

Submission 1**Hatchery Extra Mortality Hypothesis****J. Williams, G. Matthews, J. Myers, S.G. Smith, T. Cooney and C. Toole****June 30, 1998**

HATCHERY EXTRA MORTALITY HYPOTHESIS¹

Summary: Snake River hatchery smolt production, particularly that of steelhead, increased greatly during the time period experienced by Snake River spring/summer chinook salmon smolts of the 1968-1990 brood years. This increase is generally coincident with an increase in extra mortality experienced by most of those brood years. A negative effect of hatchery production on wild spring/summer chinook survival is hypothesized, particularly for brood years 1984-90, based on mechanisms related to reduced growth rate, stress, predation, and disease transmission. The effects of hatchery interactions are hypothesized to begin in the migration corridor prior to arrival at the first Snake River dam and to be exacerbated in areas where fish congregate, such as in forebays, bypass systems, collection raceways, and barges. It is possible that there is an interaction between hatchery production and congregation of wild and hatchery fish in the transportation program, since the trend in hatchery production and the trend in proportion of the run transported are largely coincident. Effects of hatcheries are likely to be greater for Snake River stocks than for lower river stocks because: (1) the migration corridor prior to arrival at the first dam (and also subsequent to it, including ocean entry) is much longer and more demanding for Snake River stocks than for lower river stocks, leading to a greater potential for hatchery and wild smolt interaction; (2) one of the primary concentrating mechanisms, smolt transportation, is present only for Snake River stocks; (3) only three of the six lower river index stocks (Wind, Klickitat, and

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Warm Springs) encounter hatchery fish in the migration corridor prior to reaching mainstem Columbia River reservoirs, whereas all Snake River index stocks share the migration corridor above the first dam with hatchery fish; and (4) natal streams of Snake stocks may be more nutrient-depleted than those of lower river stocks, which combined with the more demanding migration of Snake River stocks would affect fish condition and energy reserves and potentially exacerbate effects of hatchery interactions in the migration corridor above the first dam and during early ocean adaptation. The influence of these hatchery effects on performance of hydro management scenarios cannot be determined with certainty until hatchery effects are represented quantitatively in PATH models and new analyses are conducted. However, this report contains a brief discussion of likely qualitative effects.

Introduction

The purpose of this paper is to describe a potential relationship between large increases in the production of yearling spring chinook and steelhead hatchery smolts in the Snake River basin and observed or estimated trends in the survival of Snake River wild indicator stocks. Comparisons of modeled survival rates with survival rates estimated through field studies conducted as part of the PATH process have identified an unexplained component of mortality affecting these stocks. Alternative explanations have been developed that attempt to relate the Aextra mortality@ to delayed effects of the hydropower system and to ocean/climate effects. The hatchery hypothesis described below has been developed with a focus on its relationship to Aextra mortality@ for further assessment, including comparison to the other major alternatives through the PATH process. Combinations of the three major hypotheses should also be evaluated.

Development of an Aextra mortality@ hypothesis requires an understanding of the pattern to be explained. AExtra mortality@ is mortality Aoccurring outside of the [hydropower] migration corridor that is not captured by the inherent stock-recruitment parameters for a given stock (productivity, depensation, and carrying capacity terms)@ (Marmorek and Peters 1998; p. 38). AExtra mortality@ is generally considered to occur below Bonneville Dam, although it can occur anywhere above or below the migration corridor, depending upon the factors captured in the stock-recruitment parameters. Because it is defined as occurring Aoutside the [hydropower] migration corridor,@ assumptions regarding the temporal pattern of mortality within the migration corridor are critical to both the definition and interpretation of the causes of Aextra mortality@.

In general, there are four major opportunities for interactions among hatchery releases and naturally produced juvenile salmon and steelhead; within tributaries, within the migration corridor, within barges and within the migration corridor below Bonneville. The following discussion focuses on the migration corridor and barging opportunities. Similar downward trends in survival and in abundance have been observed for index stocks throughout the Snake basin. In some cases, index areas have been subject to substantial levels of hatchery juveniles while for other index stocks hatchery influences within natal tributaries have been minimal. Interactions within tributaries may be a contributing factor in some cases but are not likely to be a major element in recent declines.

The Pattern of Δ Extra Mortality

Estimates of Δ extra mortality using the delta life-cycle model and both CRiSP and FLUSH passage models was obtained from Rick Deriso and David Marmorek in spreadsheets prepared on June 9-10, 1998. A plot of Δ extra mortality estimates, which include the range of passage model estimates, is presented as Figure 1. Δ Extra mortality is expressed as $1 - e^{-(m-M)}$, where terms are as described in Wilson et al. (1997) and Marmorek and Peters (1998). Briefly, m is the total passage and extra mortality rate and M is the estimate of direct passage mortality from passage models. **[Note: it isn't entirely clear to us if M is really direct passage mortality or if it is direct passage mortality of in-river migrants and direct plus some additional mortality below Bonneville of transported fish (i.e., Δ system survival)].** With the exception of a few years in the late 1960's, estimates based on both the CRiSP and FLUSH model assumptions indicate a similar pattern of Δ extra mortality for Snake River spring/summer chinook salmon. At least four periods appear to be relevant:

(1) Period 1 (1952 BY through approximately the 1971 BY): Δ Extra mortality was experienced by Snake River stocks at what might be considered a Δ background level. When expressed using the $1 - e^{-(m-M)}$ metric, the range of estimates is generally between 0-0.6. Estimates based on both passage models are synchronous through about BY 1965, and there is considerable uncertainty regarding the pattern in the 1966-1970 brood years. However, even with this uncertainty, the range of estimates is generally consistent with, or even lower than, the 1952-1965 BY range, so we have included these years in the first period.

(2) Period 2 (Approximately 1972-1979 BY): The range of λ_{extra} mortality estimates was higher than the range during the first period for all years except BY 1973. The range using the described metric was approximately 0.6-0.9. The BY 1973 estimate, however, was as low as those during Period 1.

(3) Period 3 (1980-81 BY and Possibly 1982-83 BY): λ_{extra} mortality during the 1980-81 brood years dropped to levels experienced during Period 1. The λ_{extra} mortality experienced by the 1982-83 BY was intermediate between the levels in Period 1 and Period 2 (approximately 0.6), so may be considered in either category.

(4) Period 4 (1984-90 BY): λ_{extra} mortality has been very high relative to that in other periods (generally >0.8).

We note that the general pattern of Snake River stock-recruitment residuals corresponds closely to the pattern of Snake River smolt-to-adult return rates (SAR), estimated using two different historical age structure assumptions (**Appendix 1 to this report, with John Williams and Petrosky and Schaller (1998) SAR estimates**). Although the years corresponding to each of the four phases of the temporal pattern vary slightly among these approaches, high SARs tended to occur during the first and third periods, while low SARs tended to occur in the second and fourth periods. As with the λ_{extra} mortality estimates, SAR during the 1973 brood year (1975 migration year) was considerably higher than other SARs during the second period. For these reasons, the pattern of SARs is referred to interchangeably with the pattern of λ_{extra} mortality in some sections of this paper.

It is also important to note that the pattern described above applies to combined transported and in-river migrating smolts. Estimates of λ_{extra} mortality are consistently higher for transported smolts than for in-river migrants (Figures 2 and 3). In these figures, the total λ_{extra} mortality estimates have been partitioned between in-river and transported smolts based on the λ terms defined in Wilson et al. (1997) and Marmorek and Peters (1998). The general pattern of λ_{extra} mortality for transported and non-transported smolts is similar for most brood years when estimated using the CRiSP passage model. However, these patterns are very dissimilar when estimates are based on the FLUSH model.

Estimates of wild spring/summer chinook salmon smolts arriving at the upper Snake River Basin dam from 1964 through 1969 averaged 2.35 million fish (range 2.0 - 2.9 million; Raymond 1988). The concurrent estimates of the number of wild steelhead arriving at the upper Snake River Basin dam averaged 1.6 million fish (range 1.3 - 1.8 million.) Thus, the combined average total of wild smolts arriving at the upper dam in the 1960s was only approximately 4.0 million fish. Hatchery releases began in 1967 as mitigation for lost spawning areas from dams that blocked adult upstream passage and to provide additional smolts to offset expected losses of downstream migrants through the hydropower system (Figure 4). By 1970, the number of yearling hatchery fish released into the system exceeded wild smolt production. The combined wild smolt production remained at approximately 4 million fish through 1974, but the combined hatchery releases had risen to approximately 10 million fish. Thus, there were more than three times as many fish in the migration corridor as there were just 10 years earlier. (Since hatchery fish likely incur a 30 to 40% mortality before arriving at the dams on the Snake River, the increase in numbers of fish to the upper dam was likely less). Total hatchery production decreased slightly coincident with the 1979-81 BY migrations - steelhead production, in particular, dropped during the 1981 BY migration. Hatchery production subsequently increased, averaging nearly 20 M fish by 1988.

A comparison of the trends in hatchery production (Figure 5) with the patterns in estimated Δ extra mortality Δ indicates that, while the general trend appears consistent, it is difficult to explain the entire pattern in Δ extra mortality Δ through a simple linear relationship based on hatchery production. Increased mortality due to increased hatchery production during Period II may be masked by the initial operations associated with the Snake River dams coming on-line (Raymond 1979). The large increase in hatchery production, especially steelhead, coincident with the increase in extra mortality during period IV is most notable. The drop in Δ extra mortality Δ during Period 3 coincides with a reduction in hatchery output during BY 1981 for steelhead and during BY 1979-80 for all hatchery smolts as well as with improvements to the hydropower system. There is a very slight drop in hatchery production that coincides with the significant reduction in Δ extra mortality Δ for the 1973 brood year. That is also coincident with Lower Granite Dam coming on-line and the lack of debris in the forebay. In summary, while the general trends appear coincident (e.g., Figures 6 and 7), it is clear that any causal relationship between hatchery production and Δ extra mortality Δ will explain only a portion of the variation in Δ extra mortality Δ . Also, because Δ extra mortality Δ was present during the 1952-1971 BY period, factors other than hatchery smolt interactions (or Snake River dams, for

that matter) must be responsible for a significant portion of the **baseline** extra mortality. It is likely that hatchery interactions are just one of several mechanisms operating during this time period.

Possible Mechanisms for Hatchery Effects on **Extra Mortality**

Through 17 May 1998, 113,658 chinook salmon were measured when PIT-tagged at Lower Granite Dam for transportation studies. The average weight of hatchery yearling chinook salmon smolts was an estimated 20.5 g and the average weight of wild yearling chinook salmon smolts was 12.5 g. Through the same date, the estimated weight of steelhead PIT-tagged at Lower Granite Dam for survival studies was 110.8 g for hatchery fish and 58.7 grams for wild fish. Thus, the average hatchery yearling chinook salmon and steelhead has a biomass that was 64 and 89% greater than its wild counterpart. To sustain this increased hatchery fish biomass requires considerably more nutritional sources than would an equal number of wild fish with a smaller biomass. Furthermore, it is highly unlikely that steelhead smolt abundance exceeded (or even matched) yearling chinook abundance under natural conditions in the Snake and Columbia Rivers.

In addition to biomass differences, migrational characteristics differ greatly between wild and hatchery spring chinook salmon smolts. Wild smolts typically demonstrate a very protracted migration from headwater streams through the migration corridor and into the estuary and ocean. Conversely, the migrations of the much larger biomass of hatchery smolts is typically much more compressed than the migrations of wild smolts, increasing the likelihood of hatchery and wild fish interactions during this period.

The combined effects of huge numbers of hatchery-released fish that are larger in size than wild fish are hypothesized to affect wild chinook salmon smolts in at least two ways:

First, the large number of hatchery fish and their larger biomass may place severe constraints on the carrying capacity of the migration corridor and limit growth and energy reserves of wild spring/summer chinook. The compressed hatchery smolt migration distributions places a very high demand on a limited food supply during the middle 50-70% of the combined outmigration period throughout the entire migration corridor. For example, Dawley et al. (1986) found that stomach fullness of migrant yearling chinook salmon as they passed into the estuary was lower when the number of migrants was higher. During peak migration periods, yearling chinook salmon were the first to show empty stomachs,

followed by coho salmon and then steelhead. This suggests a competitive advantage for the other two species over yearling chinook salmon. We have not been able to obtain comparable data for the upriver reaches, but see no reason why the same condition would not apply.

Decreased growth rates and energy reserves of wild yearling chinook smolts likely result in decreased survival due to greater susceptibility to predation within the migration corridor and the possibility of decreased ability to transition to seawater. The first point is well-documented in the predation literature. For example, Poe et al. (1991) noted that northern squawfish consistently consumed more juvenile salmonids from smaller than from larger size groups available during a given month in John Day reservoir. While predation mortality occurring between Lower Granite and Bonneville would presumably be captured in estimates of direct passage mortality (M), any predation mortality that occurred above or below the hydrosystem, especially below Bonneville where predation indices are high (Ward et al. 1995), would presumably contribute to estimated M_{extra} mortality. Regarding the second point, smolts arriving at the ocean face a large energy drain associated with osmoregulation in seawater. At this point, if insufficient nutrients were available during the downstream migration and overall fitness of stocks declined, and/or insufficient food is available to support the large biomass of smolts moving into the ocean, fish with lower energy reserves or decreased growth rates would likely survive at lower rates. Mahnken et al. (1982) found for hatchery coho salmon that size at ocean entry was an important indicator of future survival, but also that growth rates were critical. Fish that did not maintain a strong growth rate reverted to parr and were lost from the population. This source of mortality/loss in the estuary could clearly be a component of the M_{extra} mortality.

The large numbers of hatchery juveniles moving through the migration corridor and into the estuary and ocean over a short period may decrease the overall survival of all stocks of fish, but selectively impact to a larger degree those fish that must migrate through a longer distance in common with the large hatchery populations and over a more protracted time period. On the other hand, in the absence of hatchery fish, the protracted wild smolt migrations, together with their much smaller biomass, would act to minimize the demand on a limited food supply in the migration corridor and upon ocean entry at any given time. For example, results of NMFS research in 1990, in which only fish for transportation were marked, and preliminary results from 1995, in which fish that migrated through the hydropower system and fish for transportation were marked, indicates that the lowest seasonal survival was experienced by fish passing

during the peak of the run. SARs of fish that passed when the bulk of the hatchery fish were in the river were as much as 10 and 4 times lower in the 2 years, respectively, than during other parts of the run.

The potential effects of large hatchery fish production might magnify the deleterious effects on stocks during periods of low ocean productivity or when upwelling in the near ocean environment is decreased or delayed, as has often occurred since the oceanic regime shift occurred in 1976. The large hatchery fish production potentially decreases the fitness of all wild and hatchery spring chinook salmon from the Snake River Basin. Stocks from lower river basins likely are impacted less as they spend less time in the presence of, and potentially competing with, the hatchery fish from upper river areas.

Second, the large number of hatchery fish the Snake River Basin likely increases the stress levels on migrant chinook salmon in areas where fish congregate, such as in the forebays of dams before fish pass (particularly at Lower Granite Dam), in collection raceways, and in transportation barges.

Stress in chinook salmon is known to increase with density (Maule et al. 1989, 1996). The problem is exacerbated by the large number of steelhead smolts released, as chinook salmon naturally do not co-mingle with steelhead during the migration. Kelsey (1997) found an elevated stress response of yearling chinook salmon when rainbow trout (used as a surrogate for steelhead) were added to a raceway, but not when additional chinook were added. Behavior also changed dramatically, with chinook exhibiting greatly reduced movements, reduced use of shaded areas, and experiencing a 16-times higher incidence of attacks than when higher densities of chinook were present. Schreck and Congleton (1994) and Schreck et al. (1994) found that stress indicators of yearling chinook remained elevated throughout collection and transportation during the peak of the run, when large numbers of hatchery fish were present, but that stress responses quickly subsided during other parts of the migration season. The observation in recent studies of lower SARs during the peak of the run, presented above, could be explained by mortality related to a stress response to high densities following arrival at the Lower Granite forebay, in addition to, or in place of, an explanation based on poor growth and energy reserves caused by high density in the migration corridor.

Stress of wild spring/summer chinook caused by high densities of hatchery steelhead and chinook in areas where these fish congregate can result in increased mortality through at least three mechanisms. The first is predation. Sigismondi and Weber (1988) and Olla and Davis (1989) demonstrated that the avoidance response of juvenile salmon decreases with increasing stress, likely resulting in higher susceptibility to

predation. Depending upon the location of the predation (as described above), this mortality could contribute to the estimated Δ extra mortality. The second is disease. The prevalence of BKD infection in Snake River hatchery chinook averaged >90% between 1988-1992 (Maule et al. 1996). Infection rates of salmonid smolts can be increased due to increased exposure to BKD pathogens (presumably shed from infected smolts) during both inriver migration and transportation (Elliott and Pascho 1995). Stress lowers the effectiveness of the immune system in chinook salmon (Maule et al. 1989) and limited evidence suggests that resistance specifically to BKD is reduced (Moffitt and Bjornn 1989). Mortality of some proportion of the wild spring/summer chinook infected in this manner may occur either during downstream migration (Pascho et al. 1993) or in seawater (Elliott et al. 1995), although some proportion is also likely to recover (Pascho et al. 1991). The stress associated with the transition from freshwater to saltwater may accelerate the mortality due to BKD infection (Sanders et al. 1992). The third possible mechanism is reduction of energy reserves as a result of stress (Davis and Schreck 1997), which could lead to predation or saltwater transition problems as described above.

Increased hatchery production, especially increases in the number of hatchery steelhead smolts may exacerbate the effects of confining wild smolts into small spaces resulting from collection and transportation. As a result, the effects of high hatchery production and the effects of the hydrosystem can be intermingled when mechanisms involving concentration of fish species are hypothesized as being responsible for stress leading to Δ extra mortality. We note that the patterns of hatchery releases and of the proportion of smolts arriving in Lower granite pool that are transported are nearly coincident (Figure 8). The opportunities for congregation of wild chinook and hatchery smolts (particularly steelhead) are especially great in the transportation program, which could partially explain the higher estimated Δ extra mortality in transported, compared to non-transported, fish (Figures 2 and 3).

Rationale for a greater effect of hatcheries on growth and energy reserves of Snake River, compared to Lower Columbia River, stocks was previously described. Effects of stress resulting from concentration in the transportation program are relevant only to Snake River stocks and those resulting from concentration in forebays at projects are more relevant to Snake than lower river stocks because of the greater number of projects at which interactions may occur. Additional reasons for greater effects of hatchery production on Δ extra mortality in Snake River stocks, compared to lower river stocks include: (1) only three of the six lower river index stocks (Wind, Klickitat, and Warm Springs) encounter hatchery fish in the migration

corridor prior to reaching mainstem Columbia River reservoirs, whereas all Snake River index stocks share the migration corridor above the first dam with hatchery fish; and (2) natal streams of Snake stocks may be more nutrient-depleted than those of lower river stocks, which would affect fish condition and potentially exacerbate effects of hatchery interactions in the migration corridor above the first dam.

Regarding the effects of natal stream nutrients on extra mortality, natal areas inhabited by wild Snake River stocks appear to differ from natal areas inhabited by wild lower Columbia River stocks in several important ways. Snake River natal areas are much farther inland and encompass a much larger and higher-elevation geographic area. Due to lower annual temperature profiles and other reasons, higher elevation streams are generally less productive by nature than lower elevation streams and their productivity may be heavily reliant on nutrient transport from the ocean in the form of salmon carcasses (e.g., Larkin and Slaney 1997). Beginning in the mid 1970s, wild Snake River stocks underwent severe population declines. The absence of nutrient-input from salmon carcasses in such a large, high-elevation area has contributed to an environment that is much more unproductive per unit of area than the smaller, lower river areas that have not undergone such severe population crashes. The condition of smolts at the time of migration is critical. Dickhoff et al. (1997) found that wild spring chinook salmon smolts from the Yakima River system had depleted liver glycogen and body lipid reserves after only one-third of their seaward migration. They suggested that the fish needed additional energy to support migration from food captured during the migration or from stored protein. If food sources are scarce, then depletion of stored protein would have potentially serious deleterious consequences on their chance of survival. They also suggest that large body size and growth during the parr-smolt transformation are important in building up stored energy so as not to deplete protein stores to support smolt migration. The result may be that Snake River smolt populations have lower energy reserves prior to their passage through a much longer, more arduous migration to the sea compared to smolts migrating from the lower Columbia River natal areas. Energy reserves in Snake river fish may be further depleted as they co-migrate and compete for limited food resources with the large hatchery biomass through the hydropower system and into the estuary. Lower Columbia River wild fish may also be impacted, but to a lesser degree, because they have not faced the rigors of growth and migration that Snake River fish have faced and may have larger energy reserves on early ocean entry and residence.

Alternative hypotheses regarding the contribution of hatchery production to the extra mortality component estimated for wild Snake River spring-summer chinook have different implications for drawdown and enhanced transportation actions. Several potential areas of interaction were described above. One area of interaction, the effects of hatchery releases within tributaries, appears unlikely given that downward trends are apparent for stocks that are exposed to significant hatchery production within natal tributaries as well as for those stocks that are not. The following table summarizes the potential impacts of the two major system configuration options against the remaining alternative hypotheses regarding the relationship between extra mortality and interactions with hatchery smolts.

A2 -Maximize transport: If the effect of hatchery fish is significant and is primarily the result of stress before or during bypass capture and barging, the prospective effect would most likely remain unchanged from recent levels or be increased as a result of exposure of an increased proportion of the run. If the effect of stress is primarily the result of interactions during the in-river migration below the collector projects, the maximum transportation option may result in a decrease in effect due to reductions in the proportion of the run remaining in-river below the collector projects. If the effect is due to interactions on entry to the estuary or ocean, maximizing transport will increase mortality as a result of a higher proportion of the hatchery and wild smolts reaching the estuary and ocean.

A3 -Snake River Drawdown In general, interactions with hatchery fish would be reduced under this option. Migration time through the area currently impounded above Lower Granite Dam would be reduced. Collection and handling at the Snake River projects would be eliminated resulting in less crowding. The Snake River collector projects currently remove more than 50% of the steelhead juveniles prior to passage below Little Goose Dam. Drawdown would eliminate Snake River transportation, resulting in significant increases in the number of smolts migrating in the mainstem below Little Goose Dam. To the extent extra mortality is increased by competition for food or by exposure of wild spring/summer smolts to hatchery smolts, detrimental impacts could be increased. This may be particularly true at McNary Dam, where a larger number of smolts will arrive at the project with the elimination of Snake River transportation than under current conditions. Alternatively, negative interactions in the corridor below the Snake River collector projects could be reduced under this option, the amount of change being dependent upon the relative

importance of cumulative stress prior to the reach and to the nature of the bypass systems remaining in place.

Reductions in the number of hatchery yearlings released during the wild spring/summer chinook migration would reduce extra mortality under all of the combinations of possible interactions and system options described above. Plotting estimates of Snake River wild spring/summer chinook extra mortality against hatchery steelhead release levels indicates a possible non-linear relationship (Figures 6,7). If that relationship holds, reductions in hatchery releases to or below those levels prevalent in the mid to late 1970's would be required to significantly reduce extra mortality.

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