Extra mortality, delayed mortality, and *D*: an overview

Prepared by

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GLOSSARY

Term	Definition
Barged fish	See "Transported fish." Most transported fish are transported by barge now, but in the past more were transported by truck.
CBFWA	Columbia Basin Fish and Wildlife Authority.
CRI	Cumulative Risk Initiative, conducted by the Northwest Fisheries Science Center, which is part of NMFS.
CRiSP	Computer model of smolt passage and transport survival.
CRITFC	Columbia River Inter-Tribal Fish Commission.
D	Differential delayed transport mortality: "...the differential survival rate of transported fish relative to fish that migrate in-river, as measured from BON tailrace to adult returning to Lower Granite Dam (LGR). A 'D' equal to one indicates that there is no difference in survival rate (after hydrosystem passage), while a 'D' less than one indicates that transported fish die at a higher rate after release, than fish that have migrated through the hydrosystem" (Bouwes et al. 1999, p. 3).
DEIS	Draft Environmental Impact Statement ("A-Fish" Appendix to the U. S. Army Corps of Engineers' Lower Snake River juvenile salmonid migration feasibility report/Environmental Impact Statement, December 1999 draft.
Delayed mortality	Mortality that occurs in a later life stage than the cause of the mortality. Equivalent to extra mortality, but "delayed"emphasizes that mortality occurs some time after the causal mechanism.
Direct mortality	Mortality that occurs in the same life stage as the cause of the mortality.
Estuary	Zone of transition from freshwater to salt water, beginning

	approximately below Bonneville dam.
Extra mortality	Another term for delayed mortality.
FLUSH	Computer model of smolt passage and transport survival.
IDFG	Idaho Department of Fish and Game.
In-river fish	Outmigrating juvenile fish from the time they leave their rearing areas, to the time they either (1) are picked up by a truck or barge or (2) arrive below Bonneville dam.
ln(R/S)	Natural logarithm of Recruits/Spawner. *Recruits* are surviving offspring of *Spawners*. In this paper, the number of recruits is assumed to be at the Columbia River mouth (i.e., before upstream migration mortality has reduced their numbers). The number of spawners is assumed to be at the tributary spawning grounds.
NMFS	National Marine Fisheries Service.
ODFW	Oregon Department of Fish and Wildlife.
PATH	Plan for Analyzing and Testing Hypotheses.
PIT tag	A small (about the size of a grain of rice) transponder that is implanted in the gut of a juvenile fish, which can be detected as the fish goes downstream or upstream through detectors at several of the Columbia and Snake River dams.
SAR	Smolt-to-adult return rate: definitions vary, but STUFA assumes this survival is the ratio of adults returning to the Columbia River mouth, divided by the number of outmigrating juveniles above Lower Granite dam. It is often defined round-trip from above Lower Granite, in order to include upstream migration mortality due to the hydrosystem and mainstem harvest.
Smoltification	Physiological changes that occur as a young (about 1½ years old)

	salmon migrates from freshwater out to the estuary and ocean, which allow the fish to "breathe" saltwater.
STUFA	State, Tribal and U.S. Fish Agencies.
Transported fish	Outmigrating juvenile fish from the time they are picked up by a truck or barge to the time they arrive below Bonneville dam.
USFWS	U.S. Fish and Wildlife Service.

Introduction

After many years of analysis by biologists from a multitude of state, federal, tribal, and other organizations, the two basic questions about what to do to save ESA listed Snake River salmon that remain are:

Can we save them without breaching the 4 lower Snake River dams?

And if we do breach the dams, will it work?

The most intense analyses have been conducted recently by PATH (Plan For Analyzing and Testing Hypotheses), the Northwest Fisheries Science Center's CRI (Cumulative Risk Initiative), and STUFA (State, Tribal and U.S. Fisheries Agencies). These groups have used a variety of models and analytical methods, though they use much of the same data, and they have all finally reached the same conclusion: the answer to the questions about whether we should breach the dams in order to save Snake River salmon depends on how much of the demise of these populations is due to the hydro system. It is not so much the direct effects of the hydrosystem that has gotten most of the attention; at this point, the arguments center instead on indirect effects. PATH came up with a parameter, D, that has drawn much of the attention around the issue of indirect effects. However, the real issue is not so much D, but rather how it relates to two other confusing terms: extra mortality and delayed mortality.

Transportation and in-river juvenile migration

There are two ways for Snake River juvenile spring and summer chinook to get from their natal streams to the Columbia River estuary. They can swim down, or they can be transported down by barge or truck. Snake River juvenile and adult salmon must migrate past 8 hydroelectric dams on their way to and from the ocean (Figure 1).

If they are collected into a barge or truck and carried downstream, about 98% of them will still be alive when they are released from the barge 3 or more days later below Bonneville Dam[1].

[1] Bonneville dam is the lowermost dam on the Columbia River, about 100 miles upstream from the ocean. For all intents and purposes, the freshwater-to-salt water transition zone, or estuary, begins below Bonneville.

Each barge transports 350,000 steelhead smolts, or 500,000 to 1,000,000 juvenile chinook. If the barge makes no stops, its travel time to below Bonneville (where the juveniles are released, about 100 miles upstream from the ocean) is about 36 hours.

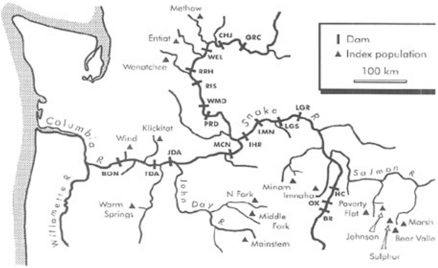

Figure 1. Map of the Columbia and Snake Rivers showing the 8 hydroelectric dams from Lower Granite Dam on the Snake down to Bonneville Dam, the lowermost dam on the Columbia River.

Since there are 3 potential pickup points (Lower Granite, Little Goose, and Lower Monumental dams, on the lower Snake River), each barge may stop on its way down to load at any other sites where fish might be migrating.

Because the Corps of Engineers operates several barges, the loading occurs nearly every day during the migration season. During peak outmigration, a smaller barge might be deployed to work a lower collection site. Though barges depart daily, collection and holding of fish can typically add a day or more to the time for most fish. When fish numbers are small, barges might be tied up a day to wait for more fish, in order to make the trip more economical. In the early season, when there are fewer migrants, the Corps uses tanker trucks which can handle 25,000 to

[2] Bonneville dam is the lowermost dam on the Columbia River, about 100 miles upstream from the ocean. For all intents and purposes, the freshwater-to-salt water transition zone, or estuary, begins below Bonneville.

30,000 juvenile fish. Trucking is being phased out because trucks are inefficient and also because the survival rates are low (explanation of barging provided by Olaf Langness, WDFW).

At this stage the juvenile chinook are about a year and a half old and are about 4 inches long. If they make their own way down through the hydrosystem, about 33% to 50% will survive to below Bonneville. Although it seems obvious that the safest route to the ocean for a smolt is in a barge, there is evidence that barged fish do not make it back to spawn at nearly the rate that in-river fish do. People do not agree about how big the difference is between barged and in-river fish, but there is consensus that there is a difference (Peters et al. 2000).

In addition to the barged-vs-in-river survival differences, there are also differences in ocean survival between fish that only have to get past 1 to 3 dams, and fish that have to get past 8 or more (Schaller et al. 1999). Regardless of how upriver fish make it past the 8 or more dams to the ocean, they do not appear to survive as well after that as fish do who don't have to deal with so many dams.

What are the different kinds of mortality?

These spring and summer chinook salmon lay their eggs (spawn) in freshwater streams in late summer, and then die shortly thereafter. The juveniles hatch around 6 months later and rear in freshwater until they migrate to the ocean, primarily in April and May the following year. During the time from when they leave their freshwater rearing tributaries, to when they arrive at the ocean, they undergo a process called smoltification. Historically this process took a couple of weeks. It allows them to "breathe" salt water.

After 1-3 years in the ocean, the survivors return to the same freshwater streams to spawn and die. Based on counts of spawning salmon in freshwater streams and returning adults from these original spawners, scientists can estimate the survival rates of salmon over their life cycle. They can also compartmentalize that survival into the various life stages: 1) egg to juvenile (rearing in freshwater), 2) downstream migration (smolt stage), 3) survival in the estuary (from below Bonneville dam through the first few months in the ocean), 4) survival during the next 1-3 years in the ocean, and 5) survival during upstream migration as adults.

Direct mortality

For some of the life stages, there is data that can be used to estimate the mortality that occurs in that life stage. For example, for fish that are harvested in the ocean and in freshwater, there are records which can be used to estimate how many fish were caught and killed and thus what the survival rate of salmon was in that life stage. Mortality that occurs in the same life stage as the cause of the mortality is called direct mortality.

Delayed mortality

What is less certain and more difficult to estimate, however, is how a fish's experience in one life stage may affect its survival in a later life stage. This mortality is called delayed mortality and is similar to the case of cigarette smoking and lung cancer. People do not die at the moment they smoke their first cigarette, but may die later as a result of the interaction between this earlier experience and long term health and fitness.

The main reason delayed mortality became an issue is that in 1996 PATH conducted an extensive analysis comparing survival of 6 Snake River spring and summer chinook populations with 6 comparison stocks from farther downstream in the Columbia River. They found that the upstream populations have declined more rapidly than the downstream populations (Deriso et al. 1996). The difference in rate of decline between upriver and downriver populations was greater than could be accounted for statistically by juvenile passage models. The most obvious difference between the 6 Snake River populations and the 6 lower Columbia River populations was the fact that there are 8 dams between the upriver populations and the ocean, but only 1-3 for the lower Columbia River populations. The evidence suggested that the most plausible explanation was some delayed effect from the hydrosystem, and so the unexplained additional mortality came to be known as delayed mortality (Deriso et al. 1996).

Because some objected that this portion of mortality may not be due to the hydrosystem (the mechanisms are discussed in "Key Issues," below), delayed mortality is also referred to as extra mortality.

The dams have sensors that can detect fish that carry tiny emitters about the size of a grain of rice, called PIT tags. These detectors allow researchers to estimate their survival from the top of the hydrosystem in the Snake River (from the uppermost dam, Lower Granite) down to below the lowermost dam in the Columbia River, near the estuary (Bonneville), or over some stretch in-between. PIT-tags carried by returning adults can also be detected. The direct mortality that occurs when these juveniles (or adults) migrate past each of the dams determines the survival in that life stage.

The direct mortality of fish that are transported by barge or truck around the dams appears to be quite low (close to 2%), in fact considerably lower than the direct mortality of fish that travel in the river and have to migrate past the dams. Research shows that in-river survival rates go up with increased flow, and that the more the Columbia River system behaves like a free-flowing river, the higher the survival rates (Cada et al. 1997); depending mainly on flow velocity, in-river smolt mortality ranges from 50% to 67% total for Snake River fish[3].

As discussed above, direct mortality for transported or in-river smolts is only one component of the overall mortality through adulthood. After they leave the estuary, these fish are also subject to very high mortality rates in the near-shore ("early ocean") period, due to a combination of direct effects and delayed effects from migration (transported or in-river). After they leave the estuary, they also suffer what are probably lower rates of mortality as they grow and mature during the next couple of years in the ocean.

Although no one knows when delayed mortality occurs, most people assume it occurs shortly after the fish leave the hydrosystem (from about the estuary through the first few months in the ocean). The current estimate is that delayed effects from the hydrosystem result in mortality rates of 79% to 82% (STUFA 2000).

What is *D*?

It turns out that, although fish that get down to the ocean in barges have a higher probability of reaching the ocean than do fish that go down the river on their own, fish that are transported suffer higher rates of delayed mortality and have a lower probability of returning to spawn. For both groups of fish—those that are transported and those that travel in-river—many scientists believe that the delayed mortality that occurs in the estuary and early ocean is related to their

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[3] The latest CRI matrix models assume direct mortality since 1980 has been over 85%. Previous CRI models assumed it was 67.8%.

experience either swimming down through the hydrosystem or during collection and transportation.

D is the parameter which describes the difference between the delayed mortality of transported fish and fish that migrate in-river. *D* is a ratio. *D* would be equal to 1.0 if there were no difference in estuary and ocean survival between the two groups of fish. If *D* is 1.0, and estimates of delayed mortality are correct, then the estimated delayed effect of the hydrosystem, for barged as well as in-river fish, would be a delayed mortality rate of about 79% to 82% (STUFA 2000). If transported fish survive better after they leave the barges than do in-river fish, then *D* is greater than 1.0. If fish that travel in-river survive better after they leave the hydrosystem, then *D* is less than one.

A major source of confusion in the debate about *D* is that if D=1.0, that does not mean the effect of the hydrosystem is negligible. It only means that delayed mortality of barged fish is no worse than delayed mortality of in-river fish. Even if *D* were 1.0, delayed mortality due to the hydrosystem would still be very high, if the estimates are correct.

In what way would the hydrosystem cause delayed mortality?

There is abundant evidence that fish from higher in the system survive at lower rates from the time they leave their freshwater rearing areas, until they return as spawners, than do fish from lower in the system (Deriso et al. 1996, Marmorek and Peters 1998a, 1998b, Marmorek et al. 1998, Schaller et al. 1999). A variety of mechanisms to explain this difference have been proposed, but the most obvious one is, of course, the hydrosystem. Due to the stress of collection and bypass at the dams, and crowding during transportation in a barge or truck, transported fish may be more vulnerable to disease and predators (Williams 1989). Similarly, Snake River fish that travel in-river must successfully migrate past the turbines, bypass systems, and reservoir predators of 8 hydroelectric dams. Stress or injury from this experience may also cause the fish to be vulnerable to disease and predation, either later down in the hydrosystem or while the fish are in the estuary and ocean.

Mechanisms for direct mortality of in-river fish seem clear enough: irrigation diversions, water temperature, and pollution problems in Columbia River tributaries impair the ability of the juveniles to get from their spawning beds down to the Columbia or Snake River; fish that evolved to find their way to the ocean via a free-flowing river have a difficult time making their way through a series of connected reservoirs (and then back again as adults); large predator populations such as pike minnows (formerly squaw fish) have developed to take advantage of the juvenile fish that are not only concentrated below the spillways but also may be stunned or injured after making their way through a dam; and then of course there are the bypass systems and gas-bubble disease, not to mention the turbine blades.

Researchers at OSU conducted a variety of studies from 1992-1998 in an effort to determine what the post-Columbia River system survival rate is for transported and in-river fish (Schreck et al. in development). They studied how juvenile fish respond physiologically to repeated stressors that they would experience either traveling past or through multiple dams, or traveling in barges; and they tracked radio tagged fish as they traveled down the hydrosystem, and subsequently after they arrived at the estuary.

What they found is that undergoing repeated stressors takes a toll on juvenile salmon just as it does on other animals, and the evidence is in the endocrine system, particularly the cortisol levels. Each time a salmon or a human encounters a stressor, cortisol and other stress hormone levels rise, and then drop after the stressor goes away. As anyone who has come down with a cold or suffered a collapse during a period of prolonged stress can attest, repeated stresses like this impair overall functioning, but in particular the immune system.

Salmon are undergoing a dramatic physiological change during this period as they adapt from the freshwater natal streams to the very different marine environment. Schreck and other researchers found that these stresses can delay or even prevent smoltification, so that the fish have to remain in the estuary longer than they normally would, just in order to complete the maturation process. The evidence is suggestive, but so far not definitive, that what may be happening is that these fish—barged or in-river—arrive at the estuary stressed out, potentially vulnerable to disease, and undergoing the physiological change called smoltification all at once. They may then be relatively easy pickings for predators like Caspian terns and cormorants. Unfortunately for the researchers, they cannot track the tagged fish in seawater. Although they can track them for a ways down through the estuary, once the fish finish the smoltification process, and swim deeper under the seawater, then no one knows what happens to them until they return as adults. Researchers studying Caspian tern predation make good use of information from transponders that end up on one of the islands, to estimate impacts of the terns on wild, hatchery, barged, and in-river fish. As for the smolts that escape such predation, however, the only inferences that can be made about delayed mortality of barged or in-river fish is via the few that were tagged and survive to return 1-3 years later.

One might guess that because barged fish only have to coast down the river in a barge for a few days, compared to in-river fish that take a couple of weeks to get through the 8 dams and reservoirs, that the in-river fish would be much more vulnerable to these stress-related problems. But that is not what Schreck et al. found. Mortality rates in the estuary appear to be just as high for barged fish as for in-river fish, and the physiological evidence of stress is just as bad. Schreck cites several studies that have shown that transportation reduces smolt-to-adult survival due to stress (Schreck et al. 1989), impaired ability to avoid predators (Olla and Davis 1989, Olla et al. 1992, 1995; Mesa 1994, Schreck et al. 1997), preparedness for saltwater (smoltification; McInerney 1964, Schreck 1982, 1992), and disease resistance (Maule et al. 1989, Schreck et al. 1993, Schreck 1996, Maule and VandeKooi 1999).

Salmon evolved to make the freshwater to seawater transition over the period of a couple of weeks, as they migrate down a river to the sea; nothing in their evolutionary history would have prepared them to make that transition in a truck or barge in a few days. The barges stop at lower dams to pick up more fish, and sometimes wait at a dock for days until enough fish migrate down from that tributary. It is difficult to separate chinook smolts from steelhead smolts because, although steelhead tend to be bigger, there is enough size overlap that separator bars used to screen out steelhead also screen out some chinook. Steelhead, bigger and more aggressive, are a major cause of stress to smaller chinook; in the laboratory, adding a steelhead smolt to a tank containing a chinook smolt causes the chinook to go into a panic that is clearly marked by its stress hormone levels. It takes only a few steelhead in a barge to have the same effect, aside from the fact that the steelhead will eat the spring chinook (hence, no doubt, the stress).

The net result of direct and delayed migration effects, as well as the rigors of ocean survival itself, is that since 1980, on average, less than 1 out of 100 outmigrating juveniles has been making it back to the river mouth, and the rate has overall been in decline (Figure 3). In recent years, the average SAR has been about 5/1,000. Today these returnees suffer another 50% or so reduction in numbers migrating back up the Columbia River and lower Snake River to their spawning grounds. Historically 3 to 5 smolts made it back to the Columbia River mouth as adults.

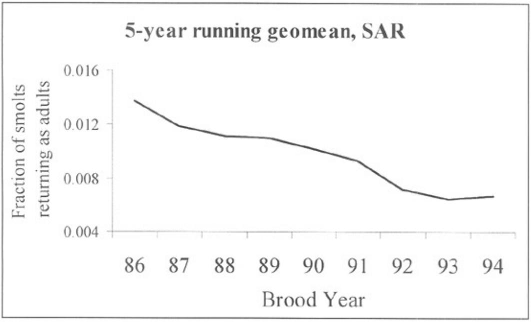

Figure 3. 5-year running average (as geometric mean) of smolt-to-adult return (SAR) rates. Running mean shown for 1986 brood year is the geometric mean of 1982-1986 brood years, and reflects returns through 1989. SAR is given from smolts above Lower Granite, to adults returning to Columbia River mouth.

Mortality rates have thus always been high for salmon, as they are for other animals that produce high volumes of offspring. It is important for decision-makers to distinguish between natural mortality that would be difficult for managers to reduce, and mortality that is caused by human activity (the 4 "H's:" Habitat, Harvest, Hatcheries, and Hydro). Mortality in the first year and a half of life even in good habitat is over 90% (5% is considered good survival for Idaho wilderness streams); in order for the population to persist, over the long run the rate of survival over the entire life cycle has to be high enough for offspring to replace their parents.

There is no disagreement that smolt-to-adult survival rates are too low to sustain these dwindling populations, and that they have been for some time. There is extensive evidence that at least for the Snake River index populations, spawning and rearing habitat quality is, for the most part, at least as good as it was before the dams went in (Schaller et al. 1999). Since transported smolts have higher survival rates than in-river fish down to below Bonneville, and mortality just below Bonneville appears to be about the same for transported and in-river fish, the question about how to save these fish boils down to what happens after that. There has been a great deal of interest in *D*, because *D* is a reflection of whether barged fish survive the ocean as well as fish that have to make their own way down through 8 hydroelectric projects. But the question about whether these populations can survive without breaching 4 Snake River dams, is about total delayed mortality: even if $D = 1.0$, delayed mortality would still be an estimated 80% (STUFA 2000).

What is *D* these days?

The higher *D* is, the better barging looks. Using the most recent PIT tag data, NMFS estimates that *D* is at least 0.8 (Peters 2000), though the most recent CRI report states that a *D* of 0.5 would be optimistic (CRI 2000). Using the same PIT tag data, but different assumptions, other agencies (USFWS, IDFG, ODFW, CBFWA, and CRITFC), estimate that *D* is about 0.59 (Nick Bouwes, ODFW pers. comm. 1999). PATH used a variety of assumptions about *D*, but basically, the value assumed for *D* depended on whether the CRiSP or the FLUSH passage model was assumed. For brood years 1980-1990, the FLUSH model assumed a geomean *D* of 0.27, whereas CRiSP assumed 0.8.

What does this mean for dam breaching?

Ideally, smolts that are transported will return to spawn at least as successfully as those that swam down the river. Unfortunately, although people do not agree on how big the difference is, there is consensus that transported fish have a lower probability of returning to spawn than do in-river fish. The only way to tell which of the returning spawners went out in barges and which swam out as smolts is if they carry PIT tags. PIT tag data are sparse, partly because the sampled populations were small to begin with and partly because the smolt-to-adult survival rate has recently been so low.

In addition, calculating *D* requires making a number of assumptions. Thus, to date there has been no way to get an estimate of *D* that everyone can agree on. State, federal, and tribal biologists have used a variety of different assumptions and models to analyze data collected over the past several years, and PATH conducted a formal Weight of Evidence process to try to come up with an estimate that everyone would accept. They failed.

In contrast to PATH and STUFA, the CRI does not explicitly employ the concepts of *D* and delayed mortality in their analytical framework. Instead, the CRI argues that breaching the 4 dams would have to increase survival through the years in the ocean by 60-120% (depending on other assumptions about current conditions), and asks what field data support the conclusion that such a large improvement can be made. In PATH, dam breaching has a low probability of recovering these fish only if (1) there is no difference between the survival of transported and in-river fish from the time they leave the hydrosystem until they return as adults ($D = 1$), and (2) the overall survival of both groups is unrelated to hydrosystem experience.

Thus, whether barging or dam breaching is likely to save Snake River spring and summer chinook depends in large part on what the true value of *D* is, and whether or not delayed mortality is related to the hydrosystem experience. If *D* is low, then barging produces much lower ocean survival rates than in-river migration. Dam breaching would be necessary if Snake River spring and summer chinook are to have any chance. If *D* is high, then whether or not breaching would be required depends on how much delayed mortality there is, and the cause: high *D* and hydrosystem-caused delayed mortality means breaching would be necessary for saving Snake River salmon. High *D* and some other cause of delayed mortality implies breaching will not be much better than other options.

Uncertainty

PATH, the CRI, and STUFA all came to the conclusion that the biggest uncertainty affecting the dam breaching question is essentially extra, or delayed, mortality[4]. The three processes evaluated uncertainty using different approaches: PATH evaluated uncertainties in a formal decision analysis in terms of how various uncertainties impact the likelihood that DEIS alternatives would meet jeopardy standards. CRI matrix models have not been used to investigate uncertainty per se, but rather to investigate the sensitivity of modeled population growth rates to variation in survival, by life stage. They nonetheless concluded that whether or

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[4] To be precise, PATH identified the two most significant uncertainties as (1) juvenile passage models (CRiSP vs FLUSH), and (2) extra mortality. One of the major differences between CRiSP and FLUSH however, is what they assume about extra mortality: CRiSP is the version that NMFS favors, and it assumes *D* is 0.8. FLUSH scored higher in the Weight of Evidence process, and assumed *D* was a range of values, significantly less than 0.8.

not dam breaching would be necessary for saving Snake River spring and summer chinook depends on whether extra mortality is actually due to the dams themselves, as opposed to some other aspect of the system that would not be addressed via breaching the dams. STUFA both analyzed uncertainties directly and also conducted sensitivity analyses.

Key issues

Recall that the fundamental questions offered at the beginning of this paper were:

Can we save them without breaching the 4 lower Snake River dams?

And if we do breach the dams, will it work?

On one side of the debate are the Corps of Engineers, the entire congressional delegation from the Pacific Northwest, the governors of Idaho, Montana, and Washington, and NMFS (or at least the NWFSC and the CRI).

On the other side of the debate are USFWS, IDFG, ODFW, the Tribes, CBFWA, Idaho chapter of the American Fisheries Society, Oregon chapter of the American Fisheries Society, and Western Division of the American Fisheries Society, most environmental groups, and the governor of Oregon.

The most compelling discussions of the key arguments in this debate are found in two sources: the PATH Weight of Evidence process (Marmorek et al. 1998a), and Schaller et al.'s 1999 paper in the Canadian Journal of Fisheries. The Weight of Evidence process was a formal judgment elicitation effort that was conducted by professional judgment elicitation facilitators using methods from the field of formal decision analysis. It was designed as a way of evaluating the evidence, pro and con, for the uncertainties which their modeling and analysis had determined were most critical. The experts whose judgments were being elicited were well respected, knowledgeable authorities from outside the Columbia and Snake River region. They evaluated arguments presented formally by PATH scientists for and against different assumptions about the critical uncertainties in the PATH decision analysis.

The Schaller et al. paper describes a detailed statistical analysis of temporal and spatial patterns in productivity and survival rates of spring and summer chinook salmon in 3 regions of the Columbia River system: Upper Columbia, lower Columbia, and the Snake. Their analyses indicated that upriver stocks showed greater declines than downriver stocks, and that these declines corresponded to construction and completion of the hydrosystem (Schaller et al. 1999). They argued that this discrepancy could not be explained by habitat quality, harvest, or hatcheries.

To successfully argue that breaching dams is not necessary to save these populations, it would be necessary to show one or more of the following:

1. Schaller et al.'s analysis and conclusions were wrong[5].

NMFS has tried to show that Schaller et al.'s statistical analysis and conclusions are wrong (CRI 2000, Zabel and Williams in review). They argue that upriver and downriver chinook populations are not comparable to one another, and that differences in survival might be due to something other than the magnitude of impact from the hydrosystem. In other words, the reason populations that have to deal with 8 or more dams have declined so much more than populations that have to deal with 1-3 dams in the same mainstem river is not because of the hydrosystem (i.e., the dams, reservoirs, increased migration time, and flow reductions); NMFS is arguing that the upriver stocks are in worse shape than downriver stocks because of some unknown, perhaps genetic difference, or a tendency to go to different places in the ocean.

Schaller et al.'s analysis was extensively peer-reviewed not only through the PATH independent peer review process but also through the prestigious Canadian Journal of Fisheries' publication process, whereas none of the NMFS critique has been formally peer reviewed. Schaller et al. rely on extensive evidence from the literature, and built their analysis within a broad context of stream-type chinook from the Columbia River and Snake River systems as well as Alaska and Canada. NMFS is using undocumented data with admittedly few data points. In contrast, the statistical methods used by Schaller et al. are standard textbook tools, applied to well documented, thoroughly reviewed data.

2. Some other mechanism which had nothing to do with the dams suddenly became effective right after the dams were completed.

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[5] Because previous PATH analyses (Deriso et al. 1996) of some of the same populations came to similar conclusions, it would also be necessary to show that Deriso et al.'s analyses were wrong.

The PATH Weight of Evidence process (PATH Scientific Review Panel 1998) examined the plausibility of other mechanisms extensively, and did not find any of them particularly compelling. They considered 3 hypotheses for the causes of delayed ("extra") mortality: (1) the hydrosystem; (2) some kind of disease or other factors that occurred at about the same time as the dams were completed and will continue into the future, dams or no dams; (3) some kind of climatological pattern that began to have serious impacts around the time the dams were completed, and affected upper Columbia River and Snake River stocks more strongly than lower Columbia River stocks.

What the Weight of Evidence indicated was this: 2 of the 4 experts found the hypothesis that extra mortality is strongly associated with the hydrosystem more plausible because the mechanism is most consistent with historical data and the explanatory mechanism is clear. The other two experts also found the hydro hypothesis plausible as well, but no more plausible than the hypothesis that extra mortality is caused by irreversible effects due to disease, genetic changes, or habitat changes. None found the hypothesis of a climatological change convincing.

3. <u>Snake River spring and summer chinook could be saved, without breaching the dams.</u>

The CRI has examined this possibility extensively, concluding most recently that "...drawdown [dam breaching] and the habitat/harvest actions are roughly equivalent in their effect on population growth, and neither, by themselves, is likely to recover Snake River chinook salmon" (CRI 2000, p. 61). STUFA also examined this possibility. While they disagreed with NMFS that any combination of actions short of dam breaching could be equivalent to dam breaching, they agreed with PATH that the only management options that had a significant chance of preventing extinction were those that included dam breaching (STUFA 2000).

Here is a summary of the debates about the key evidence in this debate.

1. As more dams were built, the declines got worse for Snake River and Columbia River spring and summer chinook. After the last Snake River dams were completed, declines got even worse for populations that are farther up the river.

There is no question that Snake River spring and summer chinook populations have been declining since the completion of the upper Columbia River dams (1968) and Snake River dams (1975). There is evidence of declines that started in the 1950's, and the aggregate rate of decline has increased as the number of dams completed increased. The rate of decline has accelerated noticeably since the late 1960's, and Schaller et al. (1999) showed that the overall survival rate of upriver stocks became sharply worse after the last dams were completed. They also showed that this change in survival did not occur for downriver stocks.

Other human impacts have, of course, also increased in this region: urbanization, pollution, logging, grazing, perhaps even global warming (harvest levels were high early on but have been very small during the recent period of dramatic decline). There is no doubt about the extent of human impacts throughout the Pacific Northwest, but if the more serious rate of decline for upriver stocks were correlated with human impacts, then the Snake River stocks that spawn in wilderness areas should be doing better than lower river stocks that spawn in areas subject to grazing, logging, and water quality problems, not worse.

Some argue that one of PATH's and Schaller et al.'s major arguments is simply wrong, that the decline did not in fact start when PATH and Schaller et al. say it did, but rather, long after hydrosystem development was complete[6], starting with the 1975 brood year (Zabel and Williams in review). To make this point, they use a simple graph of ln(R/S), in contrast to the statistical analyses Schaller et al. did. This graph is so "noisy" that it is hard to say exactly what it shows, which is one of the reasons biologists use statistical analyses to draw conclusions. Analysis of covariance (ANCOVA) analyses described in Schaller et al. show clearly that the declines began for Snake River and upper Columbia River stocks around the late 1960's, becoming most distinct in the mid-1970's (panels (a) and (b) in Figure 5). They also show that although lower Columbia River stocks were quite variable, they did not exhibit a trend (panel (c) in Figure 5).

[6] The last upper and lower Columbia River dams were completed in 1968, the last Snake River dam was completed in 1975.

Zabel and Williams also ignore the role of density dependence[7] in survival rates as well as the fact that it is not only the number of dams that were important to the upper Columbia River declines, but also the increased number of turbines (more turbines were added to existing dams) and decreased flows from the upper Columbia.

[7] "Density dependence" means that survival rates decrease as a population approaches or exceeds carrying capacity, and increase at lower population densities. A related phenomenon is depensation, in which population numbers get so low that instead of increasing, survival rates decline dramatically because reproductive success declines (there are so few fish that they can't find mates, for example).

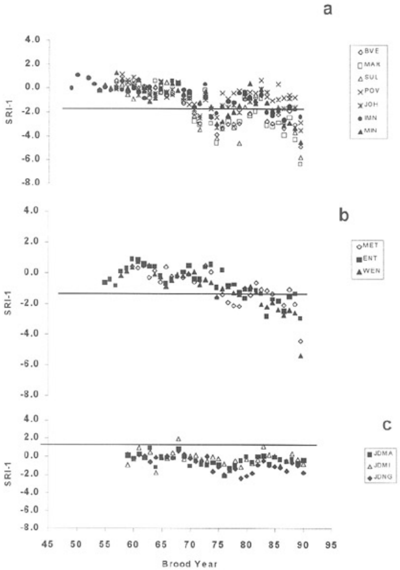

Figure 5. Deviations of ln(observed R/S)/predicted (R/S)] from ANCOVA fit to the pre-1970 data for the (a) Snake, (b) upper Columbia, and (c) lower Columbia regions, brood years 1949-1990. Abbreviations are: MIN, Minam; IMN, Imnaha, BVE, Bear Valley; MAR, Marsh; SUL, Sulphur; POV, Poverty Flat; JON, Johnson; WEN, Wenatchee; ENT, Entiat; MET, Methow; WIN, Wind; KLI, Klickitat; WS, Warm Springs; JDMA, mainstem John Day; JDMI, Middle Fork John Day; JDNG, North fork John Day. From Figure 5 in Schaller et al. 1999 (p. 1039).

2. It's unlikely the declines were caused by poor spawning and rearing habitat quality for Snake River stocks.

Schaller et al. (1999) and PATH (Marmorek et al. 1996, Marmorek and Peters 1998a, 1998b, Marmorek et al. 1998) showed that most Snake River spawning and rearing habitat degradation had occurred before the dams were completed. They also showed that patterns of decline were similar for populations in degraded and good habitat. But the clearest picture of what might have caused these declines may be a comparison of survival rates for the freshwater and ocean parts of the life cycle (Figure 7).

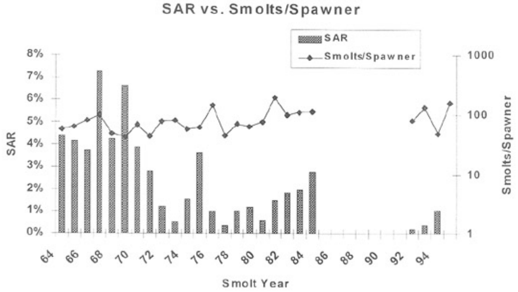

Figure 7. Patterns of SAR and smolts/spawner (natural log scale) for Snake River wild spring/summer chinook, smolt years 1962-1994. Smolt/spawner estimates represented by SP1 and FGE = 0.56 assumptions. "Smolt year" is the year of outmigration, namely 2 years after "brood year" (the year the smolts were spawned). No SAR data were available for 1986-1992. (Sources: Petrosky and Schaller 1996, 1998; Raymond 1988).

The freshwater survival rate is represented by smolts per spawner, and the ocean survival rate is

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[8] "Density dependence" means that survival rates decrease as a population approaches or exceeds carrying capacity, and increase at lower population densities. A related phenomenon is depensation, in which population numbers get so low that instead of increasing, survival rates decline dramatically because reproductive success declines (there are so few fish that they can't find mates, for example).

represented by smolt-to-adult returns (SAR). Figure 7 shows that what changed for Snake River spring and summer chinook after the dams were completed was the SAR survival rate, not the egg-to-smolt (freshwater) survival rate.

Downstream migration and delayed mortality are included in SAR, and so the analysis summarized in Figure 7 supports the contention that it is not freshwater habitat that is somehow the cause of delayed mortality, nor of the decline of Snake River spring and summer chinook.

It is also important to note that upstream migration could also play an important role. Currently only about half of the adults arriving at the Columbia River mouth make it to above Lower Granite dam. The main source of mortality for them is due to the rigors of migrating back up through the 8 dams and reservoirs, though there is also an additional harvest mortality of about 8%.

It is not known how much the upstream migration mortality would be reduced by breaching the dams, but Marmorek et al. (1998) estimated that adult survival through the Snake River (from the Columbia River confluence to the spawning grounds) before the dams were built was around 97%. He based this on a comparison of historical and current survival rates between Ice Harbor dam (the lowest dam on the Snake River) and the spawning grounds. Without the dams, that would translate to about a 94% upstream survival rate from the ocean to spawning grounds, compared to about 48% today (ignoring mortality from Lower Granite to the spawning grounds).

Although the CRI relies on the constant percent sensitivity analysis method and its indication that egg-to-smolt and early ocean survivals are the most important, the textbook sensitivity analysis method (elasticity) indicates that adult survival is the most important variable (CRI 2000). The reason that elasticity is widely accepted is because at this point in the life cycle, each spawner represents a tremendous investment on behalf of the species in the next generation; the loss of over half the population at this point in the life cycle is important.

4. It's unlikely the declines were caused by hatcheries or harvest.

On a regional basis it is impossible to separate the effects of overall hatchery production and dam construction (since they occurred hand-in-hand). However, Schaller et al. (1999) and PATH (Marmorek et al. 1996, Marmorek and Peters 1998a, 1998b, Marmorek et al. 1998) found little to no correspondence between hatchery production and declines in individual sub-basins. If hatcheries or harvest were the driving mechanism behind delayed mortality, then it would be necessary to explain how hatcheries or harvest impacted upriver stocks more than downriver stocks, or transported fish more than in-river fish. It is also unlikely that hatchery effects would have affected only smolt-to-adult survival but not egg-to-smolt survival, as indicated in Figure 7.

5. It's unlikely the declines were caused by Snake River fish going to different, more hazardous places in the ocean than lower river fish.

NMFS suggests that there is evidence that upper and lower river stocks go to different places in the ocean, and that this could explain the differential mortality (Zabel and Williams in review). They base this argument on a small, undocumented set of ocean harvest data. The dataset NMFS used indicates recovery proportion differences at the sixth decimal place, and applies only to adult fish, whereas year class strength is widely believed to be determined by the estuary and early ocean environments, where all these stocks overlap in space and time.

PATH studies indicated that data on where these fish go in the ocean is too sparse, and catch data is not representative. One of the main reasons catch data is not representative is that the period of most interest is the first few months when the young fish first get to the ocean, and not a year or two later when they would be harvested. PATH studies also indicated that statistical tests have failed to show a relationship between where they end up being harvested, and total smolt-to-adult survival rates (Marmorek et al. 1998a).

6. It's unlikely the declines were caused by Snake River stocks staying in the ocean longer.

Snake River stocks are more likely to return at age 5 than age 4 (Beamesderfer et al. 1996), giving ocean mortality additional time to affect Snake River fish. There is no evidence about survival versus years in the ocean. There is, however, evidence that most ocean mortality happens within the first few months in the ocean, in that the size of the returning three-year-old population ("Jacks") is a good predictor of how many 4- and 5- year-olds from that same brood year there will be. CRI (CRI 2000), Schaller et al. (1999), STUFA (2000) and PATH (Marmorek et al. 1997) sensitivity analyses have all indicated that analytical results were relatively insensitive to age structure assumptions.

7. It's unlikely the declines were caused by Snake River stocks simply having to travel a lot farther

Schaller et al. examined 52 years of stream-type chinook runs: 7 from the Snake, 3 from the Upper Columbia, and 6 from the Lower Columbia. Poor ocean and climate conditions existed during the early part of this series, and also again in the period since the late 1970's. They found that despite heavy harvest levels and poor climatic conditions, productivity and survival rates of the upriver stocks were relatively stable until major hydropower development began. Because upriver chinook runs are heavily weighted by populations that have to migrate the farthest, we would expect that under periods of climatic stress, they would have exhibited a dramatic downturn, compared to populations farther down in the system. But they did not. Only since the dams have been completed have the upriver populations declined more than the downriver populations.

If travel distance were the reason that upper Columbia River and Snake River stocks are in worse trouble than lower Columbia River stocks, then historical data would show this pattern. And there would be some plausible way to explain the pattern developing only after the hydrosystem was completed, not before. If anything, upriver stocks were historically more productive than downriver stocks, not less (Figure 5).

8. We cannot resolve this uncertainty in time by gathering more data.

There already is a tremendous amount of data, not to mention analysis, about the many factors that may have played a role in bringing almost all salmon populations in the Pacific Northwest under the umbrella of the ESA; but so many of those factors are confounded with one another that scientists cannot agree on their relative contributions to the problem, let alone predict how efforts to change them would play out. Even where extensive data over a long time period are available, and have been exhaustively analyzed and reanalyzed by some of the best scientists in the country, some continue to debate the validity of the conclusions.

The most fundamental experimental design question is:

How much more data would it take for decision-makers to accept the results?

Experimental design requires defining clearly what the questions are, and how likely it is that a particular experiment will answer those questions. The analyses by PATH, the CRI, and STUFA have produced a remarkable consensus on what scientists would like to know, and all 3 concluded that the key uncertainties driving the dam breaching question have to do with delayed mortality. Delayed mortality involves two critical issues: (1) basic evidence of delayed effects of the hydrosystem; and (2) mortality of transported smolts compared to in-river migrants (*D*).

PATH and NMFS have both begun the process of designing experiments to address the most critical uncertainties (CRI 2000, Peters et al. 2000), and it may be useful here to give an example of what might be involved in resolving one of the most important uncertainties, namely *D*. *D* is not a parameter that can be measured. *D* is a calculated estimate that requires knowing many things. For example: how many smolts are picked up by barge at Lower Granite, Little Goose, and Lower Monumental dams during at least the 2-month migration peak? How many smolts travel through the hydrosystem before they are picked up by barges, at each pickup point? How many smolts travel all the way through the hydrosystem on their own? And what are the survival rates to adulthood for each of those groups? Other factors that could affect the results are inter- or intra-annual variation in Fish Guidance Efficiencies[9], spill effectiveness, and collection system survival; inland and ocean climate patterns; and adult migration survival rates. Schreck et al. (in development) found that survival rates drop during the April-to-June migration peak, and so that might have to be taken into account as well. And finally, there is considerable interest in hatchery vs. wild fish survival rates.

The only way to estimate these fractions and survival rates for smolts is through PIT-tag tracking. Hatchery fish can be PIT-tagged at the hatchery, but wild fish have to be intercepted and tagged at some collection point. There aren't very many wild fish left, and tagging a large enough sample of non-hatchery fish is a problem. And finally, on average, less than 5 out of 1,000 smolts has recently been making it back to spawn (Figure 3; C. Petrosky, IDFG, pers. comm.); in 1999 the total run of Snake River index populations consisted of about 652 spawners at the Columbia River mouth. About half of those would survive to the spawning grounds. Thus, determining the smolt-to-adult return rates for transported versus in-river fish becomes more problematic. Data would be needed from multiple run years, and then because the adults do not return for 1 to 3 years, it would be close to a decade before the first data collection was

[9] FGE: the rate at which in-river smolts who have ended up in the powerhouse of any of the 3 Snake River dams are diverted to the barges—the remainder go through the turbines.

complete[10].

How many smolts would need to be tagged? Sample size calculations depend on experimental design requirements such as how exact a prediction is needed and how confident decision-makers need to be in the result, as well as what the hypothesized values are that are being tested. To take a simple example, assuming the true *D* is as high as NMFS thinks it is (at least 0.8), in order to be able to tell if the true *D* is less than 0.65 (which the other agencies think it is), just for one year, for one dam, would require tagging 114,800 barged smolts and 183,600 in-river smolts (Peters et al. 2000). To get some idea of how this sample size relates to the population, if this is a typical year, next spring there will probably be no more than about 35,000 smolts total migrating out from all 7 index streams[11]. The index populations make up about 10%-20% of the total Snake River run, and wild fish make up about 10%-15% of the total.

Paul Wilson (CBFWA) carried these calculations out in more detail to estimate how many years of study might be required, and he found that if the true *D* is actually what NMFS thinks it is, it could take over 40 years of data to determine that they're right; but if *D* is actually closer to, or less than what the other agencies think it is, it would take even longer (and/or the sample sizes would need to be larger). If the populations continue to decline, CRI risk estimates indicate that many of the Columbia and Snake River stocks could be gone by then (CRI 2000).

This is not an argument that such experiments are not needed. The issue is that these populations are already in steep decline, with high probabilities of extinction, even with what NMFS admits are optimistic extinction models. PATH and STUFA have concluded that although experiments like these are important, CRI's own extinction analyses show that waiting for such experiments to be designed, carried out and analyzed, means accepting a high probability of extinction in the meantime for many of the Columbia and Snake River salmon populations.

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[10] Some tagged fish have returned from earlier years, already, and although the numbers are very small, these returns are the source of the estimates of *D* that are now so contentious.

[11] 652 (adults at the Columbia River mouth in 1999) * 0.5 (Bonneville-basin survival, harvest, prespawning mortality) * 0.5 (females) * 0.9 (prespawning mortality) * 4700 (eggs) * 0.05 (egg-to-smolt) = 34,470. The index streams are the 7 streams in the Snake River basin analyzed in PATH, the CRI, and STUFA models.

Conclusions

Ed Bowles (IDFG) summarized the debate with a Powerpoint presentation that included a summary of what he called "dueling hypotheses." Originally the "duel" was said to be between BPA and the state and federal agencies, but since other parties have joined the fray, a revised version of that is shown in Figure 9.

Dueling Hypotheses

NMFS, BPA, COE	USFWS, CBFWA, CRITFC, ODFW, IDFG
Smolt transport has fixed the dams.	Smolt transport has not mitigated for the dams.
Little or no delayed mortality associated with transportation. Mortality: 1. Occurs in the ocean, 2. Is unrelated to the dams,	Mortality is due to the stress of collection & transport, and reservoir & dam passage.
3. Selects Snake River fish, 4. Wasn't there before the dams.	The ocean/estuary is important, but not selective for Snake River fish.

Figure 9. Summary of dueling hypotheses (source: talk given by Ed Bowles [IDFG] at the 1999 Western Division annual meeting of the American Fisheries Society).

What Figure 9 indicates is that the debate is between people who think barging solves the delayed mortality problem, versus people who think it doesn't. In order to accept that barging works, and thus that saving Snake River spring and summer chinook would not require breaching the dams, one has to accept that there is little or no delayed mortality suffered by barged fish, and that what delayed mortality there is (1) occurs in the ocean, (2) is unrelated to the dams, (3) primarily affects Snake River fish but not John Day, Deschutes, Klickitat or Wind River fish, and (4) was not there before the dams.

Scientists from IDFG, ODFW, USFWS, CBFWA, and CRITFC do not find it plausible that something in the ocean, independent of the hydrosystem, grew in importance as the hydrosystem was developed, and preferentially kills Snake River and upper Columbia River salmon. The Oregon chapter of the American Fisheries Society unanimously endorsed a resolution that agreed with these state, federal, and tribal agencies, and the Idaho chapter and Western Division chapter passed similar resolutions. These scientists believe that barging has not fixed the problem, and that delayed mortality is most likely due to effects of the hydrosystem—in particular, the stresses of collection and transport for barged fish, or reservoir and dam passage for in-river fish, let alone upstream migration for returning spawners. Finally, spawning habitat quality has not followed the pattern that smolt-to-adult survival has followed, which indicates that the most plausible explanation is the hydrosystem, and that barging has never worked.

Perhaps because delayed mortality is a complicated issue, people often debate about *D*, not recognizing that the problem is not *D*. The problem is the source of delayed mortality. If delayed mortality is caused by the hydrosystem, then even if (1) all fish were barged, and (2) *D* equals 1.0, it only means that barged Snake River fish fare no worse after they leave the hydrosystem than fish that swam down through (and returned through) 8 hydroelectric projects would have. There would have to be almost a 3-fold increase in survival, and it would have to occur for many years (likely for decades), in order to have confidence that *D* is as high as NMFS hopes it is. Scientists agree that a 3-fold increase in survival is also approximately the same increase in life-cycle survival that is needed to recover these populations.

Even if *D* is as high as NMFS hopes, it would not be enough to save Snake River spring and summer chinook unless barging also greatly reduces delayed mortality. There is, to date, little evidence that it does. The required 3-fold increase in survival is not likely to come from freshwater habitat improvements because many of the few remaining populations spawn in good habitat already; the CRI says little increase in direct survival is likely to come from mainstem passage improvements, even with 100% barging (CRI 2000); harvest of these populations has already been almost eliminated; and there is no imaginable way for human management efforts to do anything soon about direct mortality in the ocean.

That leaves upstream migration and delayed mortality. Upstream migration losses are now over 50%, whereas historically they were probably less than 10%. If delayed mortality for juveniles is as high as analyses and models suggest it is, then barging has not even come close to allaying it, and there is no evidence that it soon will.

It is highly likely that these populations will continue to exhibit high rates of variability: it is probably just as likely that they will experience a few years of higher survival, as it is that they will experience a few years of worse survival. If they experience the same, or worse, survival rates compared to the average over the past 20 years, then several more Snake and upper Columbia River populations will most likely be gone before too long (Mundy 1999, CRI 2000). If they experience better survival rates, which it is hoped (as it has been hoped since the early 1980's) that improving ocean conditions will provide, the debate will still not be over.

Because survival rates of these populations are so inherently variable, it would take many years to have much confidence that the problem of delayed mortality has been solved. If agencies other than NMFS (i.e., the state, federal, and tribal agencies identified above), and the American Fishery Society scientists who voted to support those resolutions, are right, then the problem of delayed mortality will not be reduced significantly until the dams are breached.

If the dams are not breached—and soon—then if these agencies and professional organizations are right, the good news is that the debate will soon be over. The bad news is that it is difficult to imagine anyone feeling that they have won.

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