervals) for juvenile Chinook salmon and steelhead tagged upstream of Lower Granite Dam. A. Wild Yearling Chinook returning as adults to Bonneville Dam; B. Wild Yearling Chinook returning as adults to Lower Granite Dam; C. Wild steelhead returning as adults to Bonneville Dam; and D. Wild steelhead returning as adults to Lower Granite Dam. Sources: Tuomikoski et al. 2013 and NOAA Fisheries' Northwest Regional Science Center (Smith 2014, unpublished data).

2.2.6 Key Uncertainties

Direct survival rates of both juvenile and adult salmon and steelhead migrating through the mainstem Snake and Columbia Rivers are estimated annually and well documented (Faulkner et al 2013; Tuomikoski 2013; NMFS 2014). The degree to which mortality in the estuary and ocean is caused by the prior experience of juveniles passing through the FCRPS (i.e., delayed or latent mortality) is unknown and hypotheses regarding the magnitude of this effect vary greatly (ISAB 2007; ISAB 2012). The relative magnitude of delayed or latent effects, the specific mechanisms causing these effects, and the potential for interactions with other factors (ocean conditions, toxics, etc.) remain key uncertainties. Answering these key uncertainties would greatly enhance the ability of hydrosystem managers to improve survival (and SARs) through additional structural improvements or operational modifications at the mainstem dams in future years.

2.2.6.1 Latent Mortality of In-River Migrants Due to Route of Dam Passage

As previously discussed, juvenile migrants can pass through dams via spillways (either conventional or surface oriented), screened bypass systems, or turbine units. Although estimates of direct survival through spillways and bypass systems tend to be high (>98%), there is evidence that fish bypass systems are associated with some latent mortality. The ISAB (2012) summarized the two competing hypotheses explaining this association and noted that the hypotheses have very different implications for hydrosystem operations:

> "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)."

Simply put, if sick, distressed, or injured fish are substantially more likely to pass a dam through the screened bypass systems (selection hypothesis), then actions to move these fish to spillway routes of passage will have little bearing on the long-term survival of these already compromised fish or their likelihood of returning as adults. However, if the fish are randomly entering the screened bypass systems and being injured or otherwise impacted by these systems, then actions to move these fish to spillway routes would be expected to increase long-term survival and likelihood of returning as adults.

Some of the fish losses included in latent mortality estimates undoubtedly include mortalities stemming from fish being injured within the bypass systems or from predation in the vicinity of the bypass system outfall. Many modifications were made during the early 2000s to improve survival rates through these systems, i.e., screens and debris management improvements, use of "full flow" systems, and outfall relocations (USACE et al. 2007, Appendix A: Overhaul of the System; BPA et al. 2013; and BPA et al. 2014). Most recently, the outfalls of several juvenile bypass systems have been relocated to areas that better protect juvenile migrants from predators (Little Goose Dam in 2010, McNary Dam in 2011, and Lower Monumental Dam in 2012). Improvements are also planned for completion at Lower Granite Dam prior to 2018 (BPA et al. 2014).

Assuming that the "damage hypothesis" is correct, these improvements should result in some reduction in rates of latent mortality for bypassed juveniles. Detections of adult fish, that were both PIT tagged and bypassed as juveniles should provide evidence, over time, that supports or refutes this hypothesis.

The Corps of Engineers, with the assistance of NMFS and other regional parties, is designing a PIT tag detector to be installed in a spillway bay at Lower Granite Dam before 2018 (BPA et al. 2014). This system would, for the first time, allow a direct comparison of the survival rates and downstream detection probabilities of juveniles passing this dam via the spillway and bypass system. However, this tool, by itself, would not allow for a comparison of the condition and health of these fish, information that is needed to support either the "selection" or "damage" hypotheses. . This would require a study that either captured smolts in the forebay of a dam and compared their condition and health to that of juveniles collected from the bypass system on the same day or captured smolts passing through the spillways into the tailrace to compare with those taken from the bypass system.

2.2.6.2 Proposed Spill Experiment

Consistent with the "damage" hypothesis noted above, in recent annual reports for the Comparative Survival Study, Tuomikoski et al. (2011, 2012, 2013) hypothesized that substantially increasing spill levels (to reduce exposure of juveniles to juvenile bypass systems and turbines) would substantially increase both inriver smolt survival and SAR rates (inriver plus ocean survival). The CSS reports present prospective modeling results for four scenarios, ranging from current levels of spill at the eight mainstem dams to spill that creates total dissolved gas levels up to 125% of saturation in each tailrace. The CSS participants recommended that the region design and implement a large-scale operational study to evaluate this hypothesis (CSS Workgroup 2013).

NMFS considered the proposed spill test in the 2014 Supplemental FCRPS Biological Opinion (NMFS 2014):

> "NOAA will continue to monitor the effects of project operations on juvenile survival and adult returns as reported by CSS and the NWFSC. We note the adult returns from the year 2011, a year that had high levels of spill and flow, has produced below average adult return rates. Results such as this reinforce our current management approach to hydrosystem operations. Substantial progress has been made toward improving survival of juvenile anadromous fish in the hydrosystem. Models of the system effects will continue to improve through 2018 as more data from current operations is added, and NOAA Fisheries will continue to consider opportunities to make further improvements to hydrosystem operations or configurations."

NMFS also identified several technical issues and other factors to be addressed in consideration of a spill test and ultimately did not determine that such a test was necessary to avoid jeopardy within the time frame of the 2014 Supplemental Biological Opinion (i.e., through 2018). The proposed spill test was also reviewed by the Independent Scientific Advisory Board (ISAB 2014), which identified several weaknesses in the proposal and advised additional scrutiny of the available data. However, the ISAB also indicated that a spill test with appropriate controls and adequate monitoring would increase the region's base of knowledge "regarding spill, juvenile salmonid dam passage survival, impacts on adult fish passage and other species, and total dissolved gas effects."

Proposals for large, multi-year operational experiments must be based on the best available science, have a high potential to improve fish survival, and possess a sound study design. A study must also be consistent with state and federal laws, deemed operationally and economically feasible by the operating agencies and be subject to independent scientific reviews. Assuming these and other necessary conditions are met, such experiments could be used to inform future management decisions regarding configuration and operational improvements at mainstem dams.

2.2.6.3 Adult Survival Rates from the Estuary to Lower Granite Dam

Adult survival rates in the estuary (except in the Bonneville Dam tailrace, where passage may be delayed while adult salmon and steelhead find and enter adult fishway entrances) is likely not related to the Hydropower system. However, salmon and steelhead losses in the lower Columbia River estuary are important to consider in the context of recovery planning; and injuries resulting from sea lion attacks or from harvest activities (gillnets, recreational fishing, etc.) are likely affecting survival rate estimates in reaches upstream of Bonneville Dam.

After accounting for harvest, Rub et al. (2012a, 2012b) estimated survival rates from Rkm 45 in the estuary to Bonneville Dam for adult spring Chinook of 88% during 2010 and 85% in 2011. These estimates include losses to pinnipeds in the Bonneville tailrace. Direct annual estimates of survival in the lower Columbia River are not available for other salmonid species. The numbers of California sea lions and Steller sea lions are increasing (Scordino 2010; Carretta et al. 2013), and predation below Bonneville Dam is likely substantial, especially for spring migrating adults.

Average recent conversion rates for adult Snake River spring/summer Chinook salmon, sockeye salmon,[12] and steelhead (see Table 1) are about 6 to 10% than expected (see Section 3.3.3.1 in NMFS 2014). Most of these losses appear to occur between Bonneville and McNary dams for spring/summer Chinook and sockeye salmon and between McNary and Lower Granite dams for steelhead.

Factors that could potentially be affecting adult passage and observed conversion rates upstream of Bonneville Dam include: environmental factors (flows, spill operations, temperature, etc.), structural modifications, errors in the harvest or stray rate estimation methods, variability in stock run timing, or some combination of these factors. NOAA plans to evaluate these factors in relation to PIT tag based conversion rate estimates (Dygert and Graves 2013) in the coming years.

Annual estimates of adult survival allow managers a means of determining whether or not management actions are having the intended effect. Extended to the estuary and Columbia River below Bonneville Dam, annual survival estimates would allow managers to assess if predation from increasing numbers of pinnipeds was causing adult survival rates to decline.

NMFS is exploring systems to obtain PIT tag detections in the lower Columbia River annually. Beginning in 2014, PIT tag detectors will be present in the fish ladders at every mainstem dam except John Day in the lower Columbia River. PIT tag detection systems have similarly been installed in the lower reaches of many tributaries to the mainstem Snake and Columbia rivers upstream of Bonneville Dam, as well as in many locations in tributaries upstream of Lower Granite Dam. Recent and future improvements to the network of PIT tag detection systems,

[12] These estimates do not include effects of the adult passage blockages at Lower Granite Dam in 2013, which are discussed in Section 2.2.2 of this Hydro Module and in more detail in the 2014 Supplemental FCRPS Biological Opinion (NMFS 2014).

occasional adult radio-telemetry studies, and efforts to evaluate how environmental and management factors affect PIT tag based conversions rate estimates should substantially improve the ability of mangers to identify issues and implement corrective measures, if warranted.

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