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To : Ed Bowles, Ron Boyce, ODFW

From: Chris Peery, Matt Keefer, and Chris Caudill, University of Idaho

Re: Summary of Survival of Returning Adult Salmon and Steelhead in Columbia River

Date: 5 October 2005

The University of Idaho and NOAA Fisheries have monitored adult salmon and steelhead behavior and survival in the Columbia and Snake River drainages since 1996. During this period, more than 18,000 fish have been radio-tagged, monitored and the fates of individual fish have been assessed. Monitored groups have included spring, summer, and fall Chinook salmon, steelhead, and sockeye salmon. Samples from later years have included adults that were PIT-tagged as juveniles at known locations, allowing us to assess behavior and survival for individuals with known homing destinations. The tagging program has included several ESA-listed stocks. This work has been funded primarily by U.S. Army Corps of Engineers, Bonneville Power Administration with support from the Pacific Salmon Commission, Bureau of Reclamation, NOAA, USFWS, and others. Additional information related to research results described here can be found at, http://www.cnr.uidaho.edu/uiferl/. Following is a summary of some of the major findings.

SURVIVAL, HARVEST, AND PRE-SPAWN MORTALITY

● ***Survival.*** Survival through the Columbia River Hydrosystem (Bonneville Dam to Lower Granite or Priest Rapids dams) averaged 73% for spring–summer Chinook salmon, 61% for fall Chinook salmon, and 63% for steelhead and can vary significantly among years (Figure 1). Fish that do not reach spawning areas are lost to harvest and other causes. Lately, losses to predation from pinnipeds downstream from Bonneville Dam, and late migration mortality upstream from the Hydrosystem have been areas of concern.

● ***Harvest***. Harvest in the main stem Columbia and Snake rivers have averaged 9% for spring–summer Chinook salmon, 22% for fall Chinook salmon, and 15% for steelhead. An additional 3–6% of radio-tagged fish have been harvested in lower river tributaries. These estimates should be considered minimums, because harvest reports have been voluntary, with reward incentives.

- Although considerable effort has been invested in monitoring harvest, accurate estimates are difficult to collect and verify. Unreported and illegal harvest does occur in the basin. Delayed mortality associated with fisheries (i.e. following sport releases, contacts with gill nets, etc.) has not been well studied.

● ***Non-Harvest Mortality.*** After accounting for fishing mortality, an average of 12–17% of adults died before reaching spawning tributaries or exiting the monitored Hydrosystem. Causes for these mortalities are unknown, but likely include extended migrations, stress from elevated

water temperatures, energetic exhaustion, disease, unreported harvest, delayed mortality due to injuries sustained during fallback or from encounters with fisheries, or other factors. Survival for all runs has tended to be lowest in the lower Columbia River and higher through lower Snake River reaches. Factors correlated with fish loss are discussed in more detail below.

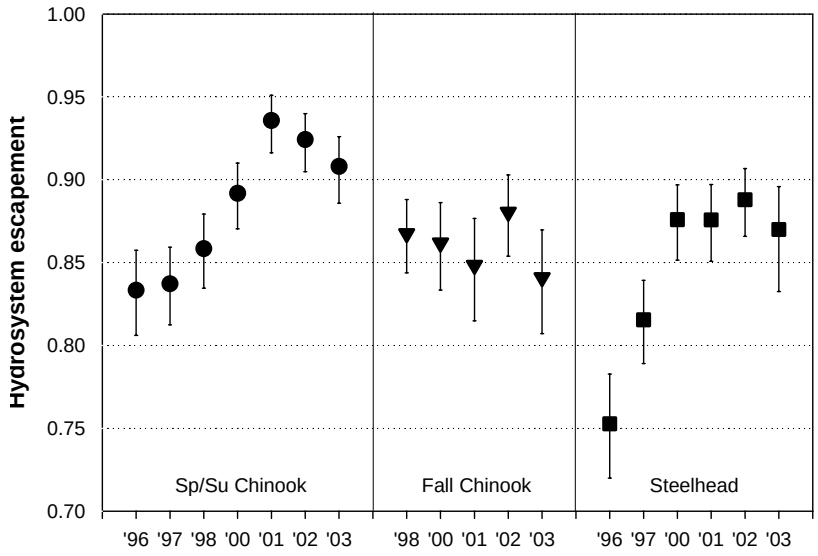

Figure 1. Average escapement for adult spring/summer Chinook salmon, fall Chinook salmon, and steelhead through the Federal Columbia River Power System, adjusted for known commercial and sport harvests.

● ***Pinnipeds.*** The proportion of adult salmonids consumed by pinnipeds in the near vicinity of Bonneville Dam during spring (1 January to 31 May) has trended upward; 0.3%, 1.1%, 2.0%, 3.4% during the four years 2002-2005, as reported by USACE Fish Biologist Robert Stansell. Actual population level impact from pinniped predation on salmon is difficult to estimate because predation levels downstream from Bonneville have not been documented.

- o Measures are being evaluated at Bonneville Dam to deter pinnipeds from feeding on salmon and from interfering with salmon migrations.

● ***Pre-Spawn Mortality.*** Additional mortality occurs upstream from the Hydrosystem and prior to spawning, but quantitative summaries of these components of adult survival are conspicuously limited. Intensive surveys of spawning areas in the South Fork Salmon River, Idaho, reveal 25 to 60% of successful Chinook salmon migrants die before spawning each year. A study is underway to determine how migration history, water temperatures in and upstream from the Hydrosystem, and fish energetics are related to pre-spawn mortality for this population.

- o Similar studies with other populations are needed.

● ***Straying***. Permanent inter-basin straying is a challenging component of assessing adult survival because they could be considered either successful migrants (they reached a spawning area) or unsuccessful migrants (they did not home to their natal site). On average, 2–4% of known-origin spring–summer and fall Chinook salmon and 7% of steelhead in the radiotelemetry study strayed into non-natal basins where they may have spawned with native stocks. Hatchery

fish and fish transported (barged) from the Snake River as juveniles were more likely than other groups to stray. Many strays entered the Deschutes and John Day rivers, where some wild populations are considered at risk.

● ***Wandering.*** In warm years and during warm periods within years, large proportions of summer and fall Chinook salmon and steelhead runs encounter temperatures considered stressful for salmonids. In response, many fish seek cool thermal refuges—and particularly cool non-natal tributary streams. During the warmest times, majorities of the fall Chinook and steelhead runs concentrate in these refugia, where they may be highly vulnerable to harvest. While the behavior likely has immediate energetic benefits, delays and elevated harvest risks during warm water periods may lead to overall decreases in system productivity. There is some evidence that survival consequences of high temperature exposure may be greater for obligatory migrants like Chinook salmon than for steelhead, which migrate many months in advance of spawning.

EFFECTS OF DAMS AND OPERATIONS

● ***Passage Rates.*** Most adult salmon and steelhead pass individual dams in 1 to 2 d, and pass quickly through reservoirs. However, a proportion of each run (typically between 2–12%) has taken several days to weeks to pass individual dams. Fish that take a relatively long time to pass individual dams were less likely to migrate successfully to spawning tributaries. Similarly, relatively slow passage through the lower Columbia Hydrosystem (multiple dams and reservoirs) was associated with unsuccessful migration. Though causation is unknown , the association described above may have resulted from inadequate passage facilities 'delaying' some individuals, the expenditure of large amounts of energetic stores, and resulting in premature death. Alternatively, individuals in poor condition at river-entry may have been both slow and less likely to reach spawning grounds, regardless of passage conditions at dams. Studies are on-going to determine the relative roles of these two mechanisms.

- Improving passage efficiency has been a management goal, and incremental improvements to fishways (transition pools, count windows, entrance and exit conditions) and operations (spill, fishway temperatures) are being studied and implemented.
- It is important to note that fishways were designed for adult salmonids and most improvements have also been directs towards these strong swimmers. However, increasing concern over Pacific lamprey passage and survival through the Hydrosystem may require substantial changes and/or fishway modifications.

● ***Fallback.*** Some fish from all runs pass dams and then fall back downstream. Approximately 22% of spring–summer Chinook salmon, 15% of fall Chinook salmon, and 21% of steelhead fell back at one or more dams during migration. Fallback is associated with both direct and delayed mortality, slowed migration rates, and increased likelihood of straying. Fallback rates have been highest in years with high river flow and high spill at dams, at least in part because most fish fall back via dam spillways. Fish also appear to fall back as a result of orientation errors, including failure to locate natal tributaries and imprinting problems associated with juvenile barging. Providing benign downstream passage routes for these individuals could lessen the survival costs of fallback.

- Operational changes may help reduce fallback and therefore increase overall survival, but it is unclear how large a reduction is possible given the management constraints.

● ***Juvenile Barging.*** Currently, about 70% of juvenile migrating seaward in the Snake River are collected and transported by barge below Bonneville Dam. Returning adults which had been barged as juveniles were ~10% less likely to migrate to spawning grounds, exhibited less direct migrations, and strayed to non-natal tributaries at rates that were approximately twice that of adults that had migrated in the river as juveniles. Barging probably interrupts the 'sequential imprinting' process whereby adults use olfactory memories from the juvenile seaward migration during homing. It should be noted that fish used in this study are captured at the Washington shore fish trap which may have influenced our results.

● ***Spill.*** Results three years when spill levels were manipulated at Bonneville Dam suggest that high spill volumes (>100 to kcfs at Bonneville) increase adult passage times slightly compared to moderate spill volumes of ~75 kcfs. Higher spill was also associated with higher fallback rates in spring Chinook salmon and in steelhead. As already noted, longer passage times and fallback events have been associated with lower survival for individual fish.

● ***Summer Spill.*** Preliminary results from the adult radiotelemetry project suggest that moderate spill during summer would likely have only a limited impact on adult passage. Summer Chinook salmon also exhibited slight increases in passage time and fallback rate at high spill levels at Bonneville dam. However, these effects should be weighted against the potential benefits of limited spill for those adults that volitionally fallback (i.e. those that overshot natal tributaries) because fallback via spillways is more benign than through turbines.

● ***Fishway Temperatures***. Elevated water temperatures and large temperature differentials (between the top and bottom of ladders) in dam fishways can deter passage. Mean passage times for spring-summer Chinook at Lower Granite Dam increased from 6.6 hours when temperatures at the ladder exit were similar to those at the base of the ladder, to 19.1 hours when exit temperatures were $\geq 2^{\circ}$C warmer than at the base. Similarly, the proportion of fish requiring more than one day to pass the dam increased from 32.7% with no temperature barrier to 71.4% when temperatures differed by $\geq 2^{\circ}$C. Greater numbers of fish reject fishways at John Day Dam when water temperatures exceed 18ºC. Temporary temperature barriers contribute to adult passage delay that may result in permanent straying to downstream sites or migration failure.

● ***Dissolved Gas.*** High spill at dams can create supersaturated dissolved gas condition in tailraces and downstream areas, and there is concern that fish that encounter these conditions may develop gas bubble disease. Results from an archival tag study that monitored fish swimming depths suggest that adults do not avoid plumes of high dissolved gas and frequently experience high dissolved gas conditions. However, most adults remained at depths that provided adequate "hydrostatic compensation" and consequently prevented expression of gas bubble disease. Little is known about the effects of the observed frequent, but short, exposures to supersaturated conditions.

- o Addition of flow deflectors and increased use of surface flow weirs at spillways should moderate dissolved gas conditions in the system. Additional study of this issue may be warranted given the incidence of gas bubble disease symptoms in adults in some years.

RIVER AND OCEAN ENVIRONMENT

● ***Flow and Survival.*** Adult Chinook salmon appear to have lower Hydrosystem survival in years with high flow (discharge). This pattern is probably the result of higher fallback and slower migration rates in high-flow years, two energetically demanding aspects of migration. Survival for runs that migrate during typical low-flow times (most fall Chinook salmon and steelhead) has not been correlated with river flow.

● ***Temperature and Survival.*** Water temperatures in the Columbia and Snake Rivers have been increasing since dam construction began due to development and management of the Hydrosystem as well as from regional climate and water use patterns, resulting in longer summers and higher summer temperatures. Adults returning in the late spring, during summer, and in the early fall frequently choose the coolest water available to them to migrate in, but still frequently encounter stressful temperatures. Higher temperatures were associated with altered migration behavior and lower migration success. Predictions for continued warming will probably adversely affect migrating adults because migration through stressful temperature conditions requires more energy and may contribute to higher rates of prespawn mortality.

- o A study is underway to evaluate effects of temperature exposure on gamete quality and spawning success.
- o Cool water releases from Dworshak Reservoir, Idaho, can moderate temperatures somewhat in the lower Snake River.

● ***Temperature and Straying/Wandering Behavior.*** Interactions between river temperatures and wandering/straying behaviors were outlined above. Use of non-natal cool-water refugia will continue and possibly increase if current temperature trends persist.

- o Managers should be aware of the use of cool-water refugia streams relative to habitat and fisheries management actions for these areas.

● ***Ocean Conditions.*** Ocean conditions have strong effects on salmon. Much of our monitoring program has been conducted on adults returning after "good" ocean conditions. Consequently, the results may represent the "best case scenario" because fish were probably returning in good condition. If so, a future downturn in ocean conditions may be associated with a downturn in adult condition with subsequent effects on adult performance.

- o We are in the process of trying to evaluate effects of ocean conditions and initial fish energetic state on migration and reproductive success.

ENDANGERED SPECIES ACT CONSIDERATIONS

● ***Survival and Harvest.*** Many of the topics described above have important implications for ESA-listed populations in the Columbia basin. Many regulations are in place to protect listed stocks, but it is not clear that all are effective, as many populations continue to decline. The radiotelemetry results suggest that some listed populations may be harvested at unexpectedly high rates (i.e. upper Columbia River steelhead, Snake River fall Chinook salmon), and low survival to spawning for these groups may be slowing recovery.

● ***Straying.*** High water temperatures, juvenile barging, and fallback at dams have all been associated with increased straying by adult salmon and steelhead. Straying is an important

management concern in the basin, due to the potential for increased interbreeding between ESA-listed stocks and non-listed stocks, especially those of hatchery origin.