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MEMORANDUM

TO: Olney Patt Jr.

FROM: Michele DeHart

DATE: September 29, 2004

RE: Comments on Draft Biological Opinion

In response to your request the FPC staff has reviewed the Draft Biological Opinion and offer the following comments for your consideration. In accordance with our normal procedures, a copy of these comments are being provided to the Fish Passage Center Oversight Board and Fish Passage Advisory Committee and posted on the FPC website.

I. The proposed measures contained in the DRAFT Biological Opinion do not avoid jeopardy. This Draft Biological Opinion is based on a flawed concept and insufficient scientific analysis.

Section 7(a)(1) of the Endangered Species Act (ESA) mandates that all federal agencies "insure" that all actions they authorize, fund, or carry out are not likely to "jeopardize the continued existence of" listed species or "result in the destruction or adverse modification" of critical habitat of threatened and endangered species. The Federal Columbia River Power System (FCRPS) is responsible for adversely modifying the critical habitat of ESA listed salmonid species. Consequently, in the present configuration of the power system the continued operation of the FCRPS is likely to jeopardize the continued existence of the species. Unlike previous versions of the Biological Opinion (BiOp), this current draft steps away from biological criteria for determining jeopardy and establishes criteria that are limited by the continued and uninterrupted operation of the present hydrosystem. The Draft BiOp throws in additional vagueness of interpretation by adopting what is referred to as a "regulatory definition" of jeopardy stating that the proposed action cannot "appreciably reduce" the likelihood of survival and recovery of the ESU. However, the method of interpreting jeopardy in the draft BiOp does not even address the proposed regulatory definition. The Draft 2004 BiOp establishes a biological baseline to describe the impacts of the federal power system on juvenile salmonid survival. The biological baseline is described as the juvenile survival obtained in the base period of 1994 to 2003 in a hydrosystem configuration as developed in 2004. This baseline capitalizes

on the recent good ocean conditions that yielded increased numbers of adult returns. These ocean conditions compensated for the effects of the hydrosystem and the net effect is setting the biological baseline too high. The BiOp then develops a theoretical operation of the power system (reference operation) that is purported to operate the hydrosystem in a way that maximizes the survival of all ESU's. It is difficult to interpret this reference operation and its role in providing maximum survival because of the constraints imposed in its development. These constraints include:

1. Limiting maximum flows to those what could be obtained under current waiver standards for total dissolved gas. The BiOp does not address the flow potential if the waiver standard was increased, or if the hydrosystem was altered to remove projects (dam removal or drawdown) in order to remove the requirement of a total dissolved gas waiver.

2. The addition of 24-hour spill at all the projects in the summer is not included. Spreading the risk for summer migrating juveniles is not included in the Snake River or at McNary Dam. Data suggest that the benefits of summer spill for fish passage have been under-estimated in deliberations thus far and that a decision to eliminate summer spill carries a significant risk of being in error, particularly in regard to impact on returning adults and assumptions regarding the benefits of the transportation. (See Attachment 1, Fish Passage Center Memo dated April 6, 2004). Extensive technical comments were provided to NOAA and the Action Agencies relative to the proposal to not implement the 2000 Biological Opinion measures related to summer spill. These comments were not incorporated into the Draft BiOp analysis.
    - Smolt-to-adult return rates for transported fall chinook indicate that a spread the risk policy such as that implemented for spring chinook should be considered for fall chinook. The adult return data indicates that the best returns occurred when spill occurred at McNary throughout the summer period. The fall chinook SARs on transported fish are disappointing and may not achieve the recovery goals assumed in the 2000 BiOp. This will affect the analysis of impacts of the summer spill program modifications because a spread the risk policy will result in a larger proportion of Snake River fall chinook migrating in-river. The SIMPAS analysis conducted to date did not examine the impacts of discontinuing summer spill with the implementation of a spread the risk policy for transportation.
    - PIT tagged adult fall chinook actual returns from 1994 through 2001, that were detected as juveniles, indicate that a large proportion of the fall chinook that survived to return as adults migrated, as juveniles, past Ice Harbor in late July and August and past McNary in August. This indicates that the SIMPAS predictions of impact on adult returns should be regarded with caution because the juvenile passage distribution assumed in BPA's analysis does not reflect actual adult return data and does not provide a robust basis for decisions. Spill may be much more important to adult returns than inferred from juvenile modeling data.
    - Review of the data and research results indicates that there is a flow survival and flow travel time relationship for fall chinook. Analysis of alternative management scenarios and mitigation offsets have not considered or utilized this information. Low flow conditions will shift the passage distribution to later in the migration.

SIMPAS analysis of average conditions does not capture this effect because it does not vary flow nor does it relate flow to passage distribution. Elimination of spill in August as discussed by BPA will affect a larger proportion of the migration in low flow years than estimated with their model.

3. The model relied upon to determine survival in the analysis does not contain a strong flow survival relation. The use of seasonal average flow and the methods of extracting pool survival from reach survival seriously underestimate the benefits of flow. This means that changes in flow will have little effect on the potential survival improvement. The net result is that the difference between the proposed operation and the reference operation (the gap) is extremely small. The goal is set very close to the biological baseline identified in the Draft BiOp. Consequently, the measures that are needed to close the gap are relatively insignificant. This makes achieving the goal very easy in the present system.

4. In addition, the determination of jeopardy does not represent a biological goal as contained in the past Biological Opinions for these species. The Draft BiOp does not provide any technical rationale for this departure from the determination of jeopardy used in past BiOps. There is no consideration if the small increases in juvenile survival will translate to the continued existence of the species. The present BiOp relies heavily on the fact that recent good ocean conditions have resulted in increased numbers of returning adults. However, they do not define how the hydrosystem operational improvement might fare in average to below average ocean conditions.

5. Moreover, the survival improvements associated with closing the "gap" are often speculative and some of the measures like "heavy up", and Caspian Tern redistribution are double counted because they are already contained in the biological baseline and are also proposed for filling the gap. Once again, this subject was extensively addressed in the technical comments on summer spill implementation, which appear to be wholly ignored in this Draft BiOp.

6. All measurements are in terms of juvenile survival and the link between adult survival and delayed mortality due to the hydrosystem are not addressed for in- river migrants. The relation between juvenile migration through the hydrosystem and subsequent mortality was the subject of the Comparative Survival Workshop held on February 11-13, 2004 (see Attachment A – CSS Workshop document). The Workshop addressed the evidence for and against hydrosystem passage, delayed mortality, time of ocean entry and travel time and concluded that the hypothesis relating stress to increased vulnerability to mortality factors was likely. Other factors and hypotheses were considered for additional analyses and promising applications to support the hypothesis were developed. There is considerable evidence of delayed mortality for in-river migrating fish after passing through the hydrosystem and NOAA did not incorporate any of that information into the Draft BiOp.

In summary, given all of the concerns about the design and the execution of the analysis the proposed measures contained in the Biological Opinion are unlikely to avoid jeopardy.

II. The Gap used in NOAA's analysis was underestimated.

NOAA calculated the "gap" in survival between the reference and proposed operations. The proposed operation was essentially the 2000 Biological Opinion. The reference operation was anticipated to represent the "best" the hydrosystem could do, and essentially consisted of: storage projects operating as run-of-river projects remaining full and passing inflow unless water was needed for flow augmentation or to reduce TDG downstream, pool operations to MOP at John Day, and elimination of irrigation withdrawal at Banks Lake.

Table 1 displays the flows under each of the scenarios and years that NOAA presented for the Snake River. Table 2 displays the Water Transport Time (WTT) for each flow in Table 1. Because the reservoir replacement method was used to calculate the WTT, the project reservoir elevation was important in the calculations. For the calculation of WTT in Table 3, all Lower Snake projects were assumed to be at minimum operating pool (MOP) in accordance with both the proposed and reference operations.

Table 1. Snake River Flows presented by NOAA from hydrosystem modeling under each of the proposed and reference operations from 1994-2003.

	Spring Flows (Kcfs)		**Summer Flows (Kcfs)**	
Year	**Proposed Action**	**Reference Op**	**Proposed Action**	**Reference Op**
1994	55990	57190	26760	27760
1995	93600	94380	43370	47180
1996	125140	125750	53980	57850
1997	145370	148070	59740	64840
1998	105290	106530	44140	47590
1999	112740	113090	47910	54520
2000	80020	79670	35200	37790
2001	53950	47850	27330	26900
2002	85300	84060	42280	46410
2003	73320	73460	35620	38740

Table 2. Calculations of WTT from LGR to IHR were developed using the reservoir replacement method and the flows presented in Table 1. All Snake River pools held at MOP, in accordance with both the proposed and reference operation.

	Spring Flows WTT (days)		**Summer Flows WTT (days)**	
Year	**Proposed Action**	**Reference Op**	**Proposed Action**	**Reference Op**
1994	11.3	11.1	23.6	22.8
1995	6.8	6.7	14.6	13.4
1996	5.1	5.1	11.7	11.0
1997	4.4	4.3	10.6	9.8
1998	6.1	6.0	14.3	13.3
1999	5.7	5.6	13.2	11.6
2000	7.9	8.0	18.0	16.8
2001	11.7	13.2	23.1	23.5
2002	7.4	7.5	15.0	13.6
2003	8.6	8.6	17.8	16.3

From the following tables it is clear that both the Snake River flows and WTT were not significantly different between the proposed and reference operations in any given year. This seems to make sense, as the only major difference between the operations in the Snake system is the operation of Dworshak. One interesting point is that in several cases (usually during lower water years) the reference operation actually produced lower flows and higher WTT than the proposed operation. This is likely a result of how the runoff was shaped in the surrogate years chosen for the analysis.

Perhaps a more realistic "gap" would have been between the proposed operation and a reference operation that included the drawdown of Snake River pools also with modified Dworshak operations. In the "Columbia River Salmon Mitigation Analysis System Configuration Study Phase I: Biological Plan – Lower Snake River Drawdown Technical Report" prepared by Battelle PNNL Laboratories for the COE, Water Transport Time was estimated for several levels of drawdown. Under the 5,9 Drawdown Option (57 feet of drawdown at LGR, LGS and LMN and 49 feet of drawdown at IHR) Water Transport Times[1] were 9.6 days, 4.2 days and 2.5 days under low flow (25,000 cfs), moderate flow (60,000 cfs) and high flow conditions (160,000 cfs), respectively (see Table 4-4 of reference document. These WTT are less than one-half of those in either the proposed action or reference operation.

Table 3 displays the flows under each of the scenarios and years that NOAA presented for the Lower Columbia River. Table 4 displays the WTT for each flow in Table 3; WTT calculations included using average pool elevations for Bonneville, The Dalles, and McNary[2] and MIP at John Day under the proposed operation and MOP at John Day under the reference operation.

Table 3. Lower Columbia flows presented by NOAA from hydrosystem modeling under each of the proposed and reference operations from 1994-2003.

	Spring Flows (Kcfs)		**Summer Flows (Kcfs)**	
Year	**Proposed Action**	**Reference Op**	**Proposed Action**	**Reference Op**
1994	161930	157230	124340	172660
1995	244340	245390	139130	178740
1996	315890	321330	188060	213430
1997	401750	424800	196320	220030
1998	257840	268530	136050	177720
1999	310880	319190	182410	209610
2000	246200	252200	130990	177330
2001	156140	143540	115160	165970
2002	256310	269210	167720	201530
2003	194860	182490	128920	175190

[1] WTT were calculated from the Clearwater confluence with the Snake River to the Columbia River.
[2] Average pool elevations were calculated between the dates April 1 and June 30 over the years between 1999 and 2002.

Table 4. Calculations of WTT from IHR to BON were developed using the reservoir replacement method from the flows presented in Table 3. All pools were at average levels with the exception of John Day, which was held at MIP under the proposed operation, and MOP under the reference operation.

	Spring Flows WTT (days)		Summer Flows WTT (days)	
Year	**Proposed Action**	**Reference Op**	**Proposed Action**	**Reference Op**
1994	14.1	13.8	18.4	12.6
1995	9.4	8.9	16.5	12.2
1996	7.2	6.8	12.2	10.2
1997	5.7	5.1	11.7	9.9
1998	8.9	8.1	16.8	12.2
1999	7.4	6.8	12.5	10.4
2000	9.3	8.6	17.5	12.3
2001	14.7	15.1	19.9	13.1
2002	8.9	8.1	13.6	10.8
2003	11.7	11.9	17.8	12.4

From Table 4, flows and WTT are similar under springtime conditions in the lower Columbia, as reservoir storage is not needed in large volume in attempts to meet spring flow objectives. The differences in flows and WTT are more pronounced under summer conditions. The elimination of draft limits from Libby, Hungry Horse and Grand Coulee (and elimination of pumping from Banks Lake) appear to increase summer flows between approximately 25 to 50 Kcfs and reduce WTT between approximately 2 and 6 days. Although the "gap" between operations presented by NOAA is larger for the lower Columbia relative to the Snake River, it is possible the "gap" could have been larger considering the WTT's under a natural unregulated system would have been much shorter than either the Proposed or Reference operations. Perhaps NOAA could have included an operation where some or all of Chief Joseph, McNary, The Dalles, and Bonneville pools were drawn down to a lower elevation. Also not discussed are the assumptions in the models concerning the Mid-Columbia projects. Considering the entire storage potential of Mid-Columbia projects is over 1.6 Maf, flows anticipated for flow augmentation or reducing TDG could be easily re-shaped.

Overall, the "gap" between operations does not appear to represent a comparison between current operations and the "best" the hydrosystem can do. Instead, the difference between the two operations appears minimal in the Snake River and slightly better in the Columbia River. The true "gap" would be the difference between current operations and free flowing or natural conditions.

III. The Proposed Action Does Not Close the Gap

We do not agree with either the biological baseline, or with the constraints placed on the reference operation. However, even if one accepted the "gap" analysis the proposed actions are not adequately documented, understood or quantified for assessing the response of the fish population.

There are many problems with the SIMPAS Model, which we have commented on before. These were originally documented in an October 16, 2002 letter from the Columbia basin Fish and Wildlife Authority to the Northwest Power Planning Council and reiterated in a February 20, 2004 Joint Agency and Tribal Technical Staff Review of the Bonneville Power Administration summer spill analysis. Those pertinent comments from these documents are:

We agree with the recommendation of the Independent Scientific Advisory Board (ISAB) to the NWPPC, that it is not appropriate to develop a long-term management plan on the basis of SIMPAS analysis. Management alterations of the magnitude being considered by the NWPPC should be approached in a much more scientific manner as recommended by the ISAB. The SIMPAS (simulated passage) spreadsheet model was initially developed by the National Marine Fisheries Service staff to evaluate potential actions for the 1995 FCRPS Biological Opinion. This model was subsequently used for generating point estimates of potential actions associated with the 2000 FCRPS Biological Opinion. The following comments describe the serious limitations of utilizing the SIMPAS model and must be considered within a management context:

- Many passage models have been employed over the years as a tool to compare alternate scenarios in a qualitative sense. Using the models beyond this application in a relative sense is inappropriate. The relations and point estimates used in these simple passage models are far too simple to adequately capture the complexity of salmonid survival relations and are, therefore, inappropriate as the primary basis for management decisions.
- The NMFS 2000 BiOp recognizes the limitations in the use of the SIMPAS model and caveats SIMPAS results because the model does not account for the potential effects of various fish passage options (such as spill) on forebay passage in terms of reducing delay, residence time, or predation.
- The SIMPAS model was not designed to make inferences about the likelihood of adult returns (see Caveats to SIMPAS Modeling Results NMFS 2000 BiOp). This is due, in part, to the fact that SIMPAS simulations were not designed to include delayed hydrosystem mortality, i.e., extra" mortality. This class of models has limited application for realistically predicting the overall effects of an action on salmon survival.
- SIMPAS is calibrated to reach survival estimates from primarily high flow years. Even the lowest flow year in the data set used extrapolations for a shorter reach in 1994. In 2001 NMFS recognized that this direct survival estimates are too optimistic for low flow conditions expected in 2001.
- A key concern is that although SIMPAS assumes NMFS' BiOp values of delayed mortality for transported fish ('D') it does not explicitly consider delayed hydrosystem mortality that is common to both transported and in-river migrants.

- SIMPAS survival estimates do not simulate historic stock performance (see April 20, 2001 letter).
- Considerable evidence suggests that the source of "extra" mortality, which occurs in the estuary and early ocean, is related to earlier hydrosystem experience, i.e., delayed hydrosystem mortality (Budy 2001; Sections 3.3.1.1. and 3.3.1.2. in ODFW 2000). Evidence from the literature suggests numerous mechanisms that would explain this delayed mortality in relation to a fish's experience through the hydrosystem. Based on recent tagging data, there is direct evidence of delayed mortality by route of passage through the hydrosystem, including transportation and in-river routes (specifically collection/bypass). Spawner and recruit data demonstrate that there is a portion of delayed mortality specific to Snake River spring/summer chinook stocks that is coincident with the completion of the hydrosystem and greater for upriver stocks relative to downstream stocks (Fig. 1, 2, 3 in April 20, 2001). In addition, life-cycle survival for Snake River stocks is associated with annual smolt passage conditions, mainstem flows, and spill (Fig. 1 and 2 in State of Idaho 2000). The April 20, 2001 analysis (referenced in the first paragraph), regarding spill ignored this critical assumption of SIMPAS, and completely discounted these delayed impacts of eliminating spill on population viability and recovery.

In addition to our comments, we urge the NWPPC to heed the advice of their ISAB who commented on the use of SIMPAS on April 19, 2001. They urged caution in the emphasis placed on the model results and noted specific limitations:

> "While the assumptions behind the input values used in the modeling are consistent with the available data, and are also consistent with professional judgment of many scientists (they represent committee consensus), these are only "point estimates" and are subject to a considerable degree of uncertainty. For this reason, it is not appropriate to develop a long-range management plan just on the basis of results from assuming that these uncertain estimates are true. "Best science" under these circumstances would explore the results from a range of assumptions corresponding to the range of the uncertainty. "Best professional judgment" under these circumstances would recommend a course of action that was predicted to perform acceptably throughout the range of predicted possible outcomes. "Precautionary" best professional judgment would be sensitive to plausible worst cases within the range of predicted possible outcomes. Although not possible before decisions must be made this year, the importance of uncertainty in assessments of this type needs to be evaluated carefully."

The Draft BiOp analyses also contain problems with specific values used to "model" survival benefits under different operational scenarios. Many of the changes made between the Reference Action and the Updated Proposed Action (UPA) appear speculative, uncertain and overly optimistic.

Turbine survival improvements contained in the updated proposed action are highly uncertain. For example, the turbine survival improvement at John Day Dam for fall Chinook from 0.72 in the reference action to 0.85 in UPA is overly optimistic. For example the UPA in SIMPAS shows turbine survival improvements for yearling chinook at all sites except The Dalles Dam compared to the Reference case, with the highest survival improvement 3.5% at

Lower Monumental Dam. These improvements in survival are not justified by reference to any study or analysis.

Spillway survival improvements at Little Goose, Lower Monumental, McNary dams are based on unknown structural improvements. If it is bulk spill, that should be included in the Reference Action survival improvements and if not, it is unknown what changes are proposed to improve survival via spill. The survival assigned to the spillway at Lower Granite Dam of 0.93 is questionable. In the 2000 Biological Opinion the value was 0.98. Based on results from one Radio-Telemetry study the value has been reassigned to 0.93. This change in spillway survival seems arbitrary and is not discussed in the document. It highlights the subjective nature of survival value assignments within the model and brings into question the validity of the approach in demonstrating survival improvements. It is the only case we could find, where the assigned survivals (at least for yearling chinook) in the Retro Analysis is higher than that of other scenarios.

Improvements in bypass survival at McNary and John Day dams of 3% and 2%, respectively, are based on "outfall relocation" and other operational changes. The proposed changes may not show the improvements in survival listed. No attempt is made to justify the improvements in survival chosen. These small changes at each site seem inconsequential but when added together significantly improve the UPA gap closer analysis.

Benefits of RSW installations are speculative and highly uncertain at this point, since survival estimates have only been done at one site for one year and this value is expanded to all sites.

Increased pike minnow removal benefit is based on assumption that predation mortality in the Columbia River is additive, and that removal of a single predatory species will significantly decrease predation, but that basic assumption has not been adequately tested. Benefit of tern colony removal from the estuary, in Updated Proposed Action, may have little effect on overall survival in the estuary if mortality due to predation is not additive. The heavy up predation proposal was discussed in the summer spill implementation and was rejected as mitigation for eliminating summer spill. Ironically, it is being offered as mitigation as part of this draft BiOp. These predator-related actions are part of the baseline and should not be considered in the updated proposed action.

Effects of predator are speculative and likely overly optimistic, since predator removal assumes that predation effects on salmonids are purely additive within the hydrosystem when that is just as likely not to provide any benefit given if the predation is non-additive (compensatory). There are many potential predators smallmouth bass, walleye, double crested cormorant, terns, gulls and pelicans, for examples, that are not removed and could compensate for the decreased pike minnow predation (and therefore increased density of smolts) by increasing predation and thereby filling the void left by pike minnow removal.

Survival through estuary is not known so survival benefits to be gained from estuary improvements are highly speculative. The weight of evidence approach was used to address the

improvements in the estuary in the CSS workshop. The benefits of improvements in the estuary were determined to be highly uncertain.

The effect of removing terns from estuary may not have any effect on predation of juvenile salmonids in the estuary because there are multiple species of predators (e.g. fish, birds, pinnipeds) that could increase predation on salmonids in response to an increase in prey availability or change in distribution of prey as a result of the removal one type of aerial predator.

Heavy up on predator control as well as tern colony reduction, pinniped predation should be part of reference operation, thus negating any benefit in the 2010-2014 Updated Proposed Action

Non-hydro habitat improvements are flawed in that they are not following very likely to happen or to be sustained given they are according to NOAA opportunistic and rely on the good will of land- owners to both implement and maintain.

Any use of bulk spill should not be considered as an improvement since this could be included in the reference operation.

The flow pool survival relationship is confounded by delayed mortality associated with route of passage at dams, which is not taken into account in direct measures of survival. Pool survival is derived by dividing project survival by dam survival. This yields separate pool and dam survivals for modeling purposes. And because dam survival is accounted for by route specific survivals which are based on survival of passage only (i.e. direct survival), any latent or delayed effects of passing through turbines for example, is then accounted for in the flow pool survival relationship. In other words, assigning a benefit to flows based on pool survival may not adequately explain the delayed effects of fish passage through the dam.

IV. The "Gap" for fall chinook is not closed in this Draft BiOp.

A key weakness in the NOAA draft BiOp Remand Document occurs for fall chinook with regard to how transportation is handled in the reference operation. On page 5-15 in the Environmental Baseline chapter and page D-10 in Appendix D, the decision of NOAA is to continue the same operation as called for in the 2000 Biological Opinion. This decision was based on the Williams et al (2004) paper, which stated "no empirical evidence exists to suggest that transportation either harms or helps fall chinook salmon." NOAA concludes that since there have been such high adult returns during the past four years, it must be better to err on the side of continued transportation even though the subyearling fall chinook could potentially do better by simply migrating in-river under the current "less than ideal" riverine conditions that occur now. The evaluations to date of PIT tagged fall chinook released for the NOAA transportation studies did not show any differences in SARs between transported and in-river migrating smolts.

The analysis by the FPC (April 6, 2004) showed that SARs of PIT tagged subyearling fall chinook detected at a collector dam and returned to the river (Category C_1) were similar to or greater than the point estimate of their transported counterparts (Category T_0) in 6 of the 7 years reported. The results for the fish in these two study categories reflect fish collected at one or more collector dams during the stated migration year, so it is possible to obtain a valid estimate of starting population of PIT tagged smolts in Lower Granite Dam equivalents. This is true in spite of the fact that recent scale analyses of returning adult fall chinook show a sizeable portion of the population overwinters each year. This overwintering aspect of the fall chinook does make estimating the starting population of fish not detected at collector dam (Category C_0) more difficult since most fish in that category are never detected at any dam for PIT tagged fall chinook. However, the trend observed in 6 of 7 years where SAR for collected subyearling fall chinook that are returned to river is similar or greater than the SAR of transported fish does support the Agencies and Tribes recommended "spread-the-risk" policy. Therefore, NOAA should be considering this change in policy from the current maximum transportation as a "proposed operational action" to compare with their stated reference operation.

The efficacy of the "spread-the-risk" approach could be evaluated through the implementation of the Agencies and Tribes proposed Fall Chinook Transportation Study (proposed for Corps of Engineers funding). This proposal design compares the SARs of transported versus bypassed PIT tagged fall chinook smolts at the collector dams. It would provide an answer to whether simply bypassing subyearling fall chinook is preferable than transporting them even under the existing "less than ideal" in-river conditions, where BiOp2000 flows targets are missed in most years and no spill occurs at Snake River collector dams. In addition, if the Agencies and Tribes recommended "spread-the-risk" policy was adopted, the population of the run-at-large subyearling fall chinook present in the river would be greatly increased and should be better able to "swamp" its predator base than currently occurs. This could lead to higher overall survival rates for in-river migrating fall chinook than currently being estimated with PIT tagged fish.

The estuary habitat improvement projects, such as restoring intertidal marsh and riparian forest at Crims Island and a seasonally wet slough and riparian forest in the Sandy River delta, are admirable goals, but their benefit to subyearling fall chinook may be more limited and highly

uncertain than suggested in the NOAA document. In addition, NOAA does not indicate how they would evaluate whether this non-hydro "proposed operational action" would be evaluated. It would appear studies to estimate smolt-to-adult survival rates would need to be conducted, however, the NOAA document makes no mention of using SARs as a component of their analyses to determine success of the overall "package" of mitigation measures implements in any given migration year.

In the NOAA draft BiOp Remand Document, the Snake River fall chinook have the largest "gap" that needs to be filled of any species in order to avoid jeopardy. However, the measures outlined to address the "gap" such as sticking to the status quo transportation program and a few non-hydro "proposed operation actions" seen too limited in their scope to be as effective as NOAA Fisheries alludes in their determination of no jeopardy. Maybe it is time of NOAA Fisheries to work with the Agencies and Tribes on a "spread-the-risk" policy with coordinated studies to evaluate such a policy.

The Updated Proposed Action for fall chinook falls short of what is needed to likely avoid jeopardy. According to NOAA the UPA proposed hydro configuration is expected to "…reduce the in-river survival of the single major population of SR fall chinook…by 12.7% compared to reference operation". But the UPA does not include all options available to the Action Agencies. For example RSW or spill operations at collector projects (Lower Granite, Little Goose, Lower Monumental, McNary dams) could significantly improve in-river survival.

Specific Comments

Turbine survival improvement at John Day Dam from 0.72 in reference case to 0.85 in UPA seems overly optimistic. Turbine increases in survival were assigned at all sites in the UPA for fall chinook and yet the benefit of improved turbine operation is unknown. Spillway survival improvements at Ice Harbor, McNary and The Dalles also are questionable and since they are likely due to "bulk spill" should be included in the Reference Action not the UPA.

Estimates of tern predation of Snake River Fall Chinook are not reliable so that the effects of tern management, or habitat improvement are unlikely to improve survival. There is no evidence that Snake River Fall Chinook utilize the habitat areas identified for improvement in estuary so that net benefit is unlikely.

In conclusion, the delay of the fall chinook transportation evaluation until 2008 is not founded on any science. The 2000 BiOp delayed the study until 2005 because of a need to upgrade transmission facilities. Those upgrades are completed. The proposed delay of the transportation precludes closing the gap for fall chinook because it delays the identification of measures that could be used to close the gap.

ATTACHMENT A

CSS WORKSHOP DOCUMENT

Comparative Survival Study Workshop

February 11–13, 2004

Comparative Survival Study Workshop
February 11–13, 2004

Prepared for

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Executive Summary

The Comparative Survival Study (CSS) Oversight Committee convened a workshop in February 2004 on the effects of hydrosystem configuration and operation on salmon and steelhead survival. The workshop was attended by 17 scientists who have studied hydrosystem effects at a wide range of spatial/temporal scales and levels of organization.

Specific objectives of this workshop were to:

1. synthesize the results of Comparative Survival Study Oversight Committee (2002) and other research studies;
2. document and assess evidence relating to various factors that can affect survival rates over different life history stages, including hydrosystem passage, delayed mortality, time of ocean entry, and travel time;
3. produce a report synthesizing and assessing the evidence for and against hypothesized mechanisms for differential survival (hatchery-wild; upstream-downstream) and smolt to adult returns; and
4. provide the foundation for a series of publications in peer-reviewed journals.

The organizing structure for the workshop took the form of a series of hierarchical *impact hypothesis diagrams* designed to represent an increasingly more detailed set of hypotheses about possible mechanisms for differential survival. This provided a clear framework within which workshop participants were asked to evaluate varied hypotheses relating to delayed mortality, and to evaluate the strength of evidence for and against these hypotheses. Workshop participants were separated into 2 groups (Subgroup A and Subgroup B).

Subgroup A was charged with evaluating evidence for the overall hypothesis that passage through or around the hydrosystem causes **indirect** mortality to smolts that may not be expressed until the estuary/ocean life stage (Hypothesis 2). Subgroup A was also charged with analyzing and evaluating recent evidence for five of the six suggested mechanisms for delayed mortality (i.e., hydrologic changes, timing of estuary entry, changes in developmental state, fixed mortality/day, effects of smolt bypass structures).

Subgroup B was charged with evaluating existing evidence relating specifically to the hypothesis that smolt passage routes through or around the hydrosystem cause various types of **stress** on smolts that increase vulnerability to mortality factors. In addition to evaluating the more general evidence relating stress to indirect mortality, Subgroup B assessed the value of evidence linking four specific stress-induced mechanisms hypothesized as causing delayed mortality: 1) increased vulnerability to horizontal transmission of pathogens; 2) reduced growth rates or condition of smolts; 3) increased vulnerability to predation; and 4) reversal of, or incomplete smoltification.

The evidence available to the two subgroups differed, and therefore there are also differences in the summaries of their work in this report. Subgroup A conducted several new analyses directly focused on key uncertainties. Subgroup B reviewed and evaluated existing studies, both published and unpublished, for their relevance and support of specific stress mechanisms. Much of the behavioral and physiological evidence reviewed by subgroup B is focused on studies of the responses of individual fish on relatively short time scales and restricted spatial scales. By contrast, Subgroup A examined survival information on

seasonal to multi-year time scales for widely separated fish stocks. One of the major challenges of the workshop was to begin to synthesize research results across such diverse scales. This effort needs to continue, with further analyses required that attempt to correlate physiological/behavioral indices with survival rate estimates.

The specific hypotheses evaluated by each workshop subgroup, the evidence examined, and their conclusions/recommendations in regard to each hypothesis are presented below.

Subgroup A

Subgroup A participants focused their initial efforts at more clearly documenting the patterns that suggest delayed mortality is occurring. This included developing new assessments of the observed differences in SARs between different stock groups (i.e., hatchery vs. wild, transported vs. inriver, upstream vs. downstream). Secondly the subgroup directed their efforts at evaluating many of the hypothesized causal mechanisms for such differences, and pursued some new analyses in this regard. These analyses are preliminary, and have not been published previously.

Hypothesis 2: *Passage through or around the hydrosystem causes indirect mortality to smolts that may not be expressed until the estuary/ocean life stage. Indirect effects may be expressed differently for hatchery and wild fish.*

Evidence:

- Spatial and temporal comparisons of stock performance provide indirect evidence of delayed mortality and that delayed mortality is linked to hydrosystem experience.
- Recent mark-recapture data also provide evidence of differences in delayed mortality by route of passage through the hydrosystem.
- Different agencies have used somewhat different SAR metrics and drawn different conclusions about recent changes. Progress was made to determine why the results and conclusions were so dramatically different between agency analyses, however resolution of the "best" method to estimate SARs for the run-at-large has not been finalized.
- Updated estimates for the time series of λ_n (post-Bonneville survival factor for in-river fish) employing the Delta model (Deriso et al. 2001) indicate that λ_n has stayed low in recent brood years. These results are contrary to the interpretation of SAR information by NOAA Fisheries that in recent years there may be very little delayed mortality of in-river fish.

Overall conclusions/recommendations:

- Results from updated model runs suggest that delayed mortality for Snake River spring/summer chinook populations has remained high in recent years.
- The various management agencies responsible for the Columbia Basin should endeavor to work more cooperatively to evaluate common datasets, and agree on assumptions used in future shared analyses.

Hypothesis 2.1: *The hydrosystem indirectly affects smolt-to-adult survival (SARs) by causing changes in hydrologic conditions in the estuary.*

Evidence:

- Little directed work has been done to date that would allow clear evaluation of this hypothesis. There is a general lack of science-based information concerning attributes of tidal freshwater and oligohaline transition zones needed to support juvenile salmon, particularly in the Columbia River estuary.
- However, recent evidence supports the concern that flow in the Columbia River significantly affects the availability of estuarine habitats and that flow is much reduced compared to historic levels. Annual spring freshet flows through the Columbia River estuary are ~50% of the traditional levels that flushed the estuary and carried smolts to sea, and total sediment discharge is ~1/3 of 19th Century levels.
- Effects of flow regulation on habitat opportunities for subyearling salmon remain equivocal due to uncertainties in available bathymetric data.

Overall conclusions/recommendations:

- Analyses to date indicate that habitat and food-web changes within the estuary and other factors affecting salmon population structure and life histories have likely altered the capacity of the Columbia estuary to support juvenile salmon, though it isn't clear how the effects differ for transported vs. in-river, or hatchery vs. wild groups of fish.
- Further work is required to revise historical bathymetric data and acquire new data on present-day, shallow water bathymetry and circulation. Simulations should be pursued that include three dimensional modeling of salinity intrusion and stratification as a third environmental variable important in determining juvenile salmon distribution and residence time.

Hypothesis 2.2a: *The hydrosystem indirectly affects smolt-to-adult survival (SARs) by delaying (in-river) or accelerating (transport) arrival of smolts in the estuary.*

Evidence

- Spring/summer chinook transported from LGR and LGO arrive below BONN 2 to 3 weeks earlier than fish that migrate in-river. Transported fish arriving below BONN in early April have lower SARs than later groups and take longer to travel from BONN to lower Columbia River.
- The Snake and Columbia River dams and reservoirs have doubled to tripled the travel time of in-river spring/summer chinook and steelhead through these rivers, delaying ocean entry time.
- SARs for transported hatchery smolts appear correlated with the total number of salmonid smolts passing BONN. In 1999 the early April transport groups had fewer co-migrants and alternative prey for predators. Increased vulnerability to predators and immature smolt development stage might explain the lower SARs of early transport groups.
- The start of the optimal "window" of ocean entry appears to be around April 30th for both in-river and transported fish, based on CSS PIT-tag data for 1998-2000. The end of the optimal "window" of ocean entry appears to be around June 18th for in-river fish, and (with adequate flows) June 30th for transported fish.

- Post-Bonneville survival of in-river Snake River spring/summer chinook (λ_n) has remained at low levels in brood years 1991–1996, levels consistent with brood years 1985–1990, though lower than brood year 1986.
- SARs could, in theory, be affected by Water Travel Time (WTT) only through changes to direct mortality (e.g., greater predation rates in reservoirs). However, post-Bonneville survival (λ_n) also appears to be negatively correlated with WTT, suggesting that higher WTT is associated with higher levels of both direct and indirect mortality.

Overall conclusions/recommendations:

- The number of alternative prey available to smolt predators in the Columbia River plume and nearshore ocean likely plays a key role in determining smolt survival (i.e., probability of avoiding predation). Presence of alternative prey will (to some extent) be dictated by smolt entry time to the estuary.
- Differences observed in post-Bonneville Dam survival rates between transported and in-river migrating smolts may be influenced by duration of time the smolts spend in the lower Columbia River before actually entering the ocean. Early transported wild chinook smolts may be migrating below Bonneville Dam at very slow speeds and therefore may be more vulnerable to predators.
- Delayed arrival of in-river fish in the Columbia estuary related to WTT likely continues to cause post-BONN delayed mortality of in-river fish.

Hypothesis 2.2b: *The hydrosystem indirectly affects smolt-to-adult survival (SARs) by changing and delaying the smolt development processes, through both altered timing of entry and stress.*

Evidence:

- Fish appear to smolt as they migrate.
- Fish that are given insufficient time to complete smoltification will likely experience high energetic costs in attempting to osmoregulate in salt water, resulting in decreased resistance to pathogens and increased susceptibility to predators.
- Smolt indices such as gill ATPase suggest that early-run fish are less smolted than later run fish.
- Barged early-run spring chinook may have less opportunity to migrate a sufficient distance in freshwater, necessary in some fish to stimulate smolt development.
- In-river fish that are stressed may have delayed or reversed smolt development.

Overall conclusions/recommendations:

Causes of variation in D and SARs relating to timing of entry are most likely a combination of different factors. These include:

1. Developmental stage of smolts; both a lack of readiness for saltwater entry of early transport groups, and possible stress-induced changes in development for in-river fish.
2. The number of outmigrating smolts of various species (i.e., variation in schooling protection that can potentially swamp predators).
3. Year to year and seasonal variation in the condition of the estuary and availability of alternative prey.

4. Water Travel Time, which is negatively correlated with λ_n, the post_BONN survival of in-river fish.
5. Immature smolt developmental stage and increased estuarine predation are probably more important than stress in explaining low spring chinook D's for early season runs, but stress is likely a factor in consistently depressing SARs and λn for in-river fish.

Hypothesis 2.4: *The hydrosystem indirectly affects smolt-to-adult survival (SARs) by shifting the timing of mortality of transported fish to post Bonneville Dam, based on the hypothesis that fish experience a fixed rate of mortality.*

This hypothesis asserts that fish migrating in-river experience an inherent mortality rate per day that will be expressed in the SARs. Transported fish collected at the uppermost dam don't have the opportunity to be culled from the population. Therefore, the transport fish SARs include unfit fish that were destined to die anyway, but because of the short duration of transport were not exposed to the challenges of inriver migration (i.e., transported fish have experienced only 1.5 days of mortality pre-Bonneville, whereas in-river fish have had 12–22 days of pre-Bonneville mortality). The analyses to explore this hypothesis looked at upstream-downstream and between year differences in D.

Upstream-downstream differences in D: If continual "culling" were the primary cause for the in-river mortality experience through the hydrosystem, then the D values for smolts Lower Monumental Dam should be higher than for smolts transported from Lower Granite (due to some culling between LGR and LMO).

Between year differences in D: If continual "culling" is occurring the entire time that smolts are migrating in-river throughout the hydro system, then in-river smolts migrating in low flow years should have lower pre-Bonneville Dam and higher post-Bonneville Dam survival than do smolts migrating in high flow years. This scenario would lead to lower Ds in low flow years and higher Ds in high flow years.

<u>Evidence:</u>

- ***Upstream-downstream differences in D:*** Data presented by NMFS made no case for continual "culling" of hatchery chinook and only a weak case for continual "culling" of wild chinook. But there were too few PIT tagged wild chinook smolts transported from Little Goose Dam (and even fewer from Lower Monumental Dam) to obtain enough adult returns to properly conduct this type of analysis with the available data on PIT tagged wild chinook.
- ***Between year differences in D:*** The analysis compared the high flow year of 1999 with the low flow year of 2001. Post-Bonneville Dam survival rates between the two years were compared using a modified D* value computed using fish from study Category C1. Contrary to the hypothesis, the D* values were much higher in the low flow year, which reflects the extreme difference in survival in the estuary between these two years rather than a continuous "culling" mechanism. The SAR for Lower Granite Dam transported chinook was 3 to 4 times higher in the high flow year than in the low flow year.

<u>Overall conclusions/recommendations:</u>

Overall, both upstream-downstream and among year patterns did not appear to support the culling hypothesis. Analyses on other years' data would be worthwhile.

Hypothesis 2.5: *The hydrosystem indirectly affects smolt-to-adult survival (SARs) through size selectivity and annual variation in bypass survival.*

Zabel et al. (2003) suggested that fish size (length) is an important factor in both survival through Columbia dam bypasses and detection at these bypasses, although the overall analysis indicated size-selection at the bypass detection systems is relatively weak. A reanalysis of existing PIT tag data from 1998 to 2000 was conducted to assess whether biologically meaningful size-selectivity at the bypass systems was occurring. Other potential sources of bias in SARs estimates were explored in supplementary analyses.

Assessment of size selection at Columbia bypass systems (Section 3.9.1, T. Berggren)

Evidence:

- Reanalysis of data for wild chinook collected at Lower Granite Dam and PIT tagged for transportation studies by NMFS in 1998 to 2000 showed a weak trend in size selectivity at Little Goose Dam with the largest sized fish generally showing the lowest collection efficiency.

Overall conclusions/recommendations

- There does not appear to be any strong size-selectivity trends apparent in the PIT tag data from the Lower Granite Dam transportation studies.
- The weak pattern of observed size-selectivity could be associated with this particular study design. Further investigation utilizing PIT tagged smolts that have had a longer duration between tagging and detection at downstream dams is needed. However, this duration cannot be too long as to allow smolt growth to confound differences between size at tagging and size when the PIT tagged fish are being detected in the bypass systems at the dams.

Effects of varied bypass operations/systems on past differences in survival of C0 and C1 fish (Section 3.9.2, T. Berggren)

Evidence:

There are elements of dam operations and detection protocols that have varied over the years, and could also contribute to confounding of perceived patterns in SARs and D, as well as compiling any analyses of the changing pattern in the ratio of C0:C1 survival.

- ***Changes in Spill:*** The change in the pattern of SARs for PIT tagged wild spring/summer chinook in study categories C0 and C1 since 1998 may be influenced by recent changes in hydro project operations.
- ***Sample sizes:*** There were extremely small PIT tag sample sizes for the 1994 to 1997 adult returns.
- ***Changes in PIT detection ability:*** The full bypass detection history through all six dams equipped with PIT tag has only been available since 1998.
- ***Overall patterns of detection rates and spill:*** Changes in the makeup of the C0 group appeared related to higher spill volumes in recent years, but small sample sizes prevent further analysis. Increased spill would also have decreased the number of bypasses experienced by the C1 group as the probability that they passed in spill increased.

Overall conclusions/recommendations:

- Although some inferences can be made from the data as to why C0 and C1 detections may have changed over the years, the CSS study was not structured to specifically address the question of the effects of bypass passage on SARs. Furthermore, retrospective analysis of this question is difficult due to small sample sizes for the early years and because the full 6-dam detection history was not available until 1998. Within these limitations inferences can be made from trends in the data as to why there may have been a change over the years in the pattern of SARs between smolts in categories C0 and C1, though no strong conclusions can be made.
- An alternate way to address the question might be to conduct an analysis of data from 1998 and beyond, and group all of the juvenile data by the number of bypass detections. This would lead to groups with from one to six detections, and the adult returns from these data could be compared. This would be a cleaner analysis.

Subgroup B – Stress (Hypothesis 2.3)

Subgroup B discussions focused on links between stress related to hydrosystem passage and increased risk or susceptibility to hypothesized mortality factors, not on the links between those mortality factors and patterns in overall survival.

Discussion and review of the papers established that the general link between hydrosystem stress increased vulnerability to mortality factors is likely and that there are at least two likely pathways (based on the current strength of evidence available) through which this can occur: disease and predation. However, discussions and review did not establish the specific underlying mechanisms by which these effects would occur, or the magnitude of such effects.

Similarly, the subgroup discussions did not explore how these pathways could result in differential rates of delayed mortality between smolts with different life history experiences, or the spatial and temporal onset of delayed mortality. The pathway and mechanisms by which delayed mortality occurs may be different for smolts with different passage histories (e.g., transported vs. hydrosystem), different origins (e.g., wild vs. hatchery), or emigrating from different geographic regions (e.g., upriver vs. downriver).

Hypothesis 2.3.1: *Smolt passage routes through or around the hydrosystem cause various types of stress on smolts that increase vulnerability to mortality factors (2.3.1.1 – 2.3.1.4).*

Evidence: Workshop discussions and eleven papers reviewed during and after the workshop.

Overall conclusions: The hypothesis is **likely**.

Recommendations: There is a need to undertake greater synthesis of current work and design/undertake controlled lab/field experiments to link stress responses in the field to subsequent stress-related mortality outside of the hydrosystem.

Hypothesis 2.3.1.1: *Amount or extent of passage through or around the hydrosystem increases vulnerability to horizontal transmission of pathogens.*

Evidence: Workshop discussions and 7 papers reviewed during and after the workshop.

Overall conclusions: The hypothesis is **likely but uncertain**. Conceptually and based on supporting literature, Subgroup B considered this the highest ranked stress hypothesis in terms of explaining delayed mortality. However, the evidence in support of this hypothesis is generally based on laboratory studies on many animals that show increased disease susceptibility as a result of stress. There is no direct support showing that migrating smolts succumb to disease more readily after stress events.

Recommendations: There is still a need for properly designed field experiments to define the relationship between the level of stress experienced by smolts during hydrosystem passage and the degree of increased vulnerability to pathogens.

Hypothesis 2.3.1.2: *Passage through or around the hydrosystem reduces growth rates or condition of smolts.*

Evidence: Workshop discussions and 3 papers and presentations reviewed during and after the workshop

Overall conclusions: At this time, the hypothesis is considered **impossible to evaluate**. Evidence relating to this hypothesis is very weak as only two published papers were found and they provided only indirect evidence. Jim Congleton's presentation at the workshop provided much stronger evidence in direct support, but this work is not yet peer reviewed and published. Although suggestive, further work in this regard is required before an assessment can be made.

Recommendations: 1) Extend literature review to determine if any additional supporting information currently exists for this hypothesis; 2) continue and extend current studies examining the affect of stressors during hydrosystem passage on smolt condition and growth; 3) PIT tag smolts to assess smolt condition, growth rate and survival as groups with different transport histories move through the hydrosystem and beyond; 4) design specific field/lab experiments to identify stressor events and their impact on overall condition and subsequent survival.

Hypothesis 2.3.1.3: *Passage through or around the hydrosystem increases vulnerability to predation.*

Evidence: Workshop discussions and 23 papers reviewed during and after the workshop

Overall conclusions: The hypothesis is **likely but uncertain**. There is a strong body of evidence in the literature showing increased predator susceptibility of fish as a result of stress. However this evidence is derived principally from laboratory studies: field predation studies have not been designed to test the link to stress.

Recommendations: 1) Use PIT tag data to examine differential predation rates of smolts by avian predators based on transport history; and 2) Design field experiments to test the hypothesis of differential stress-mediated predation.

Hypothesis 2.3.1.4: *Passage through or around the hydrosystem results in reversal of, or incomplete smoltification.*

Evidence: Workshop discussions and 5 papers reviewed during and after the workshop.

Overall conclusions: The hypothesis is **unlikely, but uncertain**. There is at present only limited evidence from the literature for this hypothesis. However, the number of studies available for review was limited, and only two represent field-based assessments of actively migrating smolts. Additionally, there are other factors (beyond stress) that need to be more clearly accounted for in studies of smoltification.

Recommendations: 1) Improve monitoring of smoltification indices (e.g., ATPase) during hydrosystem passage. For example, use PIT tagging to allow sampling of distinct fish groups for examination of ATPase activity at different points in the hydrosystem for fish undergoing different passage routes. 2) Design field experiments to better identify if stressor events can affect smoltification with subsequent consequences for survival.

Table of Contents

List of Tables xii

List of Figures xiii

Acknowledgements xv

1.0 Introduction 1

1.1 CSS Workshop - 2004 1
1.2 Background on CSS 1
1.3 Definition of terms 3

2.0 Overview of the Framework 7

2.1 Hypothesis diagrams 7
2.1.1 General hypotheses: Figure 2.1 7
2.1.2 Alternative mechanisms for indirect effects: Figure 2.2 8
2.1.3 Effects of stress: Figure 2.3 10
2.1.4 Effects of individual components: Figure 2.4 13
2.2 Evaluating hypotheses and evidence 14
2.2.1 Overall criteria 14
2.2.2 Evidential criteria 15
2.2.3 Differences among subgroups in the approach used 15

3.0 Evaluation of Hypothesis 2 17

3.1 Critical patterns that need to be explained 17
3.2 Clarification of survival patterns 19
3.2.1 Within-year changes in SARs and D 19
3.2.2 Effects of smolt size and bypasses on survival (Hypothesis 2.5) 19
3.2.3 Comparisons of SARs among fish from different hatcheries 19
3.3 Exploration of survival patterns 20
3.3.1 Comparison of data sets and assumptions used by NOAA-F and IDFG in computing recent SARs for Snake River wild smolts *(C. Petrosky and H. Schaller)* 20
3.4 Do in-river fish currently show evidence of delayed mortality? *(Hypothesis 2; H. Schaller and C. Petrosky)* 23
3.5 Hydrologic changes in the estuary (Hypothesis 2.1) 29
3.5.1 Historical changes in freshwater flows *(E. Casillas)* 30
3.5.2 Modeling of estuarine physical conditions *(Bottom et al.; reviewed by H. Schaller)* 30
3.6 Effects of timing of entry into Columbia estuary on SARs and D (Hypothesis 2.2a) 31
3.6.1 Availability of alternative prey as a possible mechanism for temporal trends in SARS of transported hatchery spring/summer chinook salmon from Lower Granite and Little Goose Dams *(R.L. Emmett and W. D. Muir)* 32
3.6.2 Timing of entry into estuary affects extra mortality of in-river and transported fish *(T. Berggren)* 36
3.7 Changes in developmental state (Hypothesis 2.2b) 44
3.7.1 Effects of time to estuary on smolt developmental timing *(C. Schreck)* 45
3.7.2 Conclusions regarding Hypothesis 2.2a (Timing) and 2.2b (Developmental Stage) 48
3.8 Culling/selection (fixed mortality/day) (Hypothesis 2.4) 49
3.8.1 Initial workshop assessment of the culling hypothesis *(H. Schaller and C. Petrosky)* 49
3.8.2 Post-workshop assessment of the culling hypothesis for explaining observed patterns in D *(Tom Berggren)* 50
3.9 Size based or year-to-year variations in bypass survival estimates (Hypothesis 2.5) 52
3.9.1 Assessment of size selection at Columbia bypass systems *(T. Berggren)* 52

3.9.2 Effects of varied bypass operations/systems on past differences in survival of C_0 and C_1 fish *(T. Berggren)* 55

4.0 Effects of Hydrosystem Stress 61

4.1 Evidence table 61

4.1.1 Interpretations from the evidence table 69

Comments on Section 4.1.1. (*N. Bouwes*) 71

4.2 Hypothesis table 72

4.3 Summary and recommendations 76

4.3.1 Summary of review of evidence 76

4.3.2 Summary of overall review of hypotheses 76

4.3.3 Recommendations 77

5.0 Towards a Holistic Model of Basin Interactions 79

5.1 Sources of variability in patterns associated with smolt survival, SARs and migration *(H. Li and C. Schreck)* 79

6.0 Reference List 85

Appendix A. Workshop Agenda 91

Appendix B. Participants in CSS Workshop and Subgroup Assignments 95

Appendix C. Within-year changes in SARs and D for cohorts of in-river and transported chinook and steelhead that were tagged or marked during specific weeks at Lower Granite Dam *(from Williams et al. 2003)* 97

Appendix D. Glossary of Terms Used in the Delta Model Analysis *(H. Schaller and C. Petrosky)* 101

Appendix E. Effects of juvenile migration and ocean/climate conditions on smolt-to-adult return rates and recruitment *(N. Bouwes, C. Petrosky, and H. Schaller - Presentation at CSS Workshop)* 103

Appendix F. Application of Criteria for Evaluating Hypotheses and Evidence 109

Appendix G. Physiological changes in migrating juvenile chinook salmon and effects on performance and survival *(J. Congleton et al. – presentation at CSS workshop)* 143

List of Tables

Table 3.1. Apparent survival patterns (and possible implications for Hypothesis 2) for chinook and steelhead in the Columbia River. 18

Table 3.2. Historic SARs: sources, adult accounting and expansions. 23

Table 3.3. Temporal estimates of hydropower system survival (S_I), Travel time from LGR-BON (*TT*), SAR_T, SAR_I, *T:I*, and delayed mortality (*D*) for hatchery yearling chinook salmon released above and transported from or returned to the river at Lower Granite Dam, 1998-2000. 33

Table 3.4. Smolt (Lower Granite Dam)-to-adult (Bonneville Dam) survival rates for in-river migrating and transported PIT tagged wild spring/summer chinook in migration years 1998 to 2000. 37

Table 3.5. Median travel time from Lower Granite Dam to Bonneville Dam (temporal 15-day blocks) of in-river migrating PIT tagged wild spring/summer chinook in 1998 to 2000 38

Table 3.6. Estimated travel time between Bonneville Dam (BON) and lower Columbia River trawl at Jones Beach for PIT tagged wild spring/summer migrating in-river and transported 39

Table 3.7. Example of expected D values by collector project location for fixed mortality hypothesis. 50

Table 3.8. Estimated pre- and post-Bonneville Dam survival rates for PIT tagged spring/summer chinook released from hatcheries used in the CSS and for the aggregate of PIT tagged wild spring/summer chinook that migrate in-river versus those transported from Lower Granite Dam 52

Table 3.9. Collection efficiency at Little Goose Dam of PIT tagged wild yearling chinook marked and released at Lower Granite Dam in 1998, grouped by smolt length and week of release. 53

Table 3.10. Collection efficiency at Little Goose Dam of PIT tagged wild yearling chinook marked and released at Lower Granite Dam in 1999, grouped by smolt length and week of release. 54

Table 3.11. Collection efficiency at Little Goose Dam of PIT tagged wild yearling chinook marked and released at Lower Granite Dam in 2000, grouped by smolt length and week of release. 54

Table 3.12. Weighted seasonal collection efficiency for PIT tagged wild spring/summer chinook at Little Goose Dam for migration years 1998 to 2000, grouped by length at tagging of smolts. 54

Table 3.13. Relative comparison of annual amounts of spill that occurred over the spring spill periods of 1994 to 2000. 56

Table 3.14. Estimated Lower Granite Dam PIT tagged wild spring/summer chinook population and associated number of adults returning per study category. 57

Table 3.15. Number of PIT tagged wild spring/summer chinook returning as adults that were detected as smolts at McNary Dam during migration years 1994 to 2000. 58

Table 3.16. Average number of bypasses at which PIT tagged wild spring/summer chinook in study categories C_0 and C_1 were detected in migration year 1998 to 2000. 58

Table 4.1. Summary and evaluation of evidence relating to stress hypotheses. 62

Table 4.1.1. Levels of support for each of the stress-related hypotheses 70

Table 4.1.2. Average scores over the Applicability, Clarity, and Rigor criteria. 71

Table 4.1.3. Summary of hydrosystem stress-related hypotheses 71

Table 4.2. Summary and evaluation of hypotheses related to hydrosystem stress 73

Table 4.3. Subgroup B recommendations for directed field/lab studies to address existing uncertainties and better identify effects of hydrosystem stress on delayed mortality. 77

Table 5.1. Definitions for acronyms used in the Li and Schreck conceptual models. 81

Table A-1. Key PATH uncertainties for spring/summer and fall chinook. Extra mortality hypotheses are more important at higher values of D. 102

List of Figures

Figure 1.1. Process for design, implementation and review of CSS studies. 2
Figure 1.2. CSS tagging locations. 3
Figure 1.3. Salmon/steelhead life cycle in the Snake and Columbia Basins. 4
Figure 2.1. General hypotheses about hydrosystem effects on SARs: Direct effects, and indirect or delayed effects. 8
Figure 2.2. Alternative mechanisms for indirect effects of the hydrosystem on SAR. Shaded boxes are additional pathways added to the conceptual framework at the workshop. 9
Figure 2.3. The effects of hydrosystem stress on overall smolt-to-adult return ratios (SAR). 11
Figure 2.4. The effects of individual components of the hydrosystem on biological function and survival. 13
Figure 3.1. Estimated SARs for wild Snake River spring/summer chinook, for the run-at-large (untagged; IDFG) (open red squares], and for PIT-tagged smolts from the Comparative Survival Study (PIT CSS) (T0 =solid diamonds; overall T0&C0 = open circle). 22
Figure 3.2. Year effect for Snake River and John Day stocks (updated δ). 25
Figure 3.3. Differential mortality of Snake River vs. John Day stocks (updated μ). 26
Figure 3.4. Comparison of estimated λ_n from PATH (Deriso et al. 2001), brood years 1975-1990 and updated estimates, 1975-1998. 27
Figure 3.5. Estimated delayed mortality of in-river migrants, 1-$\boldsymbol{\lambda_n}$, brood years 1975-1998. 28
Figure 3.6. Comparison of the estimated common year effect, δ, from PATH (Deriso et al. 2001), brood years 1975–1990 and updated estimates, 1975-1998. 29
Figure 3.7. Daily hatchery spring/summer chinook salmon passage at Lower Granite Dam and percent smolt-to-adult return rates (5-day running average) for smolts transported from either Lower Granite or Little Goose Dams, 1999. 34
Figure 3.8. Number of salmonid smolts (all species except subyearling chinook salmon) passing Bonneville Dam and percent smolt-to-adult return rates (5-day running average) for hatchery smolts transported from either Lower Granite or Little Goose Dams, 1999. 35
Figure 3.9. Percent smolt-to-adult return (5-day running average) for hatchery smolts transported from either Lower Granite or Little Goose Dams vs. index of total number of salmonid smolts (all species except subyearling chinook salmon) passing Bonneville Dam in 1999. 35
Figure 3.10. Abundance of forage fish off the mouth of the Columbia River 1999-2003. 36
Figure 3.11. Juvenile timing at Bonneville Dam for PIT tagged wild Sp/Su chinook that survived to adulthood for migration years 1998 to 2001. 41
Figure 3.12. Juvenile timing at Bonneville Dam for PIT tagged hatchery Sp/Su chinook that survived to adulthood for migration years 1998 to 2001. Number of PIT Tags in parenthesis. 42
Figure 3.13. Juvenile timing at Lower Granite Dam for transported PIT tagged Sp/Su chinook that survived to adulthood (hatchery and wild combined) for migration years 1998-2001. Number of PIT Tags in parenthesis. 43
Figure 3.14. Relationship between λ_n (post-BONN survival factor) and WTT, for Snake River spring/summer chinook. 44
Figure 3.16. Effects of multiple stressors on saltwater preference of spring chinook (sequential stressors were separated by average migration times experienced between Columbia River dams). 48
Figure 5.1. Interaction of multiple factors with catchment basin ESUs. 79

Figure 5.2. Example conceptual model for early run, spring chinook in a high flow year. 80
Figure 5.3. Example conceptual model for late run, fall chinook in the second of two low discharge years. 82
Figure C.1. Hatchery yearling chinook (YCS) tagged above Lower Granite (LGR) dam 97
Figure C.2. Regression analysis of the data in Table 3.3 (graphed in Figure C.1), completed by (Steve Haeseker at the Feb./04 CSS workshop. 98
Figure C.3. Hatchery and wild yearling chinook marked at Lower Granite (LGR) dam. 99

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We also thank the Fish Passage Center and US Fish and Wildlife Service for funding this project.

1.0 Introduction

1.1 CSS Workshop - 2004

The CSS Oversight Committee, in response to comments by the Independent Scientific Review Board, convened a workshop in February 2004 on the effects of hydrosystem configuration and operation on salmon and steelhead survival. Specific objectives of this workshop were to:

1. synthesize the results of Comparative Survival Study Oversight Committee (2002) and other research studies;
2. document and assess evidence relating to various factors that can affect survival rates over different life history stages, including hydrosystem passage, delayed mortality, time of ocean entry, and travel time;
3. produce a report synthesizing and assessing the evidence for and against hypothesized mechanisms for differential survival (hatchery-wild; upstream-downstream) and smolt to adult returns; and
4. provide the foundation for a series of publications in peer-reviewed journals.

The workshop was held at the Bonneville Hot Springs Resort (North Bonneville, WA) on February 11-13, 2004 (agenda – Appendix A), and was attended by 17 scientists (Appendix B) who have studied hydrosystem effects at a wide range of spatial/temporal scales and levels of organization. These scales range from hourly physiological and behavioral responses of individual fish, to contrasting rates of recruitment of widely separated fish stocks over several decades. One of the major challenges of the workshop was to begin to synthesize research results across such diverse scales.

Section 2 of this report describes a hierarchical framework developed before the workshop for organizing hypotheses and synthesizing evidence. This framework was revised during the workshop to incorporate other hypotheses, but the overall structure and function remained intact, and was found to be helpful. We provide some specific examples to clarify the process of hypothesis evaluation used at the workshop.

Sections 3 and 4 present workshop evaluations of the evidence relevant to potential impact hypotheses. Section 3 focuses on a broad set of survival patterns and mechanisms, while Section 4 examines particular stress mechanisms in more detail.

Section 5 presents an preliminary draft conceptual model of smolt condition and migration timing variability (incorporating watershed, hydrosystem and estuarine interactions affecting smolt survival) developed at the workshop by H. Li and C. Schreck.

Participant comments on draft versions of the above sections have been appended at the end of individual sections.

1.2 Background on CSS

The CSS study was initiated in 1996 by the states, tribes and US Fish and Wildlife Service (USFWS) to estimate survival rates at various life history stages, compare survival rates for chinook from three areas and develop a more representative control for transport evaluations. The project (#1996020000) is funded

by BPA as part of the NWPCC Fish & Wildlife Program. Survival estimates are derived from PIT tags, with bootstrapping procedures used to determine confidence intervals. The process by which CSS studies are designed, implemented and reviewed is shown in Figure 1.1, and tagging locations are shown in Figure 1.2.

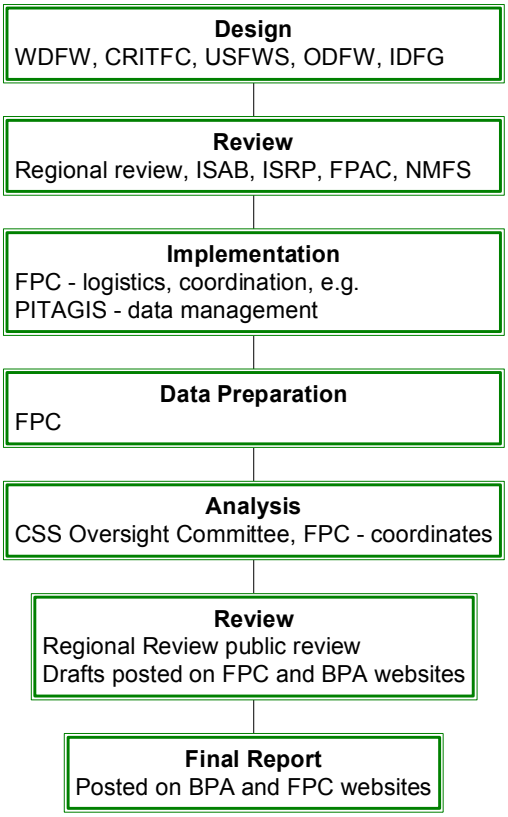

Figure 1.1. Process for design, implementation and review of CSS studies.

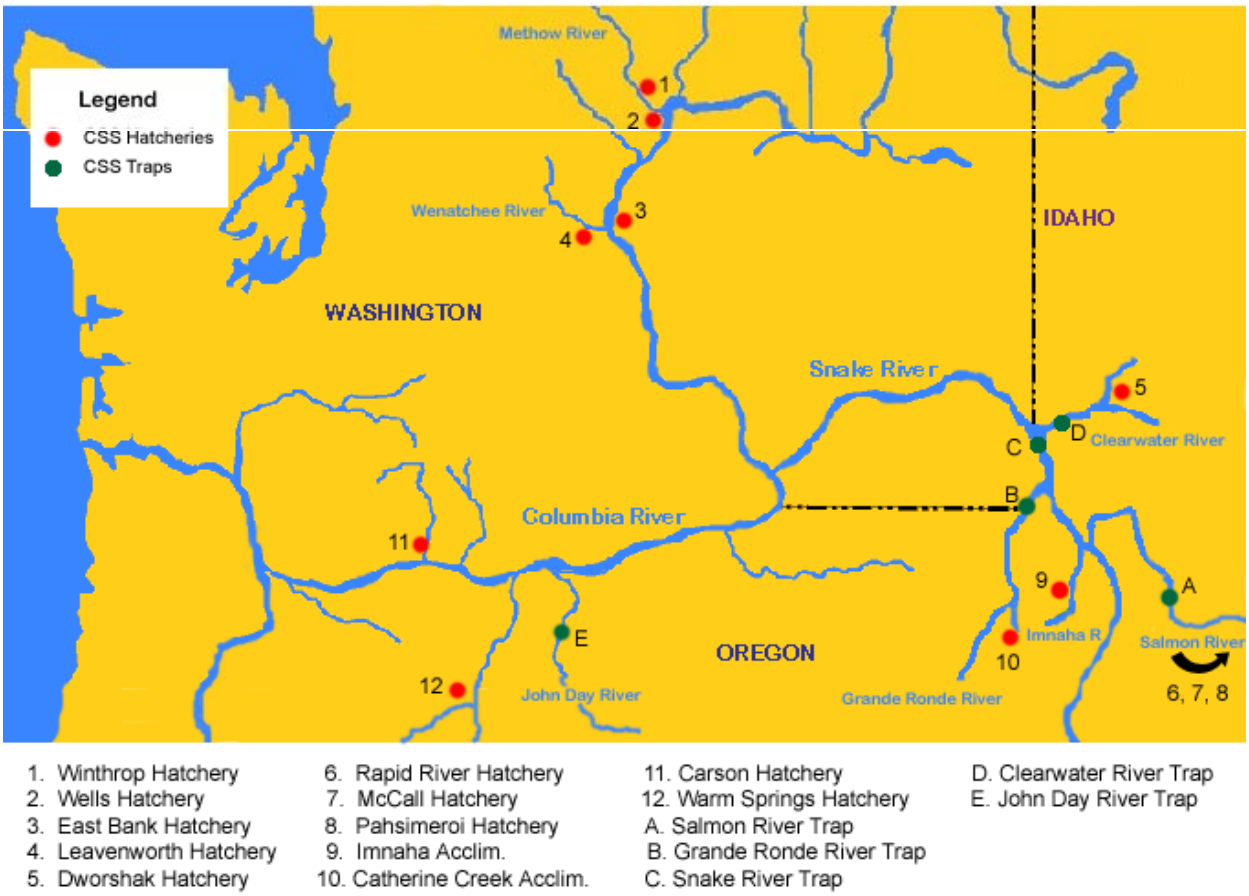

Figure 1.2. CSS tagging locations.

CSS provides a number of products useful to the region for various evaluations. These include:

1. long term, consistent indices: travel times; in-river survival rates; in-river SARs by route of passage; and transport SARs; and
2. comparisons of SARs: transport to in-river; by geographic location; by hatchery group; hatchery to wild; and chinook to steelhead.

Future CSS tasks include: steelhead marking; increased wild marking for Snake and Lower Columbia chinook; marking subyearling chinook in Snake and Mid-Columbia; and upper Columbia chinook and steelhead marking.

1.3 Definition of terms

This section provides some context for readers unfamiliar with the terms commonly used to assess hydrosystem effects in the Columbia Basin. Other readers may prefer to skim or skip this section.

Figure 1.3 illustrates the life cycle of salmon and steelhead originating from the Snake River Basin. This includes both hatchery and wild fish, which pass through eight mainstem Snake and Columbia dams either in-river or in barges.

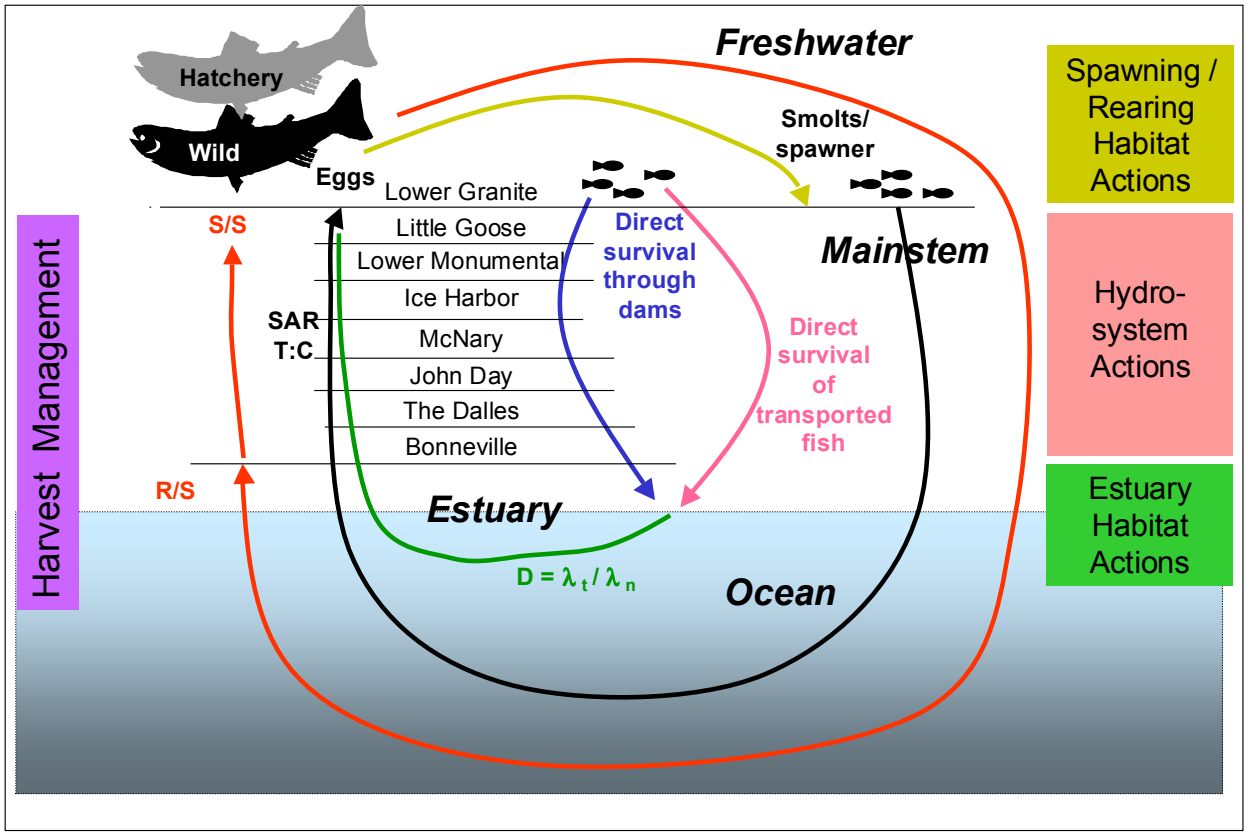

Figure 1.3. Salmon/steelhead life cycle in the Snake and Columbia Basins.

Direct survival rates past these eight projects is termed V_c for in-river fish that are never detected at any bypasses and V_t for transported fish (assumed to be 0.98). Smolt to adult return rates (or SARs) are generally estimated from the point smolts pass the first dam (Lower Granite for Snake River fish) until adults return back to Lower Granite. SARs can also be measured from the point smolts pass the last dam (Bonneville) until adults return there. The CSS study provides a means of estimating both types of SARs, as well as V_c, for different groups of hatchery and wild fish.

Survival of fish from the point smolts pass Bonneville Dam to the point that adults return to Lower Granite is labeled λ_n for in-river fish, and λ_t for transported fish. The ratio of these two survival rates (λ_t/λ_n or D) represents the relative post-Bonneville survival rate of transported fish compared to in-river fish. The ratio of the overall survival rate of transported to in-river fish (T:C) therefore equals:

$$(V_t * \lambda_t) / (V_c * \lambda_n),$$

or

$$(V_t / V_c) * D$$

T:C ratios greater than 1.0 indicate a relative benefit of transportation over in-river passage, while ratios less than 1.0 indicate that in-river passage was more successful. For example, if (V_t / V_c) were 2.0 and D were 0.5, T:C would equal 1.0.

Any indirect or delayed mortality effects of the hydrosystem would cause a reduction in post-Bonneville survival rates (λ_t or λ_n). Isolating the effects of the hydrosystem on λ_t or λ_n is difficult, since post-Bonneville survival rates will also be affected by annual changes in estuary and ocean conditions. In addition, post-Bonneville survival rates can be affected by the conditions that fish encountered earlier in their spawning and rearing habitat, which determined their condition as pre-smolts before entering the mainstem Snake and Columbia rivers. Delayed mortality is estimated from the overall life cycle survival after accounting for sources of direct mortality and climate effects. Measures of physiological condition and behavioral responses after actual or simulated dam passage, as well as estuarine survival rates, provide ways to assess if various mechanisms could be responsible for indirect mortality.

The final terms in Figure 1.3 are R/S (recruits/spawner) and S/S (spawners/spawner). Recruits per spawner are often computed back to Bonneville Dam. Recruits (R) then equal the total number of adults returning to Bonneville (plus any harvest) of fish which originated from spawners (S) in a given brood year.

Estimates of R/S require age data to properly assign each returning adult to its appropriate brood year. Spawners/spawner are computed as the number of spawners returning to the spawning ground divided by the spawners in the parent generation. If S/S > 1, the population is increasing, and if S/S < 1, the population is declining.

Contrasts in R/S between upstream and downstream stocks, which also account for common variations in ocean conditions affecting all stocks and inter-stock differences in productivity, have been used to infer patterns of delayed mortality (Deriso et al. 2001). R/S and S/S have also been used to elucidate the interactive effects of hydrosystem operation (represented by Water Travel Time) and climate/ocean conditions (State, Federal and Tribal Anadromous Fish Managers 2003).

2.0 Overview of the Framework

As a starting point for an organizing framework for the CSS workshop, we used the Budy et al. (2002) paper on delayed mortality. Their classification of evidence for delayed mortality (or indirect effects of hydrosystem passage), and their literature review of the effects of stress as one hypothesis for delayed mortality, provide convenient examples of both an intensive and extensive documentation of information related to hydrosystem effects on survival. Other papers and evidence were used to supplement the framework presented here.

The framework takes the form of a series of hierarchical *impact hypothesis diagrams* to represent an increasingly more detailed set of hypotheses about possible mechanisms for differential survival. The framework also includes a set of tables to evaluate hypotheses according to specified criteria, and to evaluate the strength of evidence for and against these hypotheses. We developed an initial framework prior to the workshop, and then revised it at the meeting. For brevity, we present just the revised framework. The hierarchical framework will hopefully facilitate publication of a linked set of journal papers, each focusing on a different component hypothesis, with an overview/synthesis paper to integrate the work and draw overall conclusions.

2.1 Hypothesis diagrams

Figures 2.1 through 2.4 represent a set of increasingly detailed hypotheses about potential mechanisms linking the hydrosystem to smolt to adult survival rates. Actions whose effects we wish to understand are shown at the bottom of the diagram, and the indicators that those actions affect are shown at the top. Below each figure we describe the hypothesis (and its component links) in words.

2.1.1 General hypotheses: Figure 2.1

Figure 2.1 shows two very general hypotheses about hydrosystem effects on smolt-to-adult return rates or SARs. We are interested in both the absolute levels of SARs and differences in SARs among different stocks (e.g., hatchery vs. wild, transported vs. inriver, upstream vs. downstream). The hydrosystem can have both direct and indirect effects. In this report, we focus on indirect/delayed effects because:

- there has been much previous research on direct effects (e.g., engineering studies of different turbine designs; predation studies in reservoirs);
- much of the Comparative Survival Study Oversight Committee (2002) report and Budy et al. (2002) focuses on indirect effects; and
- the FCRPS Biological Opinion (National Marine Fisheries Service 2000a) highlights delayed mortality as a critical uncertainty (RPAs 185-189 focus specifically on research on differential delayed mortality (D), factors affecting SARs, upstream/downstream differences, and effects of passage histories on SARs).

The more limited scope (i.e., focusing on indirect effects only) was considered most practical for workshop organization and participation, though data on direct effects (reach mortality) is required to isolate indirect mortality. A major challenge is how to separate the indirect effects of the hydrosystem on SARs from other confounding factors that affect estuary/ocean survival rates of smolts (lower right hand part of Figure 2.1; link 3)

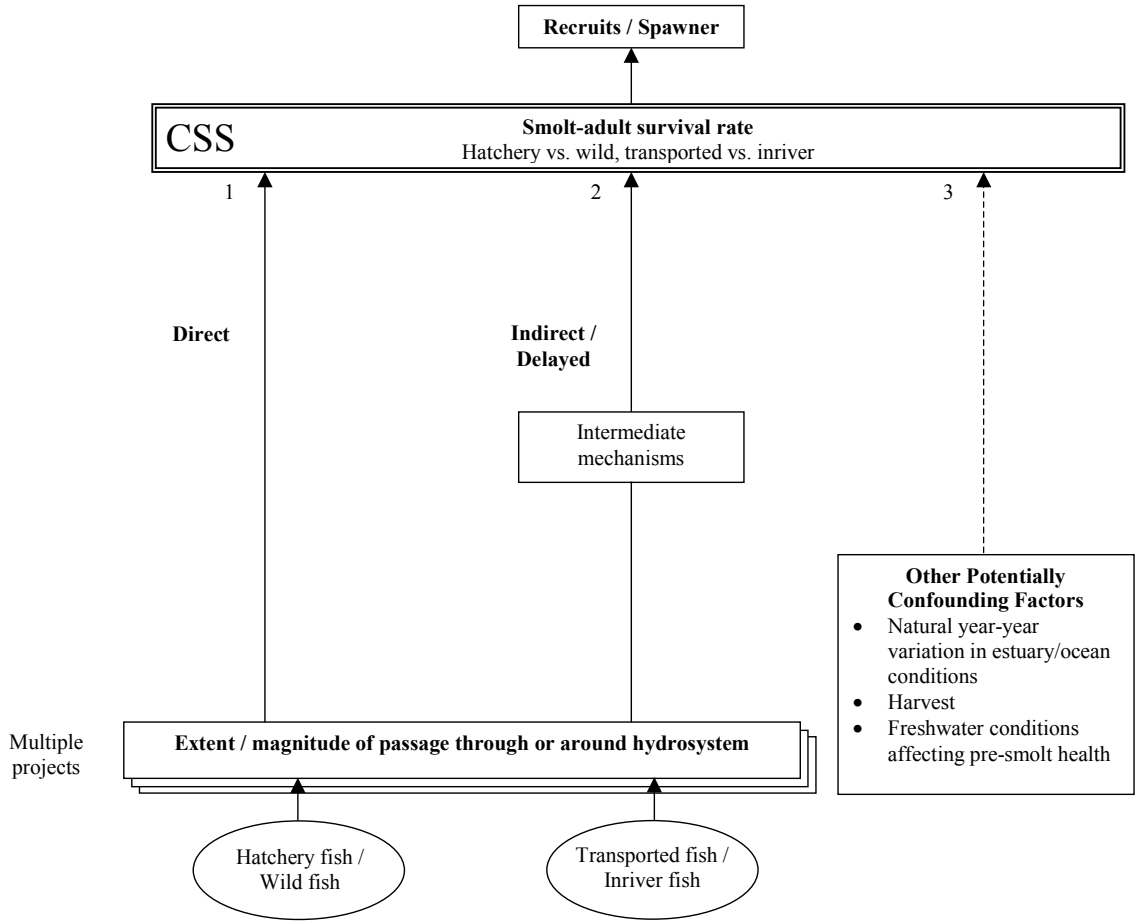

Figure 2.1. General hypotheses about hydrosystem effects on SARs: Direct effects, and indirect or delayed effects.

Description of Hypotheses:

1. Passage through or around the hydrosystem causes direct mortality to smolts. Direct effects may be expressed differently for hatchery and wild fish.
2. Passage through or around the hydrosystem causes indirect mortality to smolts that may not be expressed until the estuary/ocean life stage. Indirect effects may be expressed differently for hatchery and wild fish.
3. Other factors affecting estuary/ocean survival of smolts can potentially confound determination of indirect effects of hydrosystem passage.

2.1.2 Alternative mechanisms for indirect effects: Figure 2.2

Figure 2.2 shows a set of six alternative mechanisms for indirect effects of the hydrosystem on SAR (i.e., links 2.1 to 2.5, an expansion of Link 2 in Figure 2.1). These mechanisms are described as hypotheses below Figure 2.2. Note that these hypotheses are not mutually exclusive and occur against a background

of non-hydrosystem variability (links 3a, 3b). Note that there could be an analogous diagram for direct effects on survival, although as noted we are focusing on indirect effects.

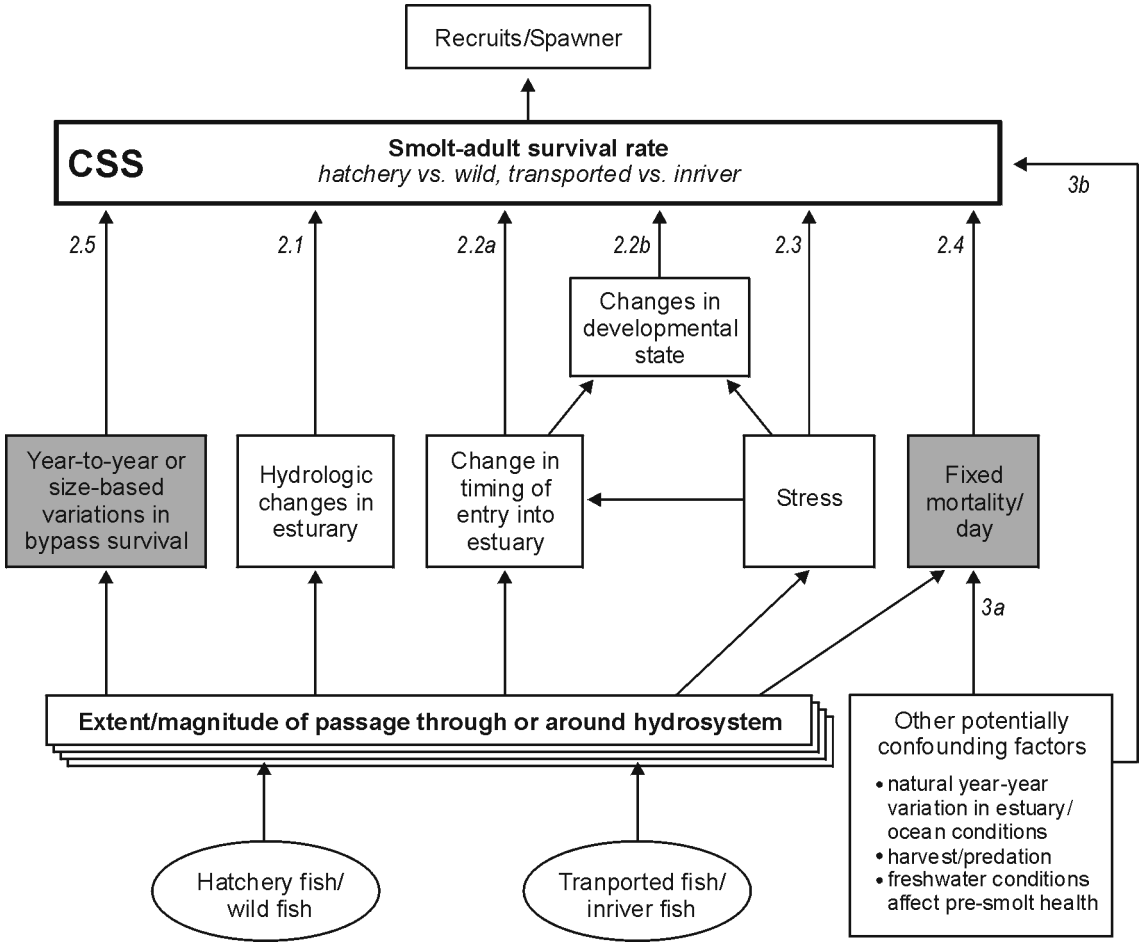

Figure 2.2. Alternative mechanisms for indirect effects of the hydrosystem on SAR. Shaded boxes are additional pathways added to the conceptual framework at the workshop.

Description of hypotheses

The hydrosystem **indirectly** affects smolt-to-adult survival (SARs) by:

2.1 causing changes in hydrologic conditions in the estuary

… possible sub-hypotheses (e.g., reduction in estuary productivity due to reduction in spring freshets, which reduces growth rates of 1st year smolts);

2.2a delaying (in-river) or accelerating (transport) arrival of smolts in the estuary

… possible sub-hypotheses (e.g., smolt arrival does not coincide with spring upwelling, which reduces growth rates of 1st year smolts; smolt arrival does not coincide with availability of alternative prey, increasing predation rates; smolt arrival is prior to ideal developmental stage for seawater entry);

2.2b changing and delaying the smolt development processes, through both altered timing of entry and stress;

2.3 imposing stress on smolts (examined in detail in Section 4);

2.4 shifting the timing of mortality of transported fish to post Bonneville Dam, based on the hypothesis that fish experience a fixed rate of mortality;

2.5 selecting smaller smolts preferentially for project bypasses, and varying bypass survival by changes in hydrosystem operations; and

3a, 3b factors other than the hydrosystem (i.e., year to year variation in estuary conditions, harvest, predation, freshwater conditions) interact with other mechanisms to cause variations in SARs.

2.1.3 Effects of stress: Figure 2.3

Figure 2.3 distinguishes four components in the effects of stress on overall SAR, and shows more detailed hypotheses about each. Hypotheses about the effects of stress on intermediate biological function (e.g., vulnerability to pathogen) are shown at the bottom of the diagram, and the subsequent effect on those biological functions on overall SAR are shown in the top part of the diagram. In many cases these intermediate biological functions are actually measured in field studies. Hypotheses about the effects of biological function on overall survival (e.g., the effect of increased vulnerability to disease on survival) are in most cases self-evident and/or basic ecology. However, empirical information linking changes in intermediate biological functions to changes in overall survival would be especially valuable for evaluating the relative importance of different mechanisms.

Note that there could be analogous expansions of the other mechanisms for indirect effects in Figure 2.2 (e.g., effects on estuary, and effects on arrival timing at estuary) if there were interest in exploring sub-hypotheses for those mechanisms. Reservoirs with large storage capacity (e.g., Mica, Hungry Horse, Brownlee, Grand Coulee, Dworshak, John Day) likely have the strongest effects on seasonal patterns of hydrology and salinity in the estuary (link 2.1). These projects' effects would logically be the focus of an examination of mechanisms for link 2.1.

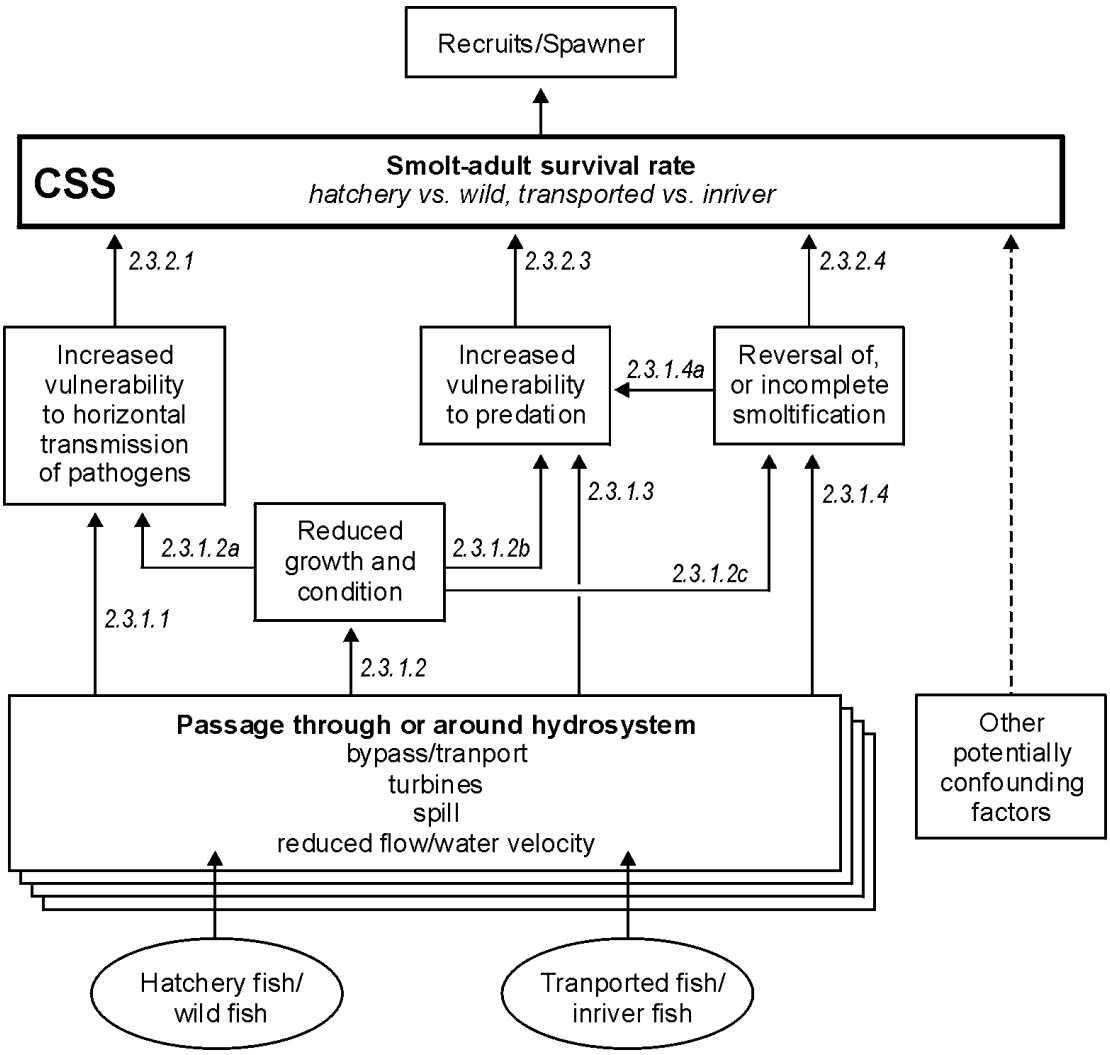

Figure 2.3. The effects of hydrosystem stress on overall smolt-to-adult return ratios (SAR). This figure expands link 2.3 of Figure 2.2. The numbered links represent impact hypotheses, which are described in the text.

Description of hypotheses

2.3.1 *Smolt passage routes through or around the hydrosystem cause various types of stress on smolts that increase vulnerability to mortality factors.*

2.3.1.1 *Amount or extent of passage through or around the hydrosystem increases vulnerability to horizontal transmission of pathogens*. Example mechanisms:

a) Physical injury sustained during passage through bypass/collection systems and turbines compromises immune function

b) Delays, reduced water velocities, and increased water temperatures in reservoirs and forebays cause depletion of energy reserves in smolts, which compromises immune function

c) Confinement of smolts at high densities in barges and collection systems can lead to

higher rates of horizontal pathogen transmission.

d) Sub-link 2.3.1.2a (reduced growth/condition due to hydrosystem stress increases vulnerability to and proliferation of pathogens)

2.3.1.2 *Passage through or around the hydrosystem reduces growth rates or condition of smolts.* This hypothesis does not represent a direct link, but instead could affect delayed mortality through various sub-links:

2.3.1.2a *(reduced growth/condition due to hydrosystem stress increases vulnerability to and proliferation of pathogens)*,

2.3.1.2b *(reduced growth /condition due to hydrosystem stress increases vulnerability to predation)*, and

2.3.1.2c *(reduced growth/condition causes reversal of, or incomplete smoltification*).

Example mechanisms that could affect growth or condition:

e) delays, reduced water velocities, and increased water temperatures in reservoirs and forebays cause depletion of energy reserves in smolts, which reduces smolt growth rates or condition;

f) sudden and extreme changes in water pressures and velocities in bypass/collection systems and turbines cause harmful physiological changes in smolts, which affect smolt growth rates or condition;

g) gas supersaturation during spill at high flows causes physiological damage to smolts passing through spillways, which affects smolt growth rates or condition; and

h) physical injury sustained during passage through bypass/collection systems and turbines affects smolt growth rates or condition.

2.3.1.3 *Passage through or around the hydrosystem increases vulnerability to predation*.

Example mechanisms:

i) delays, reduced water velocities, and increased water temperatures in reservoirs and forebays cause depletion of energy reserves, which makes smolts more vulnerable to predation (e.g., reduces ability to evade);

j) disorientation of smolts upon exiting bypass and collection systems can cause changes in behavior, which makes smolts more vulnerable to predation (e.g., surface orientation exposes smolts to avian predators);

k) sub-link 2.3.1.2b (reduced growth/condition due to hydrosystem stress increases vulnerability to predation); and

l) sub-link 2.3.1.4a (reversal of, or incomplete smoltification due to hydrosystem stress increases vulnerability to predation).

2.3.1.4 *Passage through or around the hydrosystem results in reversal of, or incomplete smoltification*. Example mechanisms:

m) exposure to stressors causes changes in smolts that lead to reversed or incomplete smoltification;

n) sudden and extreme changes in water pressures and velocities in bypass/collection systems and turbines cause harmful physiological changes in smolts, which leads to reversed or incomplete smoltification;

o) increased freshwater residence times in reservoirs result in premature onset of physiological adaptations to saltwater environments;

p) gas supersaturation during spill at high flows causes physiological damage to smolts

passing through spillways, which leads to reversed or incomplete smoltification; and

q) sub-link 2.3.1.2c (reduced growth/condition causes reversal of, or incomplete smoltification).

2.3.2 *Increased vulnerability to mortality factors leads to reduced smolt-to-adult survival rates.*

2.3.2.1 *Increased vulnerability to disease leads to reduced survival rates of smolts.*

2.3.2.2 *Decreased growth or condition leads to reduced survival rates of smolts (sublink).*

2.3.2.3 *Increased vulnerability to predation leads to reduced survival rates of smolts.*

2.3.2.4 *Delayed / incomplete smoltification leads to reduced survival rates of smolts.*

2.1.4 Effects of individual components: Figure 2.4

Figure 2.4 provides more detail on Figure 2.3 by showing hypotheses about the effects of individual components of the hydrosystem (e.g., turbines, bypass, etc.) on biological function and survival. However, the level of resolution of these hypotheses is probably much finer than what can actually be measured and the interactive effects probably cannot be separated empirically at the present. It may be that specific links shown in Figure 2.4 will become important and/or testable at some future date as more is learned subsequent to the workshop.

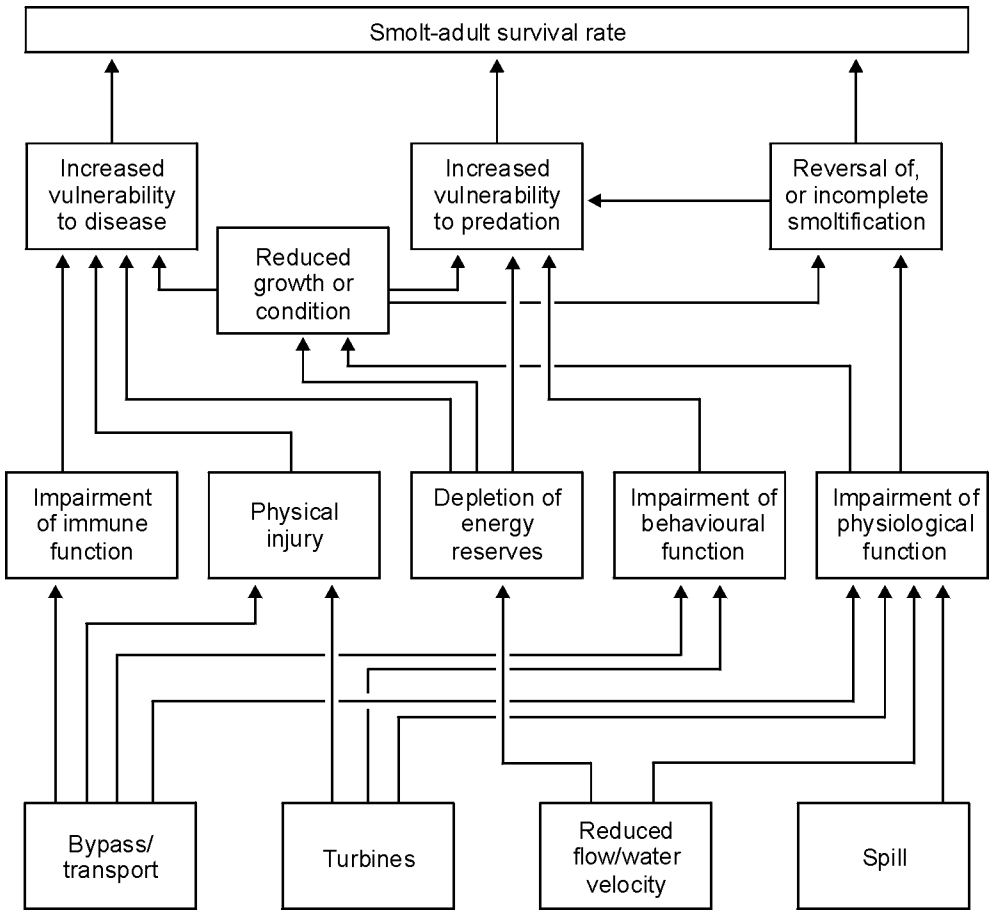

Figure 2.4. The effects of individual components of the hydrosystem on biological function and survival.

2.2 Evaluating hypotheses and evidence

We synthesized the available evidence for and against each hypothesis, and then applied criteria to arrive at an overall assessment of the hypothesis. The set of criteria used for the workshop were adapted from the PATH Weight of Evidence Approach (Marmorek and Peters 1998).

There are two sets of criteria to be specified:

1. *overall criteria* for hypotheses; and
2. *evidential criteria* for assessing the applicability, clarity, and rigor of individual pieces of evidence potentially relevant to particular hypotheses.

We proposed three *overall criteria* for assessing hypotheses. *Evidential criteria* are implicitly considered for criterion 2, and explicitly considered for criterion 3.

Note that different evidence would apply to different levels of hypotheses. For example, more aggregated evidence such as SARs and R/S apply to higher level hypotheses (such as the general hypothesis that the hydrosystem causes delayed mortality), while more detailed types of evidence apply to lower level hypotheses (i.e., specific mechanisms for hydrosystem-caused delayed mortality). The hierarchical nature of the hypotheses diagrams provided a structure for organizing evidence at various levels of aggregation.

2.2.1 Overall criteria

1. *The **clarity** of the hypothesis*

   The intent of this criterion is to assess whether the hypothesis unambiguously describes the effects that are intended. Are the stressors claimed to be driving the hypotheses represented by indicators which reflect those stressors and not other stressors that are part of competing hypotheses? The clarity criterion does not favor single factor hypotheses, since they probably ignore other relevant factors. But where multiple factor hypotheses are proposed, they should be structured in a way that clearly separates the effects of different factors.

2. *The existence of a reasonable **mechanism** or set of mechanisms by which the hypothesis operates*

   The hypothesis must propose a reasonable mechanism by which a given stress is converted into a change in survival. There should be evidence from physiological studies or direct survival measurements in the field to clearly associate a proposed stress with a reduction in survival.

3. *The consistency with empirical evidence*

   Measures of stock performance or individual fish should vary inversely with the magnitude of the stressor across contrasts in space and time. Various measures of stock performance should be examined. These may include: recruits per spawner; smolt to adult return rates (SARs); productivity (Ricker ‘a’); transport-to-control ratios; and various survival measurements (e.g., recruitment anomalies from stock-recruitment curves, estimates of post-Bonneville survival, estuarine survival, etc.). Measures of stress in fish (i.e., behavior, physiology, performance) should consistently vary with the hypothesized stressor. This involves assessing the degree to which the hypothesized stressor has consistent impacts on survival or stress indicators in different times and places, all other things being equal. The degree of consistency may vary with the type of statistical analysis used.

2.2.2 Evidential criteria

Evidential criteria are used implicitly with *overall criterion* 2 (mechanism) and explicitly with *overall criterion 3* (consistency with empirical evidence). For criterion 3, each of the three evidential criteria is assessed on a 3-point scale, where '1' is best, and '3' is worst.

i) *Applicability:* Is the evidence relevant to the hypothesis being evaluated (i.e., is it the right stock, monitored in the right place at the right time)?

ii) *Clarity:* Is the evidence clear, and not contested or confounded by other information, or an absence of sufficient good quality measurements?

iii) *Rigor:* Is the evidence: 1) well established, generally accepted, peer reviewed empirical evidence from relevant experiments and observations; 2) strong evidence but not fully conclusive; 3) theoretical support with some evidence.

No attempt was made to relate/standardize the scores across reviewers; the numerical scoring provides only a rough indication of an individual reviewer's assessment of the evidence. If two individuals reviewed the same paper, the criteria values recorded were an average of the reviewers' scores.

These criteria, and the method of synthesis (e.g., numerical score, summary conclusion in words) were open to revision by the workshop participants. The summary table developed by the workshop participants was supported by a narrative going into more depth on each component hypothesis and its level of support. Refining these hypotheses and applying appropriate criteria to evaluate them was a primary objective of the CSS workshop.

2.2.3 Differences among subgroups in the approach used

The above approach worked well for Subgroup B, which analyzed existing literature. Subgroup A, however, ended up conducting a considerable number of high-level new data analyses. As these analyses are finalized, it should be possible to apply the methods outlined in Sections 2.2.1 and 2.2.2 to some of the work conducted by Subgroup A.

3.0 Evaluation of Hypothesis 2

Subgroup A (see Appendix B) was charged with evaluating evidence for Hypothesis 2: *Passage through or around the hydrosystem causes indirect mortality to smolts that may not be expressed until the estuary/ocean life stage*.

Based on initial discussions, Subgroup A felt that their efforts should first be directed at more clearly documenting the patterns that suggest delayed mortality is occurring. This included assessing observed differences in SARs between different stock groups (i.e., hatchery vs. wild, transported vs. inriver, upstream vs. downstream).

The second step was to evaluate different potential causal mechanisms for such differences. The participants explored the evidence for five of the six possible mechanisms described in Figure 2.2 (i.e., hydrologic changes, timing of estuary entry, changes in developmental state, fixed mortality/day, bypass effects of smolt bypass structures). These mechanisms were evaluated in the context of other potentially confounding factors which also affect SARs (e.g., natural variability in freshwater, estuary and ocean conditions; harvest). The sixth mechanism in Figure 2.2, stress, was the focus of work by Subgroup B (see Appendix B).

3.1 Critical patterns that need to be explained

Are there patterns in monitored survival measurements (SARs, D, etc.) that suggest the freshwater hydrosystem experience leads to increased rates of mortality in the estuary and ocean (Hypothesis 2)? If so, are these patterns real or artifacts? Table 3.1 presents Subgroup A's summary of survival patterns (and possible sampling biases) observed among transported and non-transported, wild and hatchery released chinook and steelhead in the Columbia River. The list in Table 3.1 comes from a variety of sources, and is not a comprehensive catalog of survival patterns, but rather highlights some critical points made by various authors for and against Hypothesis 2. Assessing the reliability of analytical techniques used to identify these patterns was a major focus of Subgroup A discussions at the workshop.

Table 3.1. Apparent survival patterns (and possible implications for Hypothesis 2) for chinook and steelhead in the Columbia River. Sources indicated in footnotes. (+ = pattern consistent with Hypothesis 2, - = pattern inconsistent with Hypothesis 2, 0 = neither for or against Hypothesis 2).

ESU	Non-Transported		Transported	
	Hatchery	Wild	Hatchery	Wild
SR spring/ summer CH	+ SARs of undetected fish generally higher than SARs of fish going through 1 or more bypasses[c] - Smaller fish consistently detected at higher rates than larger fish, so lower survival just a function of size, not hydrosystem impact[d] Hatchery differences: + Durvoshak, McCall, Rapid River, Imnaha have higher SARs for C_0 than C_1[c] - Looking Glass and Carson SARs for $C_0 \approx C_1$[c] - Carson stock BON-to-BON SAR approximately equal or less than McCall and Rapid River LGR-to-LGR SARs in recent years, yet Carson only passes through 1 dam vs. 8 dams for Snake R. stocks	- No difference in SARs among fish experiencing different # bypasses in 1999 and 2000 migrants[b] + Higher SARs of undetected fish in some earlier years[c] - Smaller fish consistently detected at higher rates than larger fish[d] + Some stocks (Yakima through 1996; JDA in 2000; Warm Springs) passing through fewer dams had higher SAR relative to Snake R. stocks than can be explained by direct survival[a,e] + PATH upriver/downriver and time period contrast showed λ_n "extra mortality" for in-river fish, ~0.7 when D~0.6[f] - High recent SARs ~4%, coupled with D ~ 0.5 and max historical SARs ~ 4-6%, inconsistent with high extra mortality of in-river migrants[b] + SARs negatively correlated with Water Travel Time (WTT) and positively correlated with climate effects[a]	+ Annual D consistently <1 (~0.6)[c] 0 Annual D varies among hatcheries (spring vs. summer CH; long vs. short distance from LGR)[c] + Within-year D low early and high later in season[b]	+ Annual D consistently <1 (~0.5) + Within-year D low early and high later in season[b] + SARs negatively correlated with % smolts transported[a] + SARs for transported fish < C_0 SARs in 4 of 6 years[g]: similar conclusions in ref. h
SR Steelhead	+ SARs of undetected fish higher than SARs of fish going through 1 or more bypasses[c] - Smaller fish consistently detected at higher rates than larger fish[d]	- No difference in SARs among fish experiencing different # bypasses in 1999 and 2000 migrants[b] + Higher SARs of undetected fish in some earlier years[c] - Smaller fish consistently detected at higher rates than larger fish[d] + Steelhead SARs negatively correlated with WTT[a]	0 Annual D highly variable among years (~0.3-1.6) + Within-year D lower early in season	+ Annual D consistently <1, but variable among years (~0.2-0.8) + Within-year D lower early in season
SR Fall chinook		+ PATH upriver/downriver and time period contrast showed "extra mortality" for in-river fish, ~0.4 when D~0.2	+ Sparse info suggests D is quite low, perhaps 0.2	+ Sparse info suggests D is quite low, perhaps 0.2

[a] State, Federal and Tribal Anadromous Fish Managers. 2003
[b] Williams et al. 2003 (draft). Effects of the Federal Columbia River Power System on Salmon Populations. NOAA Fisheries Technical Memorandum (pgs. 44-53)
[c] Berggren et al. 2003; 2004. CSS 2002 and 2003 Annual Reports.
[d] Zabel et at. 2003 (draft). Estimating population survival and selection for phenotypic traits despite confounding behavioral variability.
[e] Weber, E. 2003. Proposal for debate on delayed mortality (memo).
[f] Deriso et al. 2001. Retrospective patterns of differential mortality and common year-effects experienced by spring and summer chinook (*Oncorhynchus tshawytscha*) of the Columbia River; Marmorek and Peters (eds.) 1998. PATH preliminary decision analysis report.
[g] Bouwes et al. 2001. CSS study.
[h] Sandford and Smith. 2002. Estimation of smolt-to-adult return percentages for Snake River basin anadromous salmonids, 1990-1997. Journal of Agricultural, Biological, and Environmental Statistics.

3.2 Clarification of survival patterns

On the first day of the workshop, Subgroup A spent some time discussing Table 3.1 to ensure that all of the survival patterns were clearly defined and well understood. The following three subsections summarize participants' comments; more detailed analyses completed after the meeting are presented in Section 3.3.

3.2.1 Within-year changes in SARs and D

Bill Muir presented data from Williams et al. (2003) on within-year changes in SARs and D for cohorts of in-river and transported chinook and steelhead that were tagged or marked during specific weeks at Lower Granite Dam. These data are shown in tabular form in Table 3.3 (Section 3.6.1) and graphed in Appendix C. Participants cautioned that the confidence intervals on these estimates of D and SAR will vary inversely with the number of fish tagged or marked. Estimates of D and SAR will therefore be less reliable during periods with fewer migrants, and will be less reliable for wild fish than for hatchery fish.

3.2.2 Effects of smolt size and bypasses on survival (Hypothesis 2.5)

Zabel (2003) and Williams et al. (2003) have discussed the idea that size-selection of smaller fish by bypass structures could contribute to the observed pattern (in 1994-1998 but not in 1999 and 2000) of higher SARs in fish not detected at any bypass (the C_0 group) relative to fish which go through one or more bypasses (the C_1 group).

Subgroup A raised several points on this issue:

- The size/bypass effect may not have been as strong in 1999 and 2000 due to better ocean conditions (i.e., small size or bypass stress did not create as much of a disadvantage).
- Size is clearly not the only factor affecting survival, since hatchery fish are larger than wild fish but survive less well as a group, and hatchery fish don't survive as well as same-size wild fish.

The subgroup thought it would be worth examining SARs as a function of: 1) wild vs. hatchery categories; 2) smolt-length; and 3) the interaction between variables 1 and 2.

Margaret Filardo noted that changes in hydrosystem operation could also affect the relative survival of C_0 and C_1 groups. With less spill, more of the C_0 group will go through turbines, and the C_0:C_1 ratio should decline. Carl Schreck pointed out that watershed conditions may vary from year-to-year, affecting the quality of fish entering the hydrosystem. If the bypass selects poor quality fish, then better watershed conditions would lead to less selection. Observations of fish quality are required to test this hypothesis. He also noted that experimental information on salt water preferences after stress appears consistent with the hypothesis that bypasses would reduce survival rates. Finally, Charlie Petrosky reminded participants that in order to assess indirect mortality effects, the direct survival effects need to be filtered out from SARs.

3.2.3 Comparisons of SARs among fish from different hatcheries

Contrasts between stocks from different hatcheries have been used to make inferences about the effects of dams (e.g., Carson stock point in Table 3.3; column 2). Participants stressed that the quality of fish released by different hatcheries also must be considered. For example, Carson and Looking Glass are both

collections of different stocks, and Carson has very cold water. McCall and Imnaha are considered 'clean' stocks genetically, whereas Dworshak is mostly Rapid River stock.

3.3 Exploration of survival patterns

3.3.1 Comparison of data sets and assumptions used by NOAA-F and IDFG in computing recent SARs for Snake River wild smolts *(C. Petrosky and H. Schaller)*

Different agencies have used somewhat different SAR metrics and drawn different conclusions about recent changes. SAR data therefore need to be carefully scrutinized to ensure consistent and appropriate metrics are being used (some cautionary notes on confidence intervals were presented in Section 3.2.1). Howard Schaller and Charlie Petrosky met with John Williams of NOAA to compare data sets and assumptions used by NOAAF and IDFG in computing recent SARs for Snake River wild smolts. The following sections explore why NOAA's recent year SARs are higher than the CSS PIT-tag and IDFG SARs, and why NOAA's historic SARs are lower than previously published values.

Recent year SAR data sets

Comments by state and tribal salmon managers and USFWS on the NOAAF draft technical memo (Williams et al. 2003) 'Effects of the Federal Columbia River Power System on Salmon Populations' challenged the NOAAF claim that non-transported fish do not experience delayed mortality (or have very little). The NOAAF conclusion that SARs are currently 4% for the unmarked Snake River wild spring/summer chinook was not documented well enough to determine whether it is scientifically supportable. However, NOAAF's SAR estimates exceed SARs for PIT-tagged in-river migrants in these years. Past comparisons (Kiefer et al. 2001) have shown PIT tag SAR estimates from CSS were similar to the unmarked population (Figure 3.1).

Issues raised by co-managers with NOAAF estimates of SARs for the run-at-large were addressed in March-April, 2004 through the collaboration process for the 2000 Biological Opinion Remand. Progress was made to determine why the results and conclusions were so dramatically different between these two analyses, however resolution of the "best" method to estimate SARs for the run-at-large has not been finalized.

It is important to recognize that neither the numerator (adults) nor denominator (smolts) for the run-at-large SAR estimates is count data. The adult dam counts are for wild and hatchery fish combined, from which the two components must be estimated. Because a large proportion of the dam count is now comprised of hatchery fish, estimated wild run-size will be sensitive to errors in estimating hatchery run-size. From 1985 to 2000, the *U.S. v. Oregon Technical Advisory Committee* (TAC) estimated wild adults at LGR simply as a residual of the total count after accounting for hatchery rack returns, estimated tributary harvest (tributary harvest was virtually 100% hatchery-origin in these years), and an assumed pre-spawning mortality (20% on hatchery fish) to estimate total hatchery run-size at LGR.

Accounting for wild adults at LGR has become more complex in recent years. Mass marking of hatchery spring/summer chinook with an adipose fin-clip began in 1993, and WDFW began visually counting the proportion of adults with and without adipose fin clips in 1999. Supplementation groups without adipose-clips have been released since 1999, which were not visually identifiable at the adult counting windows (these fish had blank wire tags and/or other marks). In addition, there have been a small proportion of fish with misclipped adipose fins, which were not identified visually in the adult counting windows. Therefore, TAC's recent year wild adult accounting has relied on the total adult dam count, adjusted by

the proportion of visually identifiable adipose clips, and by the proportion of non-adipose clipped fish of hatchery origin. As noted above, estimating this latter proportion has become more complex.

Accounting for wild smolts has also been complicated by release of non-adipose clipped hatchery origin fish. The FPC Smolt Monitoring Program (SMP) began in 1999 to index natural origin smolts from a combination of marks and tags: adipose clip, blank wire tag, elastomer tag (e.g., FPC 2000).

Initial diagnostics from the BiOp Remand collaboration process indicated that the NOAAF estimates of wild adults returning to LGR (Williams et al. 2001) were 28% higher than those reported by IDFG (Kiefer et al. 2001) (geometric mean from 1996-2000 smolt years). The IDFG method used TAC run reconstruction estimates for wild adults, whereas NOAAF used their own accounting methods. To date the on-going collaboration (R. Kiefer, C. Petrosky, H. Schaller, J. Williams) has identified several accounting issues related to non-adipose clipped groups, which will change (likely reduce) the NOAAF wild adult estimates. Potentially, this work may also result in changes to the TAC accounting methods.

A second issue identified with NOAAF run-at-large SARs for wild spring/summer chinook is the wild smolt accounting. NOAAF adjusted (reduced) the FPC wild passage index for non-clipped hatchery origin smolts, and IDFG did not. The result is that NOAAF wild smolt estimates averaged 5% lower than those of IDFG (1996-2000 geomean). Combined with 28% higher estimates of wild adults, the NOAAF SARs were 35% higher than those of IDFG. However, the FPC wild passage index already took the non-adipose-clipped fish into account, so it appears the NOAAF wild smolt estimates were inflated.

A third issue identified was annual adult age composition. Since 1998, IDFG has estimated age composition using length frequencies from video sampling at LGR, and aged fin-ray samples collected from carcasses on the spawning grounds in Idaho and NE Oregon (e.g., Kiefer et al. 2001). NOAAF age composition estimates were more indirect, based on age composition of PIT tag groups. Generally, errors in age structure would be expected to result in bias to individual year SARs from misallocation of adult returns to the wrong smolt years. However, average SARs for multiple years would not be as sensitive to this measurement error. NOAAF is currently incorporating the IDFG age composition estimates into their run reconstructions.

The question of whether the PIT tag SARs for wild spring/summer chinook are biased low relative to the run-at-large is not yet resolved. However, the comparison of IDFG SARs (using TAC wild adult estimates) and CSS estimates of SAR for wild spring/summer chinook do not suggest a systematic bias (Figure 3.2). Point estimates of SARs from IDFG run reconstructions fall within the confidence intervals from the CSS PIT tag groups in all years except smolt year 2000. CSS increased wild spring/summer chinook tagging in 2002, which should yield more precise SAR estimates in future years. The question of whether SARs are biased low for PIT tagged wild spring/summer chinook smolts (Williams et al. 2003) is more difficult. Because of the complexity of accounting for wild adults numbers, a difference between SARs may imply bias for the run reconstruction method, the PIT tagging or both.

Historic year SAR data sets

In the NOAAF draft technical memo (Williams et al. 2003), historic SARs appeared lower than previously published values. The source of this difference was two different run reconstruction data sets, with different accounting for numbers of wild adult returns and harvest. Differences in accounting and expansions for alternative sources of historic SARs are outlined in Table 3.2.

The NOAAF technical memo adjusted the age 4 and 5 returns from Petrosky et al. (2001; Appendix A) upward to include mainstem harvest rates (Williams, pers. comm.). The NOAAF estimates excluded jacks (age 3), and did not expand for historic upstream passage survival rates (conversion rates), but did include

an expansion for mainstem harvest rates (Table 3.2). Consequently, the NOAAF SARs are lower than those reported in Petrosky et al. (2001), which included jacks and expanded for mainstem harvest rates and conversion rates.

NOAAF's historic SARs were also less than those reported in Marmorek et al. (1998; Table B.3-7), and used in the NMFS 1998 and 2000 Biological Opinions. The SARs reported in Marmorek et al. (1998) for years before 1985 used the adult return values (with minor age structure adjustments) from Raymond (1988), which included jacks, accounted for mainstem harvest rates, but excluded conversion rates.

The "best" measure of SAR depends on the purpose of the comparison and life stage for which an inference is needed. If the desired inference is to the mouth of the Columbia River, the SAR should include effects of tributary and mainstem harvest and upstream dam passage conversion rates. Including or excluding jacks in the SARs would depend on whether one intends to count only mature fish (e.g., spawner:spawner ratio) or whether total recruits are desired. Note that for Snake River spring/summer chinook, jacks comprise a small proportion of the total recruitment (Petrosky et al. 2001; Appendix A Table A1). The Petrosky et al. (2001) SARs were based on jacks and adult returns to the Columbia River mouth, specifically to examine which life stage (adult-to-smolt or smolt-to-adult) was responsible for the historical decline in life cycle productivity and survival rate reported by Schaller et al. (1999).

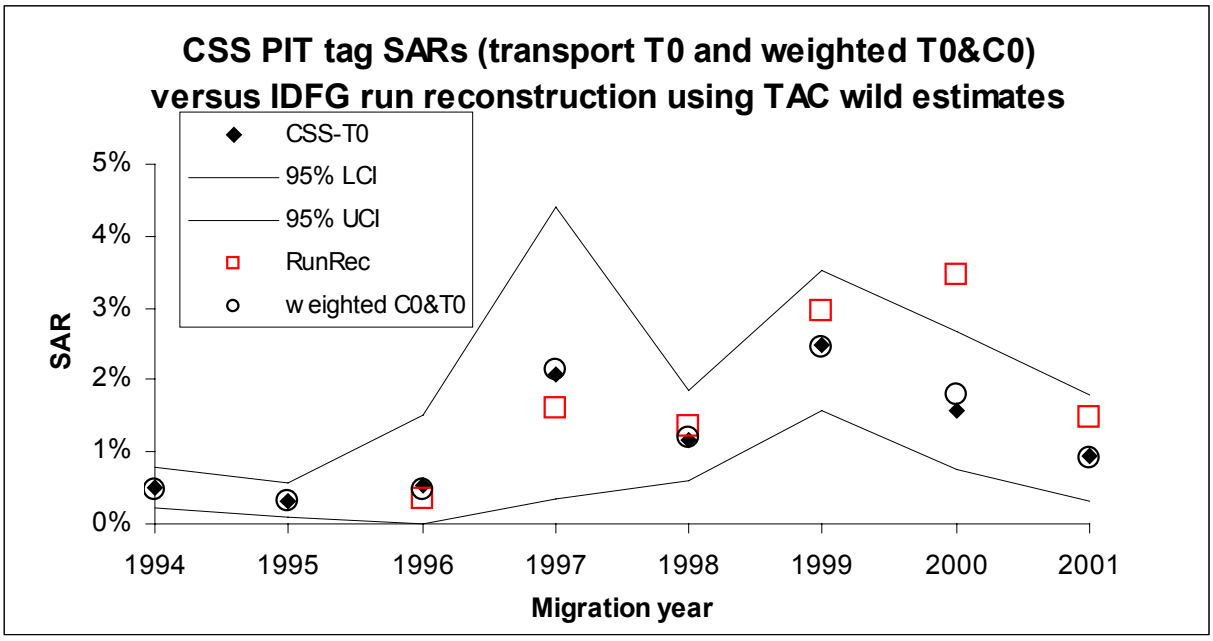

Figure 3.1. Estimated SARs for wild Snake River spring/summer chinook, for the run-at-large (untagged; IDFG) (open red squares], and for PIT-tagged smolts from the Comparative Survival Study (PIT CSS) (T0 =solid diamonds; overall T0&C0 = open circle). Confidence interval plotted for T0 only. CSS estimates from Berggren, 12/03 memo. Run reconstruction estimates updated from Kiefer et al. (2001).

Table 3.2. Historic SARs: sources, adult accounting and expansions.

	Adult run reconstruction			Expansion accounts for:	
SAR source	Run size	Age composition	Include jacks?	Mainstem harvest rate	Conversion rate
NOAAF, Williams et al. (2003 draft)	Petrosky et al. (2001)	Petrosky et al. (2001)	no	yes	no
Petrosky et al. (2001)	Run reconstruction, uses WDFW & ODFW (1999) accounting	Run reconstruction, uses age composition from index stocks	yes	yes	yes
Marmorek et al. (1998) Table B.3-7	pre-1985, used Raymond (1988); updates from run reconstructions (Petrosky and Schaller 1998).	pre-1985, used Raymond (1988); updates from index stock age composition (Petrosky and Schaller 1998).	yes	yes (SAR2); no (SAR1)	no
NMFS 1998 and 2000 Biological Opinions	Marmorek et al. (1998)	Marmorek et al. (1998)	yes	yes (SAR2); no (SAR1)	no
Raymond (1988)	Run reconstruction, upper dam counts	Spawning ground surveys from index stocks	yes	yes	no

The remainder of Section 3 examines hypothesis 2 in more detail, both the overall hypothesis (Section 3.4) and particular components (Sections 3.5 to 3.9).

3.4 Do in-river fish currently show evidence of delayed mortality? *(Hypothesis 2; H. Schaller and C. Petrosky)*

Hypothesis 2: *Passage through or around the hydrosystem causes indirect mortality to smolts that may not be expressed until the estuary/ocean life stage*.

As an overall analysis of Hypothesis 2, Howard Schaller and Charlie Petrosky examined recent data series to determine whether there is evidence of continuing upstream-downstream differences in life cycle survival that could be attributable to delayed mortality. This work involved an updated calculation of λ_n (post-Bonneville survival factor for in-river fish, see Section 1.2 and Appendix D for definitions) and a common year effect (λ which reflects ocean and climate factors affecting both upstream and downstream stocks.

Snake River salmon and steelhead *Oncorhynchus* spp. have substantially declined since the completion of the Columbia River hydrosystem. Through PATH and the CRI processes, analytical approaches were used to identify management options for halting the decline of these stocks. The benefits these actions are predicted to have on salmon recovery hinge on whether the source of mortality that takes place in the estuary and early ocean is related to earlier hydrosystem experience during downstream migration. Budy et al. (2001) reviewed evidence from the literature that demonstrates numerous mechanisms that would explain this delayed mortality in relation to a fish's experience passing through the hydrosystem. Spatial and temporal comparisons of stock performance provide indirect evidence of delayed mortality and that delayed mortality is linked to hydrosystem experience. Recent mark-recapture data also provide evidence of differences in delayed mortality by route of passage through the hydrosystem. The different types of evidence discussed in Budy et al. (2001) suggest that the delayed mortality of Snake River fish is related to the hydrosystem.

Substantial evidence supports the existence of delayed mortality for Snake River chinook salmon and steelhead and links delayed mortality to hydrosystem experience. This evidence comes in the form of published literature on causes of stress (reviewed in Section 4 of this report) and resulting delayed mortality, indirect evidence from life-cycle modeling based on historical data and known mechanisms, and direct evidence from fish-tagging experiments. The PATH retrospective life-cycle analysis provides indirect evidence of increases in delayed mortality in Snake River spring and summer chinook salmon coincident with completion of the Snake River hydrosystem (Schaller et al. 1999; Deriso et al. 2001). The declines in survival rates of Snake River fish were considerably sharper than those of downriver stocks over the same time period. Further, most survival rate declines were in the smolt-to-adult life stage, rather than the spawner-to-smolt life stage (Petrosky et al. 2001).

The Delta model used in PATH (Deriso et al. 2001) uses spawner-recruit data to estimate the instantaneous differential mortality (μ) experienced by 7 Snake River spring/summer chinook stocks relative to lower Columbia River stocks. The best fit stock-recruit models included a common year-effect (for all stocks.

We updated the Delta model with additional brood years 1991-1998, and only used the three John Day stocks for the lower Columbia River group. This is consistent with the findings of Hinrichsen (2001) that John Day stocks had the most influence of the lower Columbia River stocks. Data sources were the updated run reconstructions by E. Tinus (ODFW) and C. Petrosky (IDFG), assembled for the Interior Columbia Technical Recovery Team.

The Delta model produced estimates for common year-effects (δ) (Figure 3.2), μ (Figure 3.3), and Ricker a and β parameters. From the estimates of μ we can derive an estimate of λ_n. λ_n is a post-Bonneville survival factor for non-transported smolts. For spring-summer chinook, this variable is estimated indirectly, and depends on several other variables: the total mortality (*m)* including both passage and extra mortality; the direct mortality estimated from passage models (*M*); the fraction of fish below Bonneville which were transported (*Pbt*); and *D*. For details see the PATH Preliminary Decision Analysis report (Marmorek et al. 1998; pg. A-92), or the Delta model description attached to the AFISH Appendix (a glossary of terms used in the Delta model is provided in this report in Appendix D).

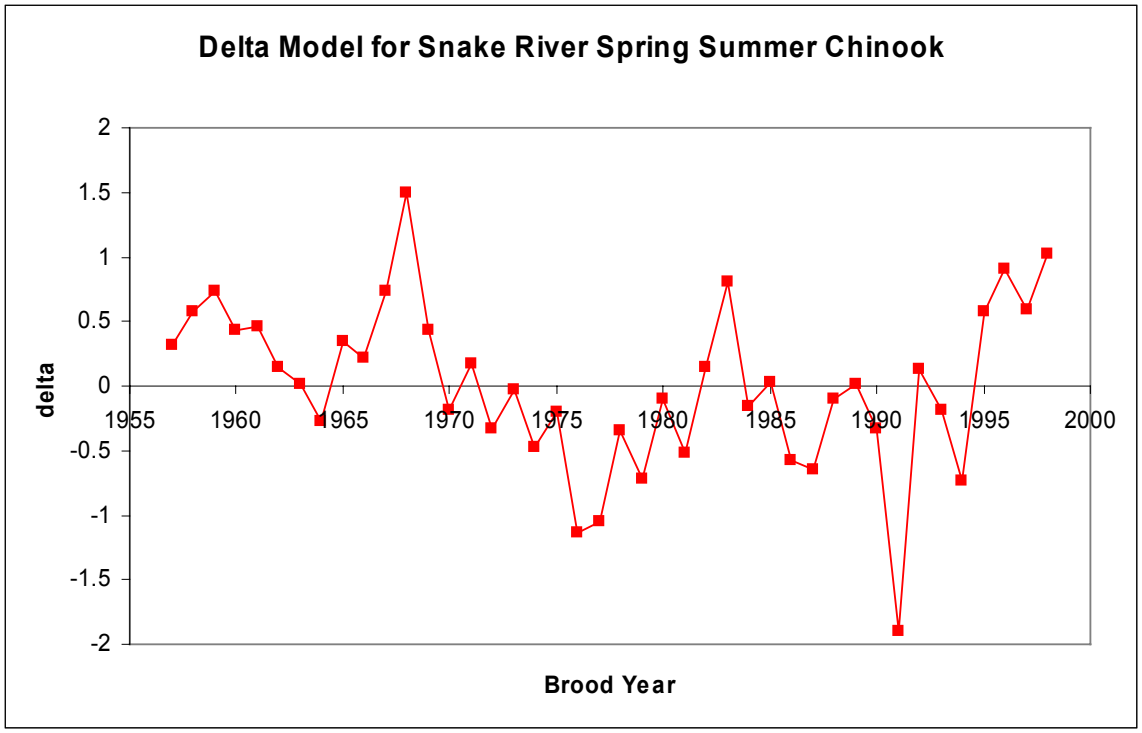

Figure 3.2. Year effect for Snake River and John Day stocks (updated δ). Updated results use 1957-1998 brood year data with 7 upriver stocks Johnson Cr., Poverty Flats, Sulphur Cr., Marsh Cr., Bear Valley/Elk Cr., Imnaha R., Minam R. and 3 downriver stocks John Day Main, John Day Middle Fk., John Day North Fk.

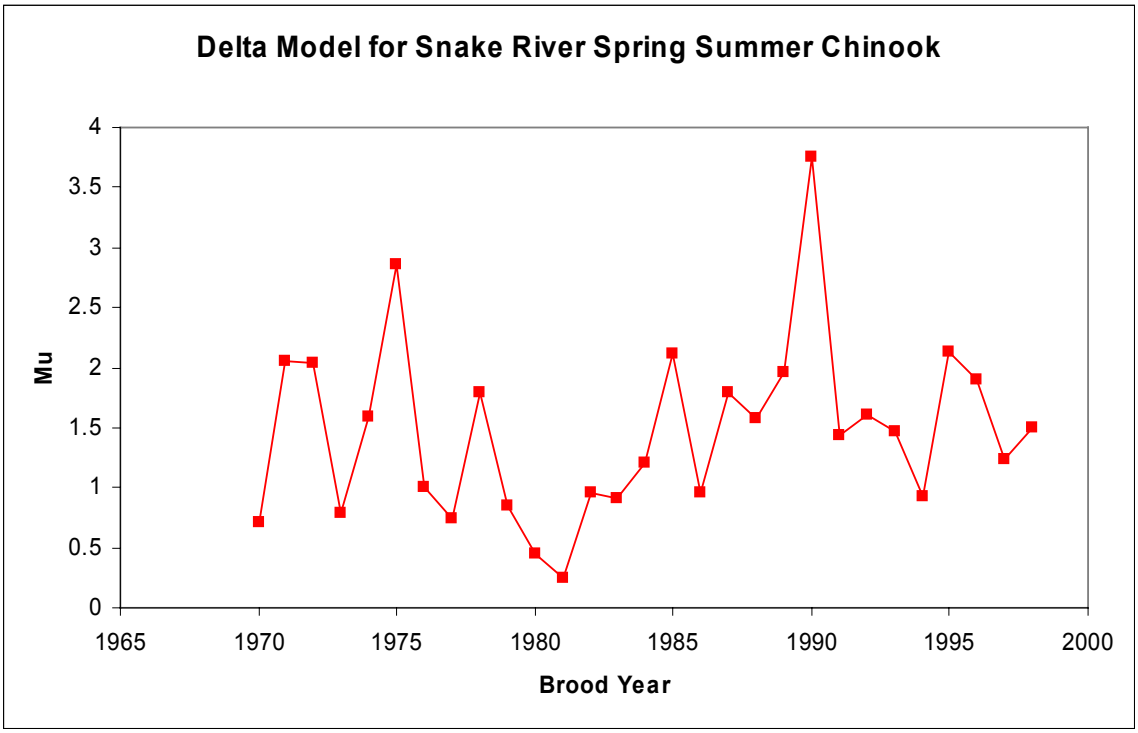

Figure 3.3. Differential mortality of Snake River vs. John Day stocks (updated μ). Updated results use 1957-1998 brood year data with 7 upriver stocks Johnson Cr., Poverty Flats, Sulphur Cr., Marsh Cr., Bear Valley/Elk Cr., Imnaha R., Minam R. and 3 downriver stocks John Day Main, John Day Middle Fk., John Day North Fk.

We estimated λ_n for all available brood years 1975–1998 using the estimates of μ from the updated run reconstructions, and compared the estimates with those from PATH. For brood years 1991-1998 (smolt years 1993-2000), we used CSS and NOAA-F data sources to partition the estimates of μ from the Delta model. CSS estimates of *D* and *Vc* for wild spring/summer chinook, brood years 1992-1998, were from Table 8 of the 2002 annual report (Berggren et al. 2003). *Pbt* was estimated from total numbers of wild PIT-tagged chinook arriving at LGR and numbers of in-river migrants in the category C_0 (Table 5 in CSS 2002 draft annual report) for these same brood years. Estimates of total direct mortality included survival through LGR pool, which we obtained from Williams et al. (2003; Table 18). Earlier brood years, prior to CSS estimates, required the use of passage model estimates for *Vc* and *Pbt*. We used average values from FLUSH and CRiSP for brood years 1975-1990, and FLUSH values for 1991 (CRiSP estimates not available), coupled with an average *D* value of 0.53 for all years before brood year 1992. The updated λ_n estimates were compared with those from PATH for brood years 1975-1990. Despite recent improvements in climate/ocean conditions (reflected in positive values of λ for brood years 1995–98; Figure 3.2), the overall mortality of Snake River stocks remains much higher than John Day stocks for these brood years λ; Figure 3.3).

The report's editors note that estimates of λ_n involve many inputs, including passage model estimates in some years. Thus λ_n is an indirect measure of delayed mortality at least without estimated confidence intervals. It should be possible (at least in theory) to generate confidence intervals for λ_n for more recent brood years that have direct CSS estimates of D and V_c.

The estimates for the time series of λ_n indicate that the value has stayed low in recent brood years (Figure 3.4). This provides evidence that delayed mortality ($1-\lambda_n$) for Snake River spring/summer chinook populations remained high in recent years (Figure 3.5). These estimates are contrary to the interpretation of SAR information by NOAA Fisheries that in recent years there may be very little delayed mortality of in-river fish (Williams et al. 2003).

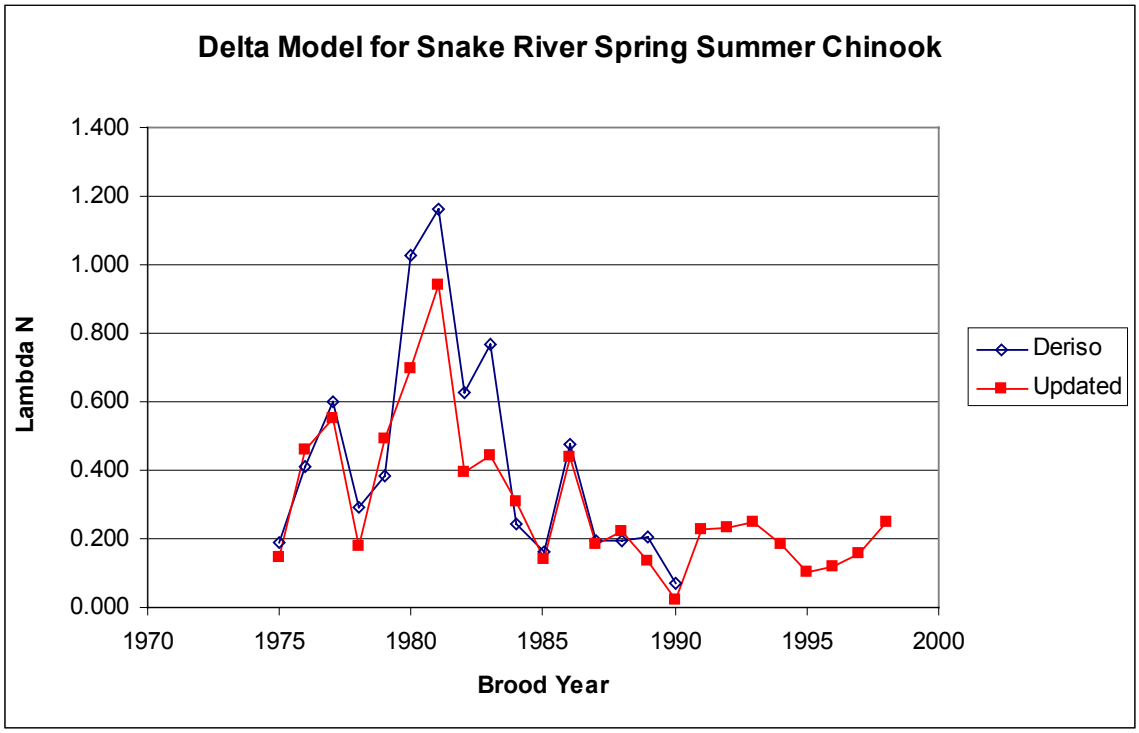

Figure 3.4. Comparison of estimated λ_n from PATH (Deriso et al. 2001), brood years 1975-1990 and updated estimates, 1975-1998.

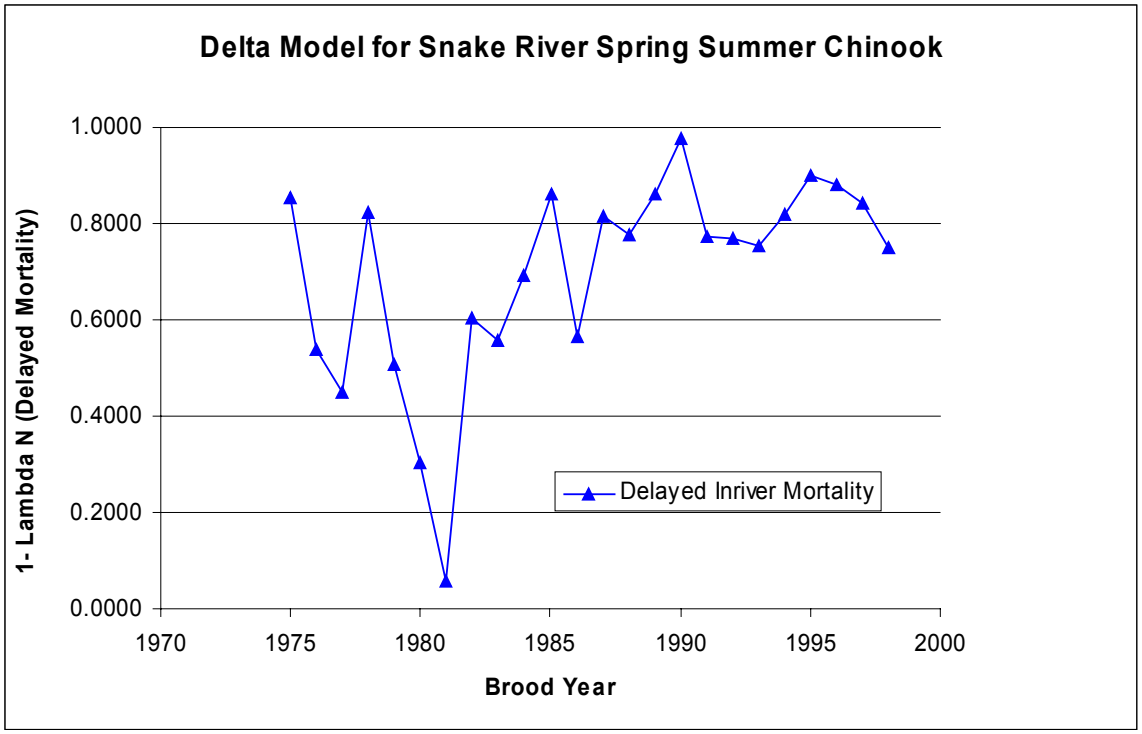

Figure 3.5. Estimated delayed mortality of in-river migrants, 1-λ_n, brood years 1975-1998.

The time series of common year effects δ (Figure 3.6) exhibited an increase beginning in brood year 1995, which is consistent with observations of improved ocean productivity and climate conditions favorable to salmonids. Updated common year effect estimates were generally similar to those from PATH for brood years 1975–1990.

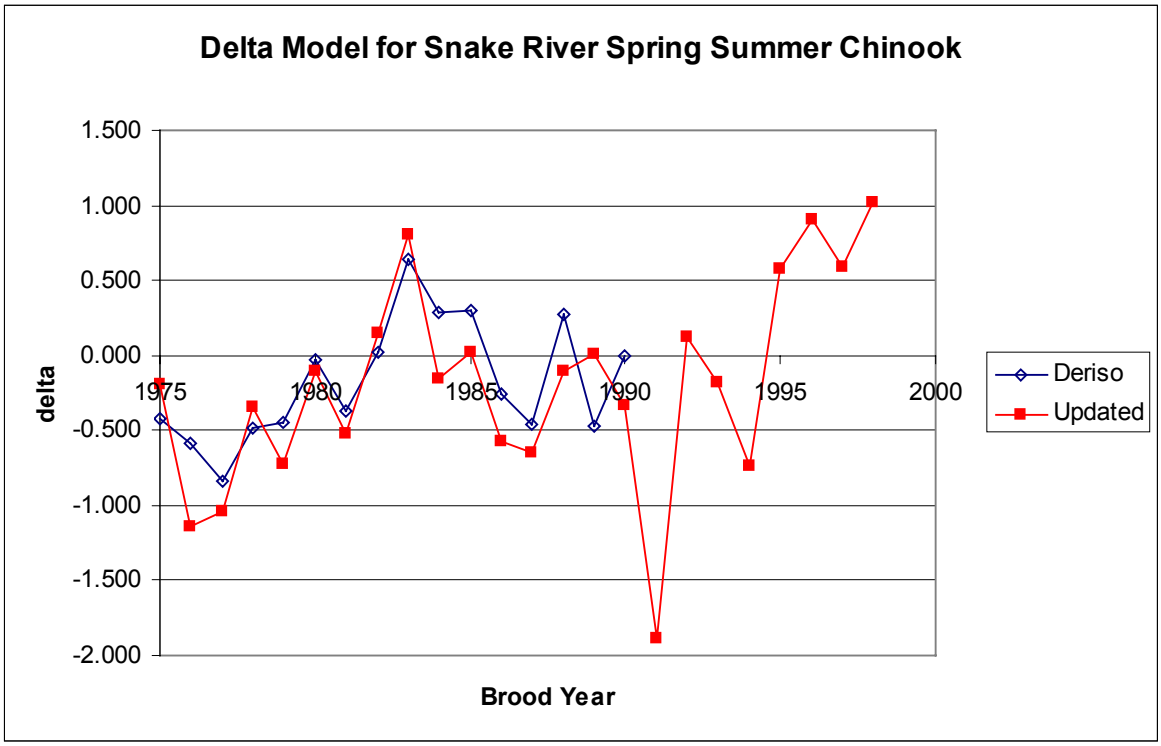

Figure 3.6. Comparison of the estimated common year effect, δ, from PATH (Deriso et al. 2001), brood years 1975–1990 and updated estimates, 1975-1998.

3.5 Hydrologic changes in the estuary (Hypothesis 2.1)

Hypothesis 2.1*: The hydrosystem* ***indirectly*** *affects smolt-to-adult survival (SARs) by causing changes in hydrologic conditions in the estuary.*

This hypothesis suggests that changes in seasonal flow patterns, turbidity or salinity could cause delayed mortality. There is little question that water management could potentially affect both direct mortality and indirect mortality, and consequently could have measurable effects on SARs. However, both transported/ in-river and upstream/downriver fish should be equally affected by estuary conditions. Hence this mechanism is probably not an explanation of differential survival between these groups, unless conditions change for transported vs. in-river fish based on arrival times (an interaction with the timing hypothesis). In this regard, estuarine conditions would be more likely to have potentially significant effects on fall chinook (than on spring chinook), as transported fall chinook arrive at a smaller size than in-river fish and spend more time foraging in the estuary.

Although little work has been done to date that might allow further evaluation of this specific hypothesis, several authors have looked at pre-development and post-development conditions in the estuary, and begun to examine spatial and temporal changes that might be useful for future analyses in this regard. We present below two extracts of recent papers relevant to this topic.

3.5.1 Historical changes in freshwater flows *(E. Casillas)*

Casillas (1999) noted that the extent, propagation and impact of the Columbia River plume on salmon productivity are affected by both marine factors (e.g., coastal upwellings and currents) and freshwater factors. He noted that there have been many changes in the freshwater factors:

> "The shape and extent of the Columbia River plume is also controlled by the amount of freshwater flowing out of the Columbia River. Not only the flow or amount of water may be important but also the amount of sediment affecting turbidity, and the amount of nutrients fueling estuarine and oceanic productivity may be important to salmon growth and survival. Historical changes in flows of the Columbia River have been observed. Flow regulation, water withdrawal and climate change have reduced the average flow and altered the seasonality of Columbia river flows and sediment discharge, and have changed the estuarine ecosystem (NRC 1996; Sherwood et al. 1990; Simenstad et al. 1990; 1992; Weitkamp et al. 1995). Annual spring freshet flows through the Columbia River estuary are ~50% of the traditional levels that flushed the estuary and carried smolts to sea, and total sediment discharge is ~1/3 of 19th Century levels. Decreased spring flows and sediment discharges have also reduced the extent, speed of movement, thickness, and turbidity of the plume that extended far out and south into the Pacific Ocean during the spring and summer (Barnes 1972; Cudaback and Jay 1996; Hickey et al. 1997). Pearcy (1992) suggests that low river inflow is unfavorable for juvenile salmonid survival despite some availability of nutrients from upwelling, because of: a) reduced turbidity in the plume (increasing foraging efficiency of birds and fish predators), b) increased residence time of the fish in the estuary and near the coast where predation is high, c) decreased incidence of fronts with concentrated food resources for juvenile salmonids, and d) reduced overall total secondary productivity based on upwelled and fluvial nutrients. Reduced secondary productivity affects not only salmonid food sources but focuses predation by other fishes and birds on the juvenile salmonids."

3.5.2 Modeling of estuarine physical conditions *(Bottom et al.; reviewed by H. Schaller)*

Recent modeling work by NOAA in evaluating the capacity of the Columbia River estuary to support salmon was documented in: 'Salmon at the River's End: The Role of the Estuary in the Decline and Recovery of Columbia River Salmon (Bottom et al. 2001)'. The following is a summary of findings from Bottom et al. 2001, as it relates to changes in estuary conditions from the pre-development (1880) to post-development (1997–1990) era.

Estuaries are considered important to rearing of juvenile salmon and represent an integral component of the continuum of habitats that salmon occupy for significant periods of time. There is, however, a general lack of science-based information concerning attributes of these tidal freshwater and oligohaline transition zones needed to support juvenile salmon, particularly in the Columbia River estuary. Further, recent evidence supports the concern that flow in the Columbia River significantly affects the availability of estuarine habitats, that flow is much reduced compared to historic levels, and that seasonal flow patterns are much different now than a century ago. The long history of wetland loss in the Columbia River estuary coupled with change in flow patterns suggests that restoration of the habitats may benefit recovery of depressed salmon stocks. The principal objective of this analysis was to assess the potential impact of flow regulation of the Columbia River on juvenile salmon use of the estuary. The analysis of historical data and hydrodynamic model simulations identified potential likely consequences for the estuarine physical environment. The authors felt it was not possible to separate or rank these effects on juvenile salmon from other compounding anthropogenic factors.

Nevertheless, this analysis indicated that habitat and food-web changes within the estuary and other factors affecting salmon population structure and life histories have altered the capacity of the estuary to support juvenile salmon.

Effects of flow regulation on habitat opportunity for subyearling salmon based on the depth criterion remain equivocal due to uncertainties in available bathymetric data. Regulation of river flow and habitat losses in the estuary cannot independently account for apparent changes in estuarine rearing patterns of juvenile salmon. Regardless of the degree of habitat loss, the authors can not eliminate the possibility that changes in population structure and life histories now prevent salmon from realizing the productive capacity of the estuary. They believe efforts to restore the estuary for salmon must be developed in concert with upriver habitat, hatchery and harvest improvements to recover the life history types that can benefit from estuary restoration.

The work to date needs to revise historical bathymetric data and acquire new data on present-day, shallow water bathymetry and circulation processes to resolve the lack of confidence in model predictions of habitat opportunity, especially those bases on depth criterion. The authors recommend conducting new simulations that include three dimensional modeling of salinity intrusion and stratification as a third environmental variable that is an important determinant of juvenile salmon distribution and residence time.

It appears, based on the authors' findings that these modeling tools will need to be refined to assist in quantifying to what degree changes in the estuary are responsible for changes in post-BONN survival of both transported and in-river fish.

3.6 Effects of timing of entry into Columbia estuary on SARs and D (Hypothesis 2.2a)

Hypothesis 2.2a: *The hydrosystem* ***indirectly*** *affects smolt-to-adult survival (SARs) by delaying (in-river) or accelerating (transport) arrival of smolts in the estuary.*

Why is D consistently less than 1? A potential mechanism for poorer post-Bonneville survival of transported fish could relate to differences in timing of estuarine entry for transported vs. non-transported fish. Bill Muir suggested that salmonid SARs are largely determined by environmental conditions in the estuary and nearshore ocean in the first few days or weeks at sea and these conditions vary both within and between years. Relevant observations in regard to D include:

- inriver migrants reach the ocean 2–3 weeks later than transported smolts; and
- transported fish are released in tight groups; while in-river fish arrivals are spread out.

Robert Emmett and Bill Muir have pursued an initial analysis of survival trends in transported chinook to determine if early arriving fish have lower survival, and have suggested that non-normative predator-prey interactions early in the migratory season (i.e., an inability at this time to swamp salmonid predators) are a mechanism that might explain such a pattern. Their analyses are presented in Section 3.6.1. Emmett and Muir's preliminary analysis of the effect of timing of estuarine entry on survival of transported smolts is supported by a subsequent analysis undertaken by Tom Berggren, that suggests that there may be an "optimal window" for timing of ocean entry by spring/summer chinook (for both transported and in-river fish). Tom Berggren's work is presented in Section 3.6.2.

3.6.1 Availability of alternative prey as a possible mechanism for temporal trends in SARS of transported hatchery spring/summer chinook salmon from Lower Granite and Little Goose Dams *(R.L. Emmett and W. D. Muir)*

Smolt-to-adult returns (SARs) for PIT-tagged spring/summer chinook salmon and steelhead transported from Snake River Dams have varied greatly within and between years. One likely mechanism to explain this observation is predation in the Columbia River plume and nearshore ocean. One of the factors determining the rate of predation is the number of available prey. As prey numbers increase, the chance of an individual prey's encounter with a predator generally decreases. In addition to spring/summer chinook salmon smolts, alternative prey species for predators in the plume include many smolt-sized prey such as Pacific herring, northern anchovy, Pacific sardine, whitebait smelt, and other juvenile salmonid species. In this analysis, we examined the relationship between numbers of smolts entering the Columbia River plume and SARs for daily groups of PIT-tagged spring/summer chinook salmon and steelhead transported from Snake River Dams in 1999.

Methods

We compiled juvenile and adult data for daily groups of hatchery spring/summer chinook salmon PIT-tagged above or at Lower Granite Dam and transported from either Lower Granite or Little Goose Dams in 1999, from which we calculated a 5-day running average SAR (Table 3.3). For each transported group, we calculated a barge release date as 2 days after the barge left the transport dam.

Table 3.3. Temporal estimates of hydropower system survival (S_I), Travel time from LGR-BON (*TT*), SAR_T, SAR_I, *T:I*, and delayed mortality (*D*) for hatchery yearling chinook salmon released above and transported from or returned to the river at Lower Granite Dam, 1998-2000. An estimate of 0.98 was used for survival during transport (R. Emmett and W. Muir). These data are graphed in Figure C-1 in Appendix C, and the general patterns from regression analysis are shown in Figure C-2.

	Apr 9	Apr 16	Apr 23	Apr 30	May 7	May 14	May 21	May 28	Jun 4
1998									
S_I	0.511	0.523	0.550	0.555	0.562	0.571	0.513	0.440	0.453
TT	26.5	22.0	18.4	17.4	16.5	15.7	11.7	12.1	13.4
SAR_T	0.43	0.59	0.77	0.98	2.22	2.37	2.39	1.74	-
SAR_I	2.27	1.25	0.88	0.51	0.54	0.82	1.88	-	-
T:I	0.19	0.47	0.88	1.92	4.11	2.89	1.27	-	-
D	0.10	0.25	0.49	1.09	2.36	1.68	0.66	-	-
1999									
S_I	0.566	0.501	0.550	0.560	0.560	0.562	0.560	0.562	0.522
TT	23.7	19.5	17.1	17.0	15.7	14.1	11.2	9.7	14.9
SAR_T	-	0.00	0.76	2.32	3.20	4.01	3.86	4.61	2.92
SAR_I	-	0.80	0.82	1.33	1.60	1.57	1.70	2.93	0.00
T:I	-	-	0.93	1.74	2.00	2.55	2.27	1.57	-
D	-	-	0.52	1.00	1.14	1.46	1.30	0.90	-
2000									
S_I	0.443	0.517	0.483	0.470	0.452	0.474	0.511	0.500	0.484
TT	19.2	19.2	17.3	15.2	16.0	14.9	12.1	11.9	15.9
SAR_T	-	1.61	1.97	2.71	3.34	3.99	4.27	2.01	-
SAR_I	-	1.12	1.48	1.80	1.95	1.08	0.50	0.91	-
T:I	-	1.44	1.33	1.51	1.71	3.69	8.54	2.21	-
D	-	0.76	0.66	0.72	0.79	1.79	4.45	1.13	-

An index of the number of smolts passing Bonneville Dam each day was obtained from the DART database (www.cqs.washington.edu/dart/). Smolt numbers included steelhead, yearling chinook salmon, coho salmon, and sockeye salmon (subyearling chinook salmon were excluded because of differences in size, timing, and behavior).

Results

For hatchery spring/summer chinook salmon smolts transported from Lower Granite or Little Goose Dams in 1999, SARs were relatively low early in the migration season, and increased as the season progressed until dropping off in early June (Figure 3.7; Appendix C). The highest SARs were observed after the peak migration. The SARs for transported smolts followed a similar trend to the number of smolts passing Bonneville Dam, near the release location for transported fish (Figure 3.8 and 3.9).

Discussion

The number of alternative prey available to smolt predators in the Columbia River plume and near shore ocean likely plays a key role in determining smolt survival (i.e., probability of avoiding predation). In this analysis, we used the total number of smolts passing Bonneville Dam because it was easily quantified. Many more smolts enter the Columbia River below Bonneville Dam, but determining when and how

many enter the plume is difficult. Alternative fish prey species (similar to chinook salmon smolts in size) are also likely to influence spring/summer chinook salmon survival, but their abundance in the plume is difficult to quantify, but presently being studied.

Other factors, such as sea surface temperature, turbidity, timing of the spring transition and other physical features affect both prey and predator abundance in the plume and near-shore ocean, and predator effectiveness. Relationships among these factors and SARs will be explored with further analysis for 1999 and other years as more SAR data become available.

Spring/summer chinook salmon smolts transported from Lower Granite and Little Goose Dams on the Snake River arrive to the Columbia River plume 2 to 3 weeks earlier than fish that migrate inriver. Migrants transported early in the season likely arrive earlier in the spring than they did before mainstem dams were built. Thus, spring/summer chinook salmon transported early in the migration enter the plume during a time period of low smolt abundance. Trawl surveys conducted off the coast of Oregon also found low abundance of forage fish in early spring in most years (Figure 3.10). Therefore, few alternative prey for salmonid predators are available at that time, further supporting the notion that the presence of large numbers of smolts or forage fish increase salmonid marine survival. This could help explain why smolts transported early in the migration season typically have low SARs.

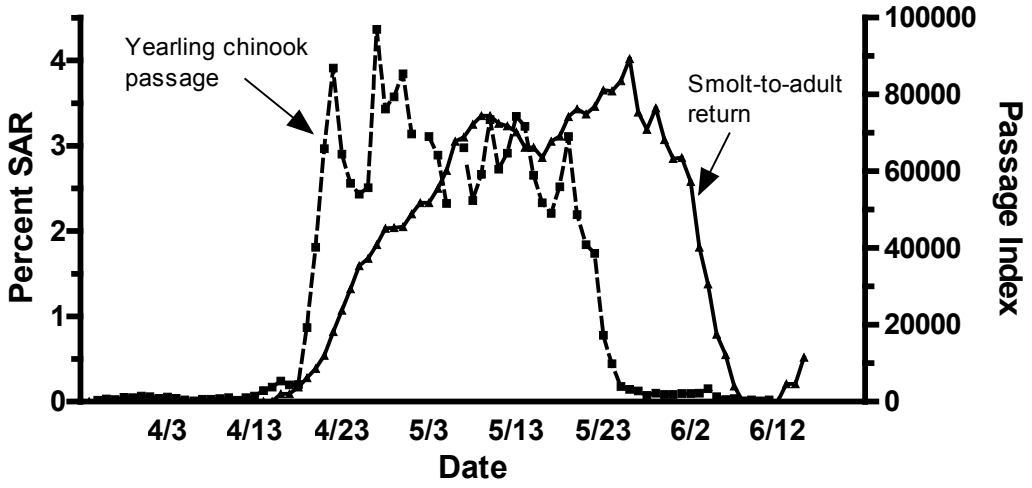

Figure 3.7. Daily hatchery spring/summer chinook salmon passage at Lower Granite Dam and percent smolt-to-adult return rates (5-day running average) for smolts transported from either Lower Granite or Little Goose Dams, 1999.

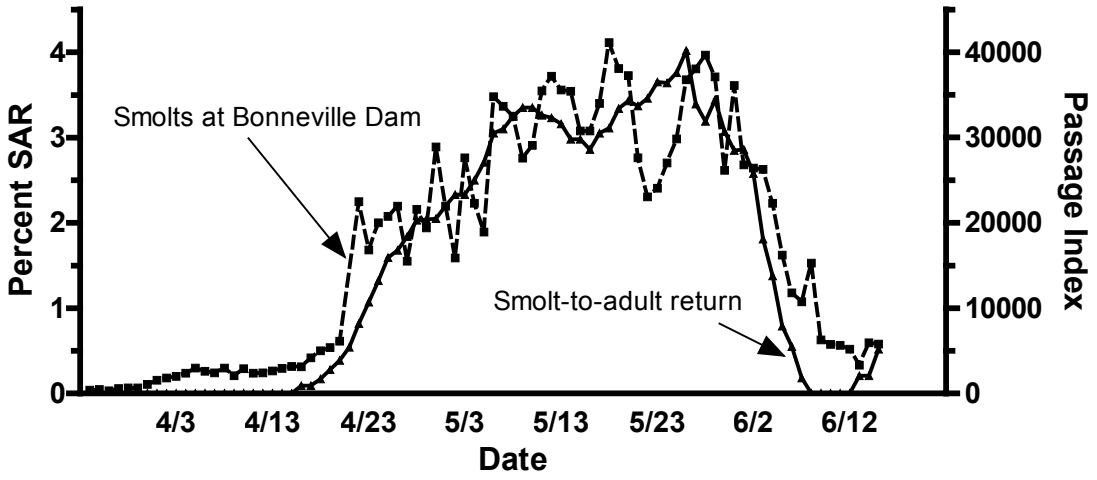

Figure 3.8. Number of salmonid smolts (all species except subyearling chinook salmon) passing Bonneville Dam and percent smolt-to-adult return rates (5-day running average) for hatchery smolts transported from either Lower Granite or Little Goose Dams, 1999.

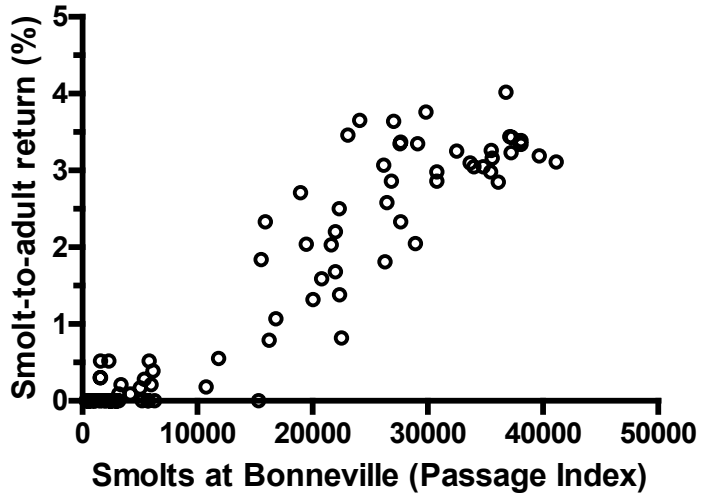

Figure 3.9. Percent smolt-to-adult return (5-day running average) for hatchery smolts transported from either Lower Granite or Little Goose Dams vs. index of total number of salmonid smolts (all species except subyearling chinook salmon) passing Bonneville Dam in 1999.

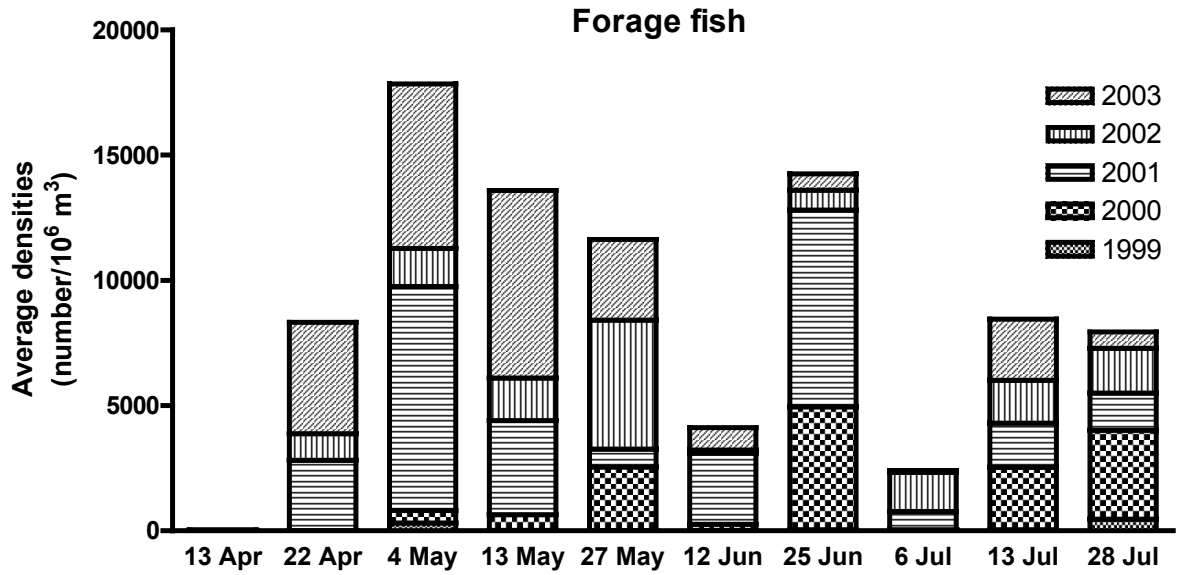

Figure 3.10. Abundance of forage fish off the mouth of the Columbia River 1999-2003.

Comments on Section 3.6.1 (*N. Bouwes*)

The hypothesis presented in Section 3.6.1 is based on a decreased predator encounter rate as prey density increases. This, however, ignores changes in functional and numeric responses of predators as prey density increases, which generally increases predation rates as prey density increases. I have found evidence that a Type 1 or Type 111 functional response (even better) explains consumption rates of pikeminnow predation on smolts in the JDA. The discussion for changes in seasonal SARs as a function of prey density should include:

- the CIs surrounding 5-day estimates of SARs must be huge (because they are large for pooled yearly estimates);
- alternative prey types were not found for most dates in 1999 (only 2 out of 9 sample dates found alternative prey at relatively very low densities);
- other individual years do not show a consistent pattern; and
- evaluation of alternative hypotheses to SARs patterns should be evaluated (e.g. how does highest SAR correspond to what arrival times would have been under a free-flowing river; degree of smoltification).

3.6.2 Timing of entry into estuary affects extra mortality of in-river and transported fish *(T. Berggren)*

The effect of time of entry into the estuary on subsequent smolt-to-adult survival rates (SARs) can be viewed in terms of the question "is there an optimal window of entry into the ocean for spring/summer chinook?" The approach to address this question of optimal time of ocean entry was to look at temporal estimates of SARs for PIT tagged chinook passing Lower Granite Dam over the season, both in-river and in transportation. PIT tagged wild chinook was the primary group of interest in order to avoid potential effects on timing from hatchery release schedules. PIT tagged wild chinook detected at Lower Granite

Dam were grouped into six 15-day intervals (starting March 26 and ending June 24 with a seventh interval containing all detections from June 25 to the end of the season).

Within-Year SAR patterns for spring/summer chinook from PIT tag data

Table 3.4 shows the SARs (smolt-to-adult survival rates) for PIT tagged wild spring/summer chinook detected at Lower Granite Dam, separated into the categories of fish that migrated in-river and fish that were transported from that site. The largest numbers of PIT tagged smolts arrived at Lower Granite Dam during intervals 2 and 3 (April 11 to May 10) during which time over 57% of the PIT tag detections occurred. For in-river migrating smolts, estimated SARs exceeding 2% occurred in the first interval in 1998, intervals 2 and 3 in 1999, and intervals 1 to 3 in 2000.

Table 3.4. Smolt (Lower Granite Dam)-to-adult (Bonneville Dam) survival rates for in-river migrating and transported PIT tagged wild spring/summer chinook in migration years 1998 to 2000.

		Date detected at Lower Granite Dam as smolt						
Year Group		**3/26-4/10**	**4/11-4/25**	**4/26-5/10**	**5/11-5/25**	**5/26-6/09**	**6/10-6/24**	**>=6/25**
1998 In-river	#Adults	28	34	25	4	0	0	0
	#Smolts	796	2093	2843	859	159	127	105
	SAR	3.5%	1.6%	0.9%	0.5%	0%	0%	0%
1998 Transport	#Adults	0	4	5	0	2	0	0
	#Smolts	148	311	234	82	32	9	4
	SAR	0%	1.3%	2.1%	0%	6.3%	0%	0%
1999 In-river	#Adults	5	49	65	14	11	1	0
	#Smolts	349	2121	2471	975	921	343	87
	SAR	1.4%	2.3%	2.6%	1.4%	1.2%	0.3%	0%
1999 Transport	#Adults	1	6	16	5	5	2	0
	#Smolts	107	351	285	99	161	59	47
	SAR	0.9%	1.7%	5.6%	5.1%	3.1%	3.4%	0%
2000 In-river	#Adults	2	104	74	13	9	0	2
	#Smolts	79	3031	2610	1128	489	146	191
	SAR	2.5%	3.4%	2.8%	1.2%	1.8%	0%	1.0%
2000 Transport	#Adults	0	3	0	0	1	1	0
	#Smolts	7	138	69	30	45	23	15
	SAR	0%	2.2%	0%	0%	2.2%	4.3%	0%

Optimal window of ocean entry of in-river fish

For PIT tagged wild chinook passing Lower Granite Dam during the first interval of 1998 to 2000, the earliest date of detection at Bonneville Dam was between April 23 and 28 (Table 3.5). Of these same PIT tagged fish from the first interval at Lower Granite Dam, the earliest date at Bonneville Dam of a smolt that also subsequently had a returning adult detection was between April 26 and May 3 for the migration years 1998 to 2000. The estimated median travel time from Lower Granite Dam to Bonneville Dam for in-river migrants was longest in the first interval (median of 20 or more days) and decreased over time to around 11-14 days for smolts passing Lower Granite Dam after May 10 (Table 3.5). A trawl equipped with PIT tag detectors is located near Jones Beach, which is midway between Bonneville Dam and the mouth of the Columbia River. Travel time from Bonneville Dam to the trawl typically is about 2 days,

and if you assume a similar migration rate from the trawl to the estuary, then it should take the in-river migrating PIT tagged smolts about 4 days on average to reach the estuary from Bonneville Dam. Adding 4 days to the Bonneville Dam passage date of the earliest arriving PIT tagged smolt that subsequently returns as an adult would place **the start of the optimal "window" of ocean entry around April 30**.

Table 3.5. Median travel time from Lower Granite Dam to Bonneville Dam (temporal 15-day blocks) of in-river migrating PIT tagged wild spring/summer chinook in 1998 to 2000, plus minimum and maximum dates of detection at Bonneville Dam for each temporal block.

Year In-river Group	Travel time Smolt date at Bonneville Dam	Smolt detection date at Lower Granite Dam					
		3/26-4/10	4/11-4/25	4/26-5/10	5/11-5/25	5/26-6/09	6/10-6/24
1998	Median (d)	29.5	19.3	16.1	13.9	12.0	11.7
	Min date	4/28	5/02	5/09	5/23	6/06	6/27
	Max date	5/21	5/30	6/01	6/06	6/21	7/18
1998	Median (d)	25.5	16.9	15.6	11.3	13.2	13.0
	Min date	4/24	4/28	5/07	5/24	6/03	6/22
	Max date	5/16	5/31	6/02	6/07	6/27	7/23
1999	Median (d)	19.5	19.1	16.2	14.0	12.5	
	Min date	4/23	4/26	5/09	5/24	6/05	
	Max date	5/05	6/07	6/02	6/11	6/23	

As for the end of this optimal "window" of ocean entry, the in-river migrating PIT tagged smolts from 1998 had SARs that dropped off quicker than in the other two years to levels of near one-half percent by May 25 at Lower Granite Dam (interval 4) (Table 3.4). The SARs continued at levels over 1% to June 9 (interval 5) in 1999 and 2000. (Aside: there were two adults that returned from fish passing Lower Granite Dam after June 25, but one of the those two smolts was not detected at McNary and John Day dams until the next year). For smolts passing Lower Granite Dam during these intervals, the latest date of detection at Bonneville Dam was between June 11 and 27 (Table 3.5). Of these same PIT tagged fish from these later intervals at Lower Granite Dam, the latest date at Bonneville Dam (Bonneville Dam date extrapolated from latest John Day Dam detection date) of a smolt that also subsequently had an returning adult detection was between May 28 and June 14 (exception is one very late in-river migrating smolt detected at Bonneville Dam on July 3 that had an adult return, but there were no detections in latter half of June). Again adding approximately 4 days from Bonneville Dam to the estuary for the later in-river migrating smolts places **the end of the optimal "window" of ocean entry around June 18**.

Optimal window of ocean entry for transported fish

Fish transported from Lower Granite Dam take on average, approximately 2 days from time of collection at Lower Granite Dam to release below Bonneville Dam. Few of the wild chinook that were PIT tagged above Lower Granite Dam in the years 1998 to 2000 were transported because the default operation was to return these PIT tagged fish to the river, but more were transported in 1999 than the other two years. There were adult returns from PIT tagged fish transported in each of the six intervals in 1999 with the earliest smolt date at Lower Granite Dam of April 4 and latest smolt date of June 17. But of the PIT tagged smolts transported from Lower Granite Dam before April 26, the earliest date of smolt passage at Lower Granite Dam for those fish with a returning adult was April 14, 4, and 12 for migration years 1998, 1999, and 2000, respectively.

Although, it may only take approximately 2 days to arrive at the releases site below Bonneville Dam by barge (or truck), the actual time to reach the estuary may be much longer for fish transported early in the season (Table 3.6). In 1998 to 2000, in-river migrating PIT tagged smolts took just under 2 days to pass the lower Columbia River trawl site midway between Bonneville Dam and the mouth of the Columbia River. In 1998, PIT tagged smolts transported from Lower Granite Dam on April 6 took approximately 17 days to reach the trawl location from release below Bonneville Dam. It shortened to about 5 days for tagged smolts transported on April 17 and 21, and finally to just over 2 days for a tagged smolt transported on April 23. In 1999 and 2000, the PIT tagged smolts detected at the trawl that were transported from Lower Granite Dam after April 23 and had median travel times more similar to that of the in-river migrants than what was observed early in 1998. **Early transported wild chinook smolts may be migrating below Bonneville Dam at very slow speeds and therefore may still not be arriving at the estuary until the end of April at the start of the optimal "window" of ocean entry.**

As for the smolts transported late in the season, the latest date of smolt passage at Lower Granite Dam for those fish with a returning adult was May 29, June 17 and 24 for migration years 1998, 1999, and 2000, respectively. Adding 6 days to these dates (two days in the transport vehicle and 4 days migrating below Bonneville Dam) would place **the end of the optimal "window" of ocean entry around June 30, twelve days after what was observed with in-river migrating smolts.** However, taking into account the earlier mentioned very late in-river migrating smolt detected at Bonneville Dam on July 3 that returned as an adult, **it is possible with adequate flows throughout June to see the end of the optimal "window" of ocean entry extend to the end of June.**

Table 3.6. Estimated travel time between Bonneville Dam (BON) and lower Columbia River trawl at Jones Beach for PIT tagged wild spring/summer migrating in-river and transported (latter obtained by subtracting 2 days from duration between collection date at Lower Granite Dam (LGR) and detection date at trawl) in 1998 to 2000.

	In-river smolts			Transported smolts		
Migration Year	Date at BON	Number smolts	Median travel time BON to trawl	Date at LGR	Number Smolts	Estimated travel time BON to trawl
1998	5/03 – 5/20	8	1.5	4/06	2	16.8
				4/17 – 4/21	2	5.0
				4/23	1	2.3
1999	5/04 – 5/20	14	1.8	4/24 – 5/06	9	2.5
	5/21 – 6/01	8	1.5	5/22 – 6/02	4	1.7
2000	5/04 – 5/20	16	1.8	5/09 – 5/12	2	2.4
	5/23 – 6/01	8	1.7			

Timing of Entry Summary

Overall, PIT tagged wild spring/summer chinook have higher estimated SARs when they reach the estuary between the end of April and end of June for both smolts that migrate in-river and those that are transported. This range of dates was based on the 1998 to 2000 migration years when flows remained above 200 kcfs in the lower Columbia River through the end of June. When springtime flows are lower as occurred in 2001 when lower Columbia River flows never exceeded 180 kcfs, an earlier end to the ocean entry window is expected as occurred in 2001 (see accompanying plots). Wild spring/summer chinook smolts that enter the hydro system at Lower Granite Dam in the first half of April have much faster migration rates in the lower Columbia River (measured from Bonneville Dam to the lower Columbia

River trawl) when they migrate in-river through past 8 dams rather than being transported pass these same dams. Therefore, **part of the differences observed in post-Bonneville Dam survival rates between transported and in-river migrating smolts may be influenced by duration of time the smolts spend in the lower Columbia River before actually entering the ocean.**

Figures 3.11 to 3.13, respectively, show timing at Bonneville Dam for PIT tagged in-river migrating wild chinook smolts and for PIT tagged in-river migrating hatchery chinook smolts, and timing at Lower Granite Dam for an aggregate of wild and hatchery chinook transported from that site. These plots utilize only the smolt dates of chinook that subsequently had an adult return in order to show timing of chinook that are known to successfully survive to adulthood. The plots split the Snake River basin chinook by tributary of origin (Clearwater, Grande Ronde, Salmon, and Imnaha rivers) and also include results for PIT tagged chinook from other tributaries in the Mid-Columbia and Lower Columbia River. These timing plots of for wild and hatchery chinook of Snake River basin and other basins support a the concept of a "window" of yearling chinook smolt entry into the estuary occurring between late April and mid-to-late June.

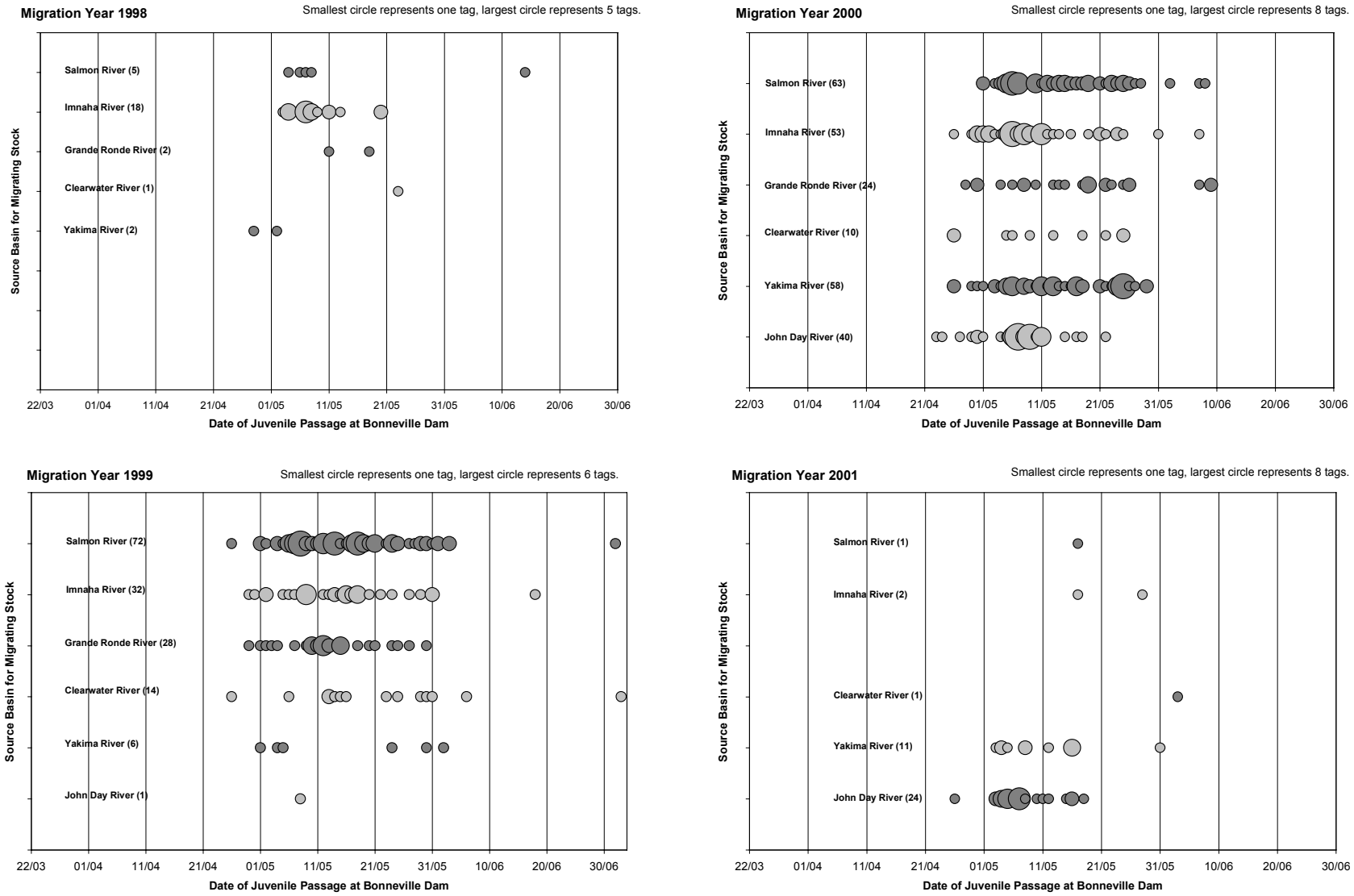

Figure 3.11. Juvenile timing at Bonneville Dam for PIT tagged wild Sp/Su chinook that survived to adulthood for migration years 1998 to 2001.

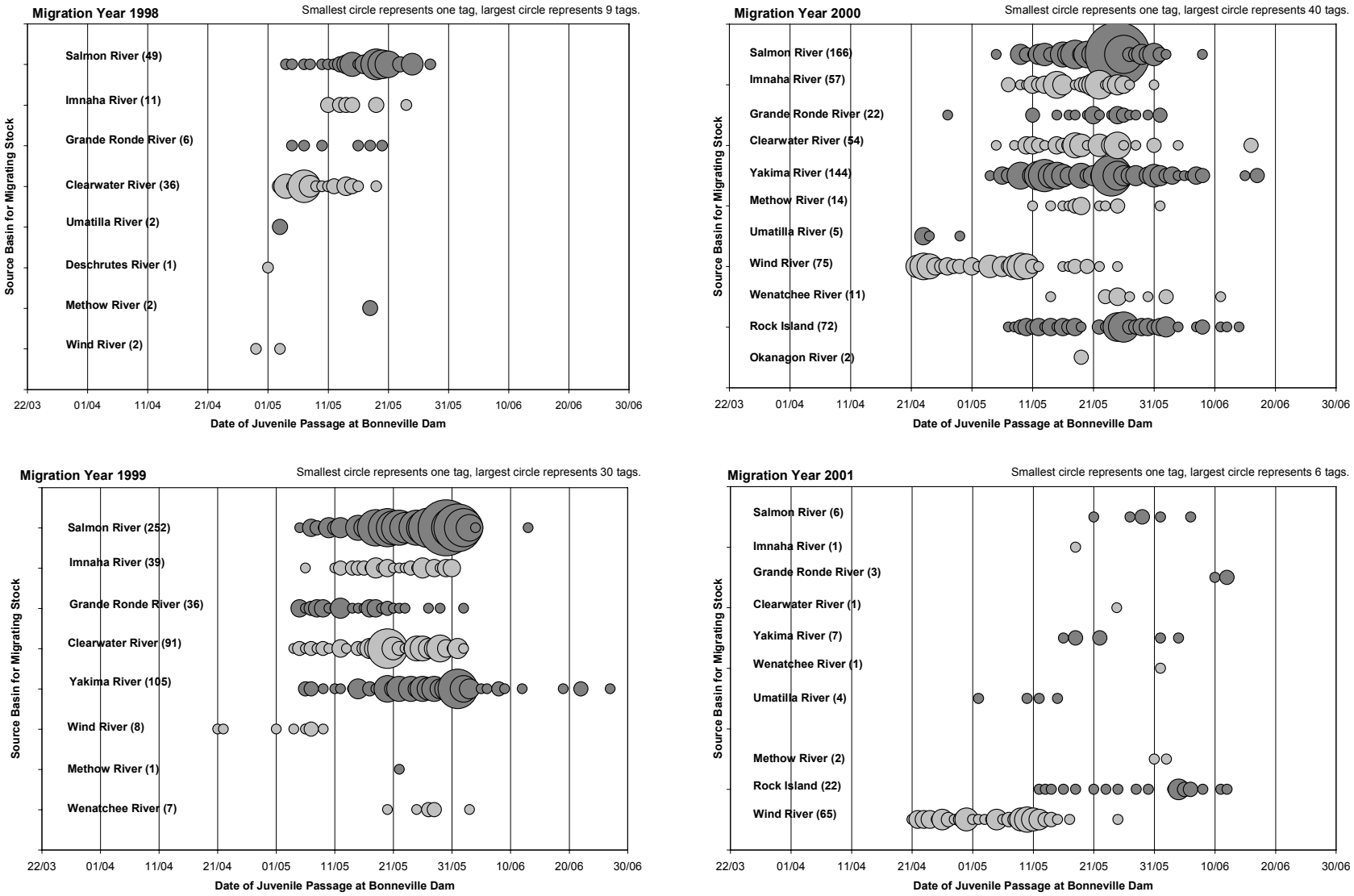

Figure 3.12. Juvenile timing at Bonneville Dam for PIT tagged hatchery Sp/Su chinook that survived to adulthood for migration years 1998 to 2001. Number of PIT Tags in parenthesis.

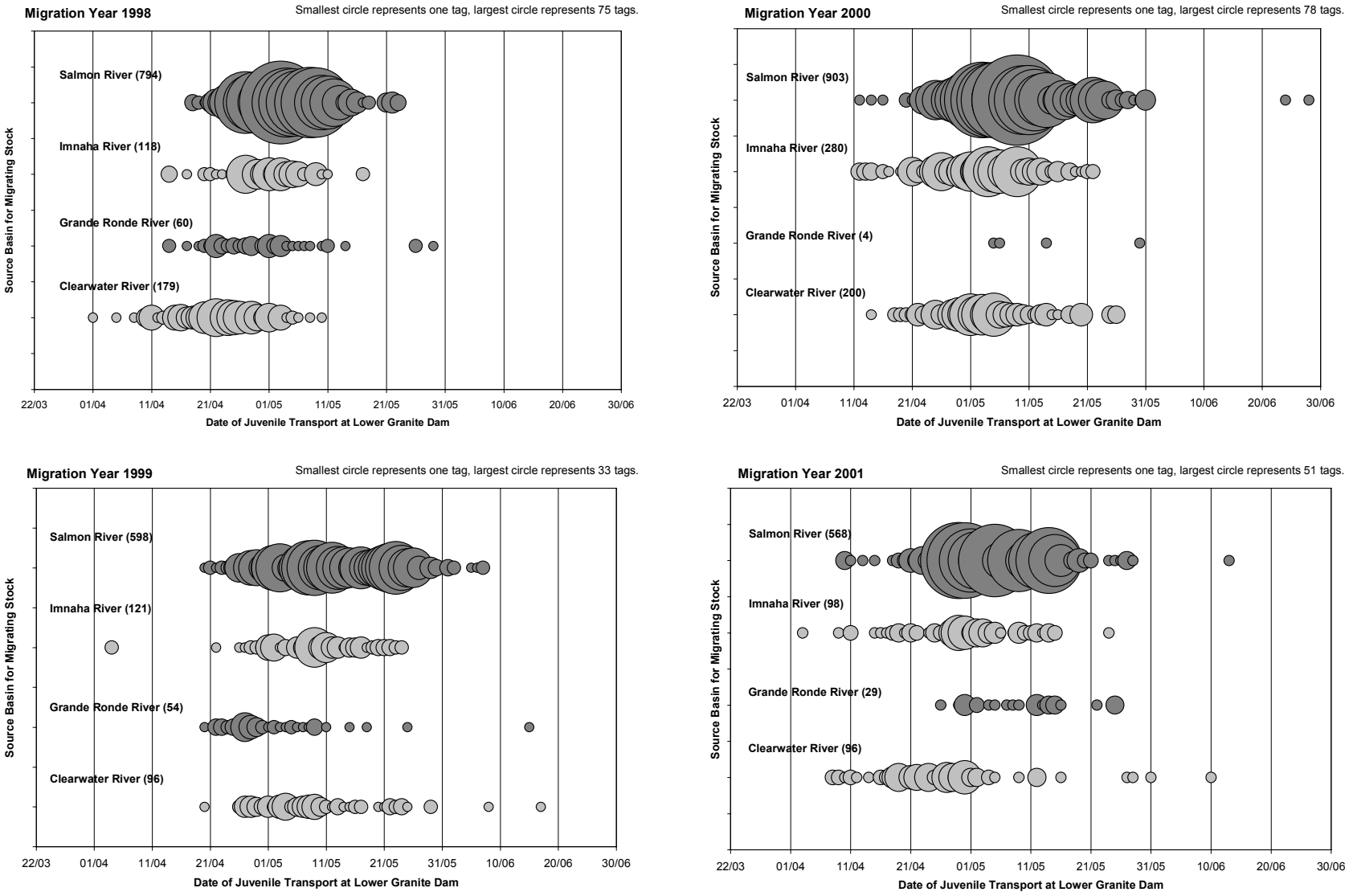

Figure 3.13. Juvenile timing at Lower Granite Dam for transported PIT tagged Sp/Su chinook that survived to adulthood (hatchery and wild combined) for migration years 1998-2001. Number of PIT Tags in parenthesis.

Relationship between Water Travel Time (WTT) and SARs

The Snake and Columbia River dams and reservoirs have doubled to tripled the travel time of in-river spring/summer chinook and steelhead through these rivers, delaying ocean entry time of in-river migrants (State, Federal and Tribal Anadromous Fish Managers. 2003). The effects of ocean entry time on SARs is supported by results of regression analyses completed by the State, Federal and Tribal Anadromous Fisheries Managers (2003), and presented at the workshop by Charlie Petrosky (see presentation in Appendix E). In these analyses WTT (which is strongly positively correlated with fish travel time) was negatively correlated with the SARs of Snake River spring/summer chinook and steelhead, as well as with S/S ratios for Snake River spring/summer chinook. SARs could, in theory, be affected by WTT only through changes to direct mortality (e.g., greater predation rates in reservoirs). However, post-Bonneville survival (λ_n) also exhibits a weak negative correlation with WTT (Figure 3.14)

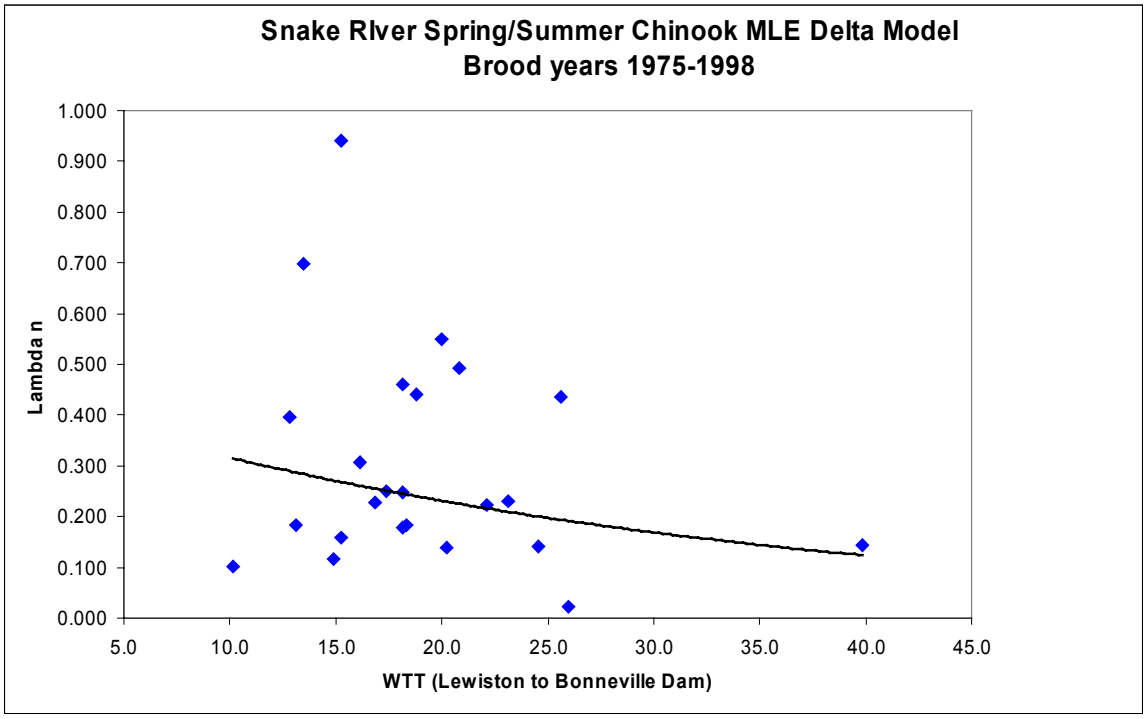

Figure 3.14. Relationship between λ_n (post-BONN survival factor) and WTT, for Snake River spring/summer chinook.

3.7 Changes in developmental state (Hypothesis 2.2b)

Hypothesis 2.2b*: The hydrosystem* ***indirectly*** *affects smolt-to-adult survival (SARs) by changing and delaying the smolt development processes, through both altered timing of entry and stress.*

Why is D consistently less that 1? A complementary hypothesis to 2.2a proposes that successful entry into the estuary is not simply affected by entry timing but also by the developmental state of the fish at time of entry (Hypothesis 2.2b). In this regard, Carl Schreck has suggested that if fish are given insufficient time to complete smoltification they may experience high energetic costs in attempting to osmoregulate in salt water, resulting in decreased resistance to pathogens and increased susceptibility to predators. Such a scenario (presented in Figure 3.15) would suggest that survival of transported fish could be dependent on

the developmental state of fish at time of transport. Timing of smoltification would vary annually but, in general, it could be considered that fish transported early in the season might often be too "immature" for successful ocean entry, while fish transported later in the season would be more advanced in terms of smoltification processes. Within each year there would be a hypothetical optimal timing "window" of ideal smolt maturity for successful ocean entry.

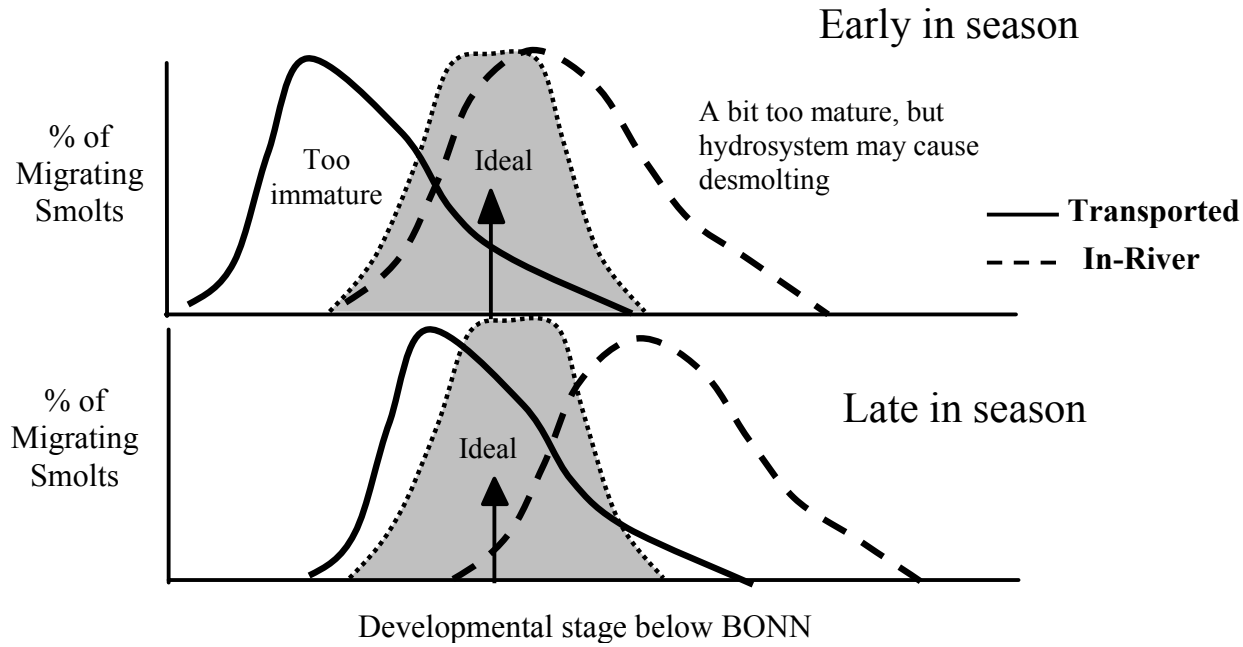

Figure 3.15. Theorized variation in developmental timing of transported and in-river smolts at entry to the estuary below Bonneville Dam.

The evidence relating to the affects of developmental timing on smolt survival post-Bonneville was outlined at the workshop by Carl Schreck.

3.7.1 Effects of time to estuary on smolt developmental timing *(C. Schreck)*

Variation in phenotype is equal to variation in genotype plus variation in the environment plus variation in interactive effects.

$$V_P = V_G + V_E + V_{GE}$$

This concept applies to all phenotypes, but here is relevant to smolting, stress effects, and resistance of environmental threats. Variation in phenotype can be subdivided into variation in smolting process, disease resistance, stress resistance, etc. This variation is a population concept but also applies to the individual (e.g., an individual can express various phenotypes as determined by its genetic heterozygosity). It can be thought of in terms of a specific stock or encompass the entire run. While there is little study of V_G, it appears that the heritability is reasonably high ($H^2 \sim 0.3$). Hence, an individual's smolt-phenotype (e.g., timing of when the smolting process is initiated and, the need for prior migration to initiate or complete the process, effects of the hydrosystem/barging, etc.) can be driven 70% by environmental factors. From a population perspective there is potential for considerable between-fish variation in both genetic heterozygosity and responsiveness to environmental variables.

This all relates to "D" in that all "smolts" are not physiologically, anatomically, or behaviorally the same. Fish from one segment of the run may differ from those of other segments for genetic and environmental reasons (Smolt Workshop Proceedings) and even fish passing LGR dam on one day can have considerable V_P relative to smolting characteristics.

Confounding effects:

1. Studies are hampered by lack of a clear understanding of the developmental state of the fish used at the start of a study. We do not know if all, some or none of the barged fish or fish passing a project are "smolts" at that time. The difficulty arises in that there is **NO** commonly accepted definition of the word "smolt". And, there are at present no means to "measure" smolting. That is, there is no way of determining when a fish initiates the process, is in the process, or completes the process. We do have some physiological, morphological and behavioral indices that can give some guidance (e.g., ATPase, T_4, behavior, saltwater challenge, K factor), but these are very inconsistent and their predictive powers have not been validated. (Steffansson). This makes comparisons of results of different studies or different temporally-separated pseudoreplicates tenuous.

2. The word "stress" needs to be carefully defined when used. There are several different but reasonable definitions of this term. I suggest avoiding a strict medical/physiological definition. Rather a definition encompassing the concept that "stress" is the response of the body to a threat that if not reacted to would lower the fish's reproductive fitness (see Schreck and Li for a tighter definition). This is a relatively broad definition.

    a. Knowns:
        i. Stress is anti-growth, anti-developmental (e.g., smolting, salt water adaptability), anti-pathogen resistance, anti-predator avoidance (reviewed by Schreck).
        ii. There is an energetic cost associate with resisting stressors, hence there is less energy available to conduct other necessary life functions (McEwen; Schreck).
    b. Unknowns:
        i. We are reasonably good at being able to say when fish are stressed; we are not able to say when fish are not stressed.
        ii. There is no way a present to measure the severity of stress.
    c. Significance to estimation of "D":
        i. It is difficult to predict the confounding effects of certain practices necessary as part of study designs.

I. Ho: Time to estuary effects on post-Bonneville survival.

1. During the early part of the general run or during the early part of the run of any stock barged fish will reach the estuary significantly (2+ weeks) before run-of the-river (ROR) fish. This has the potential of having barged fish reach sea water improperly prepared to thrive in that environment.
    a. Early-run barged fish may have had insufficient time to complete smoltification, hence it is too energetically costly for them to osmoregulate in saltwater for them to resist pathogens they may have carried or that they may encounter there. They would thus perish weeks to months later.

b. Early-run barged fish may have had insufficient time to complete smoltification and hence it is too energetically costly for them to osmoregulate in saltwater for good growth. They would thus perish weeks to months later.

c. Early-run barged fish may have had insufficient time to complete smoltification and hence it is too energetically costly for them to osmoregulate in saltwater for good performance of routine activities (predator avoidance, etc.).

2. The hydrosystem has extended the migration time down the Snake and Columbia. Fish travel times have increased.

   a. Dams cause impediments to downstream movement.

      i. Fish take longer (1 week) to go through the Snake River Dams than the Columbia River dams (hours to a day) (Adams; Snelling). (ref),

   b. Impoundments have decreased the water velocity.

      i. Fish must expend more energy to get downriver (Congleton).

3. Knowns:

   a. There is no difference in how long it takes fish over the run to migrate from Bonneville to seawater, it depends on river flow (Schreck, numerous reports).

   b. Smolt indices such as gill ATPase suggest that early-run fish are less smolted than later run fish. (Maule; Zaugg; Schreck). At Lower Granite ATPase goes up across the spring chinook run.

   c. Fish appear to smolt as they migrate—migration may be necessary to proper smolting (Zaugg). In the estuary spring chinook with lower ATPase are more shoreline-oriented; individuals with higher levels tend to move into the main flow (Zaugg).

   d. Early-run hatchery chinook have lower D's

   e. The barging process causes stress (Schreck; Maule; Congleton, etc.). Early run spring chinook appear less stressed upstream of Lower Granite and less stressed during transport than later run. Later run fish experience upstream stress or stress during transport (3-year's data, Schreck). Spring chinook are stressed by presence of steelhead (Congleton; Kelsey).

   f. Smolt migration patterns are variable. Historically spring chinook may have migrated seaward during much (all?) of the year (they still do this in the Sacramento and Rogue rivers). Within a stock there may be little variation between migration timing of many individuals but some phenotypes of a stock may express different timing of smolting (in terms of both how long it take the individual to complete the process and the date when it is initiated and/or completed) (Healey; Steffansson).

   g. Causative organism of BKD (R *s*.) present in most (if not all) Columbia River salmonids. It is also present in natural waters as well as at dams and in barge holds (e.g., Pascoe; Elliott). Early run spring chinook have lower infection rates than later run fish (Pascoe; Elliott; Schreck). Stress causes the pathogens to become pathogenic (Schreck; Wedemeyer). There is a direct relationship between infection rate (as opposed to simple disease occurrence) and volitional saltwater entry (Seals/Price). R.*s*. is induced to become pathogenic in saltwater.

II. Effects on developmental timing.

1. In-river fish may have delayed or reversed smolt development.
2. Barged early-run spring chinook may have less opportunity to migrate a sufficient distance in freshwater, necessary in some fish to stimulate smolt development.
3. Knowns:
    a. Multiple stressors "retard" development. Eight sequential stressors separated by average migration times experienced between dams caused spring chinook to "harden relative to stress resistance but eliminated the desire for these fish to go into saltwater (Figure 3.16) (Schreck; Seals/Price).
    b. Growth rate coming out of the winter preceding smolting is more important for smolting and migration than absolute size. Spring chinook migration is related to growth rate, which correlates to smolt indices.

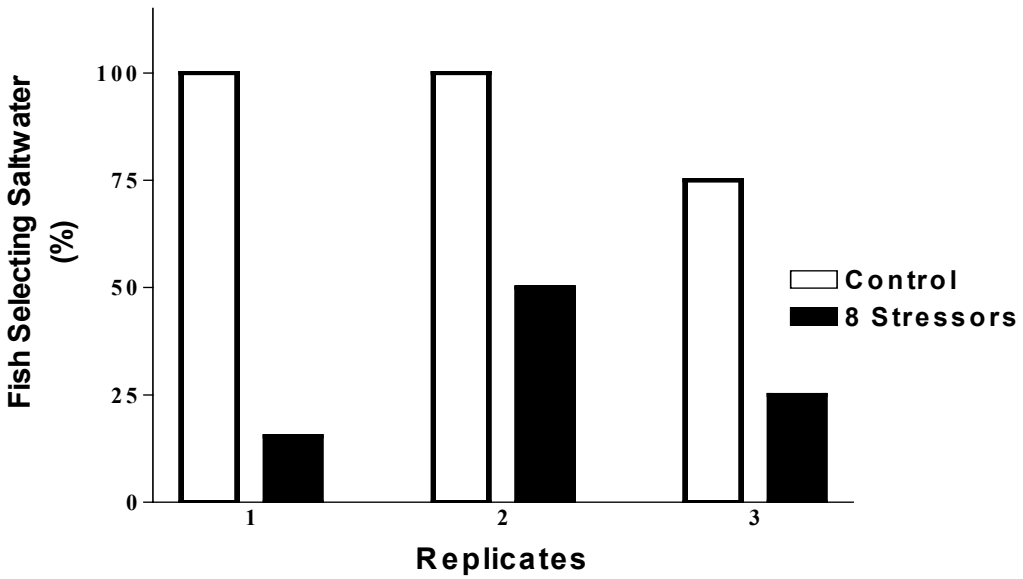

Figure 3.16. Effects of multiple stressors on saltwater preference of spring chinook (sequential stressors were separated by average migration times experienced between Columbia River dams). (C. Schreck)

* (references for papers cited in Section 3.7.1 can be obtained from Carl Schreck)

3.7.2 Conclusions regarding Hypothesis 2.2a (Timing) and 2.2b (Developmental Stage)

Observed seasonal variations in D and SARs support the hypothesis that early arrival of transported fish leads to delayed mortality post-BONN. In-river fish may also have depressed SARs and λ_n due to delays in arrival time, but this effect is likely consistent over the entire season (i.e., SARs remain roughly constant). Causes of variation in D and SARs are **most likely** a combination of different factors. These include:

1. Developmental stage of smolts (Hypothesis 2.2b); both a lack of readiness for saltwater entry of early transport groups, and possible stress-induced changes in development for in-river fish – evidence here is strongest for coho and less clear for spring chinook.
2. The number of outmigrating smolts of various species (i.e.. variation in schooling protection that can potentially swamp predators).
3. Year to year and seasonal variation in the condition of the estuary and availability of alternative prey.
4. Water Travel Time (WTT), which is negatively correlated with λ_n, the post_BONN survival of in-river fish. An assessment of WTT effects on juvenile migration and adult returns was presented at the workshop by N. Bouwes, C. Petrosky and H. Schaller (Appendix E).

Immature smolt developmental stage and increased estuarine predation are probably more important than stress in explaining low spring chinook Ds for early season runs, but stress is likely a factor in consistently depressing SARs and λ_n for in-river fish.

3.8 Culling/selection (fixed mortality/day) (Hypothesis 2.4)

Hypothesis 2.4: *The hydrosystem* ***indirectly*** *affects smolt-to-adult survival (SARS) by shifting the timing of mortality of transported fish to post Bonneville Dam, based on the hypothesis that fish experience a fixed rate of mortality.*

Subgroup A participants developed a novel alternative hypothesis (2.4) for explaining observed patterns in D and SARs. The basis of this hypothesis is the idea that fish migrating in-river experience an inherent mortality rate per day that will be expressed in the SARs. Transported fish collected at the upper most dam don't have the opportunity to be culled from the population. Therefore, the transport fish SARs could include the unfit fish that were destined to die anyway, but because of the short duration of transport these fish were not exposed to the challenges of inriver migration (i.e., transported fish have experienced only 1.5 days of mortality pre-Bonneville, whereas in-riverfish have had 12–22 days of pre-Bonneville mortality).

3.8.1 Initial workshop assessment of the culling hypothesis *(H. Schaller and C. Petrosky)*

Fish transported lower down in the hydrosystem should have experienced more culling from the fixed rate of mortality prior to transport. Therefore, the transport SARs and D values from projects lower in the system should increase. The transport SAR would increase proportionally to the inriver survival from the upper collector dam to the lower collector dam. In the example below (Table 3.7) the D value should be about 40% higher at the downstream collector dam relative to fish transported at LGR.

Table 3.7. Example of expected D values by collector project location for fixed mortality hypothesis.

Fixed SAR LGR:LGR	2.0%		Trans from LGR I	Trans from LGR T	Trans from lower site I	Trans from lower site T		
	LGR							
	LGS							
	LMN				70%[2]	70%[2]		
	IHR							
	MCN							
	JDA							
	TDD							
	BON	LGR to BON survival	50%[1]	100%[3]	50%[1]	70%		
		Survival from BON to ocean and back to LGR	4.00%[4]	2.00%	4.00%	2.8%		
		D	0.50		0.71		Ratio of D – LGR:	1.40

* D should increase from transport sites lower downriver if there is only a "culling" of weak fish

Assumptions:
1. SURV in-river, LGR-BONN = 50%
2. SURV in-river, LGR-LMN = 71%
3. Barge survival = 100%
4. SAR in-river, BONN-ocean-LGR = 4%

To evaluate whether existing information on D was consistent with a culling hypothesis Tom Berggren undertook a further analysis using computed D's existing for wild and hatchery yearly chinook in the recent NOAAF draft white paper (Williams et al. 2003), as well as new analyses employing CSS data.

3.8.2 Post-workshop assessment of the culling hypothesis for explaining observed patterns in D *(Tom Berggren)*

Upstream-downstream differences in D

As discussed above and as shown in Table 3.7, the "culling hypothesis" implies that if continual "culling" of weak smolts is occurring as they migrate downstream through the hydro system, then D values should also be increasing for fish collected and transported at dams lower in the river. The continual "culling" would be incorporated in the in-river survival estimate, whereas, it would occur after release below Bonneville Dam for the transported fish. Based on the assumptions in Table 3.7, if continual "culling" were the primary cause for the in-river mortality experience through the hydro system, then the SAR for transported smolts after leaving the barge (or truck) below Bonneville Dam could be expected to be as low as 2% (0.5*4%) for fish transported from Lower Granite Dam and as low as 2.8% (0.7*4%) for fish transported from Lower Monumental Dam. Under this scenario, the parameter D would be 0.5 (2%/4%) for the Lower Granite Dam transported fish and 0.7 (2.8%/4%) for the Lower Monumental Dam transported fish. The ratio of these two D values (0.7/0.5) is 1.4.

Tables 21D (wild yearling chinook) and 22D (hatchery yearling chinook) in the NMFS draft technical memorandum (Williams et al. 2003) can be used to examine the "culling" hypothesis. Their data shows that the computed annual D's tend to decrease at downstream transportation sites for PIT tagged hatchery chinook and increase at Little Goose Dam before decreasing again at Lower Monumental Dam for PIT tagged wild chinook. The data presented by NMFS makes no case for continual "culling" of hatchery

chinook and, on the surface, only a weak case for continual "culling" of wild chinook. But only one to two adult returns from Little Goose Dam transportation were available per year from migration years 1994 to 1997, followed by only 3 to 9 adult returns from the migration years 1998 to 2000. Basically there were too few PIT tagged wild chinook smolts transported from Little Goose Dam (and even fewer from Lower Monumental Dam) to obtain enough adult returns to properly conduct this type of analysis with the available data on PIT tagged wild chinook.

Between year differences in D

If continual "culling" is occurring the entire time that smolts are migrating in-river throughout the hydro system, then in-river smolts migrating in low flow years should have lower pre-Bonneville Dam and higher post-Bonneville Dam survival than do smolts migrating in high flow years. This scenario would lead to lower D's in low flow years and a higher D's in high flow years.

This question may be addressed by comparing the high flow year of 1999 with the low flow year of 2001 (Table 3.8). The pre-Bonneville Dam survival in the hydro system from Lower Granite Dam tailrace to Bonneville Dam tailrace in 2001 was 37 to 63% lower than in 1999 for the PIT tagged CSS hatchery groups and aggregate wild chinook group.

To compare the post-Bonneville Dam survival rates between the two years, a modified D* value was computed using fish from study Category C_1. This approach was needed because there were negligible numbers of PIT tagged smolts passing the three Snake River dams undetected (Category C_0 fish) in 2001 due to maximum transportation at Snake River collector dams. PIT tagged fish transported only from Lower Granite Dam were used as the reference to simplify the computations in the comparison since the goal was to look for patterns across the two years.

Contrary to the hypothesis, the D* values were much higher in the low flow year, which simply reflects the extreme difference in survival in the estuary between these two years rather than any continuous "culling" mechanism. The SAR for Lower Granite Dam transported chinook was 3 to 4 times higher in the high flow year than in the low flow year.

Interestingly, in both the low flow and high flow years, D* was similar between the Dworshak Hatchery chinook and aggregate wild chinook groups, and much lower than what was measured for hatchery chinook from Rapid River, Imnaha, and McCall hatcheries. The management strategy at Dworshak Hatchery has been to raise hatchery fish of a smaller size more in line with that of wild chinook, and so it may be more than just a coincidence that the relative effect of transportation versus in-river migration on post-Bonneville Dam survival rates is similar between Dworshak Hatchery chinook and the aggregate of wild spring/summer chinook.

Table 3.8. Estimated pre- and post-Bonneville Dam survival rates for PIT tagged spring/summer chinook released from hatcheries used in the CSS and for the aggregate of PIT tagged wild spring/summer chinook that migrate in-river versus those transported from Lower Granite Dam during years of high flow (1999) and low flow (2001).

Year	Reach	Dworshak H (72 miles)	Imnaha AP (130 miles)	Rapid River H (176 miles)	McCall H (284 miles)	Aggregate Wild Fish
Low Flow Year						
2001	Pre-BON surv.					
	LGR-BON (Vc)	0.24[a]	0.37[a]	0.33[a]	0.27[a]	0.23[a]
	Post-BON surv.					
	SAR(C1)/Vc	0.0012	0.0015	0.0013	0.0012	0.0040
	SAR(T_lgr)/0.98	0.0032	0.0066	0.0112	0.0128	0.0089
	D*	2.67	4.40	8.62	10.67	2.23
High Flow Year						
1999	Pre-BON surv.					
	LGR-BON (Vc)	0.58[b]	0.59[c]	0.69[b]	0.80[b]	0.62[b]
	Post-BON surv.					
	SAR(C1)/Vc	0.0164	0.0208	0.0235	0.0256	0.0305
	SAR(T_lgr)/0.98	0.0129	0.0350	0.0327	0.0445	0.0257
	D*	0.79	1.68	1.39	1.74	0.84

[a] Direct estimate over entire reach; [b] per mile expansion below John Day Dam; [c] per mile expansion below McNary Dam.

3.9 Size based or year-to-year variations in bypass survival estimates (Hypothesis 2.5)

A recent paper by Zabel et al. (2003) has suggested that fish size (length) may be an important factor in both survival through Columbia dam bypasses and detection at these bypasses. Their analysis of over 340,000 PIT tagged chinook salmon and steelhead indicated a consistent negative relationship between detection probability at fish bypass systems and fish length of seaward migrating smolts (i.e., multiple-bypassed fish tended to be smaller). They suggested that the mechanism for this could either be that 1) spatial heterogeneity related to size could result in different exposure to traps or detection sites, or 2) that individuals of different sizes may have differential abilities to escape the traps or detection sites once they are in close proximity (Zabel et al. 2003). The relationship between estimated survival and fish length, however, was not strong and was also highly variable

Zabel et al.'s (2003) overall analysis would seem to indicate that size-selection at the bypass detection systems appears to be a relatively weak effect; however, determining the extent to which size-selection may or may not contribute to the relationship between number of bypass experiences and SARs requires further evaluation. In this regard, Tom Berggren undertook a reanalysis of existing PIT tag data from 1998 to 2000 to assess whether biologically meaningful size-selectivity at the bypass systems was occurring.

3.9.1 Assessment of size selection at Columbia bypass systems *(T. Berggren)*

Before investigating whether size selection of bypass systems has impacts on the SARs of PIT tagged wild spring/summer chinook, it is important to see if any biologically meaningful difference in collection efficiency is apparent in the PIT tag data. NMFS researchers have asserted that collection efficiency may

be size related. To check this assertion, wild chinook collected at Lower Granite Dam and PIT tagged for transportation studies by NMFS in 1998 to 2000 were reanalyzed. Only fish between 90 and 130 mm in length and marked before June 1 were used to assure that the fish in the analysis were not subyearling chinook. Collection efficiency at Little Goose Dam was calculated by utilizing PIT tagged wild spring/summer chinook smolts detected downstream of Little Goose Dam from the releases at Lower Granite Dam. The PIT tagged fish were separated into three size ranges of 90 to 103mm, 104 to 117mm and 118 to 123 mm. The PIT tag releases from Lower Granite Dam were grouped by week throughout each year. For each weekly release block, the downstream first-time detections at Lower Monumental, McNary, John Day or Bonneville dams were combined and placed into one of two categories. Either a fish was seen at Little Goose Dam ($X11$) or not seen at Little Goose Dam ($X01$). A correction, f, for the proportion of PIT tagged fish removed for transportation or research purposes at Little Goose Dam from each release group was made using the following formula:

$$CE = \frac{X11}{X11 + (1 - f)X01}$$

where CE = collection efficiency.

The resulting estimates of PIT tagged wild spring/summer chinook collection efficiencies grouped by smolt size (length at tagging) and weekly block are shown in Tables 3.9 to 3.11. In some cases, the number of PIT tags released per group and subsequent recapture (downstream detection) numbers were quite small, resulting in a group's collection efficiency estimate that may be unreliable. These results show a weak trend in size selectivity at Little Goose Dam for wild yearling chinook marked at Lower Granite Dam. In about 60% of the weekly comparisons (13 out of 22), the category with the largest sized smolts (118-123 mm) had the lowest collection efficiency, while the categories with the smallest (90-103 mm) and middle-sized (104-117 mm) smolts often did not fit any size-selectivity pattern.

Table 3.9. Collection efficiency at Little Goose Dam of PIT tagged wild yearling chinook marked and released at Lower Granite Dam in 1998, grouped by smolt length and week of release.

Release end date	Smolt Length Category		
	90 to 103 mm	104 to 117 mm	118 to 123 mm
4/13	0.37	0.32	0.27
4/20	0.38	0.40	0.28
4/27	0.42	0.54	0.50
5/04	0.77	0.60	0.65
5/11	0.54	0.55	0.47
5/18	0.35	0.49	0.71

Table 3.10. Collection efficiency at Little Goose Dam of PIT tagged wild yearling chinook marked and released at Lower Granite Dam in 1999, grouped by smolt length and week of release.

Release end date	Smolt Length Category		
	90 to 103 mm	104 to 117 mm	118 to 123 mm
4/08	0.57	0.45	0.54
4/15	0.61	0.49	0.60
4/22	0.65	0.74	0.65
4/29	0.65	0.66	0.61
5/06	0.68	0.69	0.67
5/13	0.60	0.53	0.60
5/20	0.38	0.62	0.18
5/27	0.55	0.50	0.33

Table 3.11. Collection efficiency at Little Goose Dam of PIT tagged wild yearling chinook marked and released at Lower Granite Dam in 2000, grouped by smolt length and week of release.

Release end date	Smolt Length Category		
	90 to 103 mm	104 to 117 mm	118 to 123 mm
4/09	1.00	0.90	0.84
4/16	0.51	0.57	0.57
4/23	0.46	0.48	0.45
4/30	0.60	0.51	0.36
5/07	0.33	0.26	0.31
5/14	0.22	0.20	0.19
5/21	0.12	0.25	0.19
5/28	0.31	0.36	0.30

A seasonal collection efficiency estimate for each year and size group of PIT tagged wild spring/summer chinook was computed by weighting the weekly collection efficiency estimates by their respective PIT tag release number (Table 3.12). These results show a weak trend in size selectivity at Little Goose Dam for wild yearling chinook marked at Lower Granite Dam. In 1998 and 1999, the category with the largest sized smolts (118-123 mm) had the lowest collection efficiency, while the smallest (90-103 mm) and middle-sized (104-117 mm) smolt categories had similar collection efficiencies. Only in 2000 was there the trend of decreasing collection efficiency as smolt releases increased in smolt size (length at tagging). But because the differences in collection efficiency between the fish size groups were only in the range of 1 to 5%, these results were not likely biologically significant.

Table 3.12. Weighted seasonal collection efficiency for PIT tagged wild spring/summer chinook at Little Goose Dam for migration years 1998 to 2000, grouped by length at tagging of smolts.

Year	Smolt Length Category		
	90 to 103 mm	104 to 117 mm	118 to 123 mm
1998	0.45	0.46	0.41
1999	0.64	0.65	0.61
2000	0.43	0.40	0.37

Conclusions

As stated at the start of this analysis, there needs to be determination of whether any biologically meaningful difference in collection efficiency is observed in the PIT tag data before beginning an investigation into whether size selection of bypass systems affects the SARs of the PIT tagged wild spring/summer chinook. Although the results presented in Tables 3.9 to 3.12 above may be viewed as preliminary, there doesn't appear to be any strong size-selectivity trends apparent in the PIT tag data from the Lower Granite Dam transportation studies. No confidence intervals were calculated for the collection efficiency estimates, but given such closely grouped estimates, there is no reason to expect any significant differences.

On the other hand, the patterns observed may be a result of tagging effects on recently marked fish and not have bearing on fish marked at and released a considerable amount of time before passing the dams. Smaller fish may be more affected by the presence of the tag for a period of time after marking, and that effect could diminish as fish are allowed time to recover. The weak pattern of size-selectivity described here could be associated with this particular study design. Further investigation utilizing PIT tagged smolts that have had a longer duration between tagging and detection at downstream dams is needed to test this. However, this duration cannot be too long as to allow smolt growth to confound differences between size at tagging and size when the PIT tagged fish are being detected in the bypass systems at the dams.

3.9.2 Effects of varied bypass operations/systems on past differences in survival of C_0 and C_1 fish *(T. Berggren)*

Subgroup A discussions additionally noted that there are elements of dam operations and detection protocols that have varied over the years, and could also contribute to confounding of perceived patterns in SARs and D. Spill rates, sample sizes and PIT-tag detection capabilities have all changed over time, which complicates any analysis of changing pattern in the ratio of C_0:C_1 survival. To address these concerns Tom Berggren undertook a series of analyses to explore whether CSS data could be used to evaluate the impact past bypass operations/systems might have on estimates of survival for spring/ summer chinook.

Changes in spill

It was noted at the CSS workshop that the change in the pattern of SARs for PIT tagged wild spring/summer chinook in study categories C_0 and C_1 since 1998 may be influenced by recent changes in hydro project operations toward less spill at Snake River dams. The SARs of these in-river migrating smolts was close in 1999 and identical in 2000, whereas in the earlier data collected (1994 to 1997), there was often a large difference in survival between the two groups. By definition, Category C_0 smolts pass the three Snake River collector/transport dams undetected (through spill or turbines) and Category C_1 smolts have detections in the bypass of one or more of these Snake River dams. Differences in SARs between the two groups have been attributed to passage through the bypass systems. Operational recommendations were made to transport all collected fish in part to prevent further bypass passage. More recent data collected suggests that the difference between the two groups may no longer exist and questions have been raised as to why this change has occurred.

One plausible explanation centers on the fact that spill patterns in the Snake and Columbia rivers have changed considerably over the time period of interest (Table 3.13). The 1994 and 1995 spill volumes and spill percentages were much lower during the spring migration than occurred during the later five years. In those latter five years, 1996 and 1997 had the highest runoff volumes, resulting in high daily flows, high spill percentages, and thus high spring season spill volumes. Spring spill volume continued to remain

well above the levels of 1994 and 1995 through 2000 in Table 3.13 due to the implementation of the Biological Opinion. Theoretically, a Category C_1 fish could go through fewer bypasses in recent years because of the increased spill, and thereby would be more like the C_0 group.

Table 3.13. Relative comparison of annual amounts of spill that occurred over the spring spill periods of 1994 to 2000.

Snake River basin

		Lower Granite Dam		Little Goose Dam		Lower Monumental Dam		Ice Harbor Dam	
Year	Runoff volume[1]	Spill total[2]	Avg % spill[3]	Spill total	Avg % spill	Spill total	Avg % spill	Spill total	Avg % spill
1994	16	1.5	15	2.1	20	0.8	9	3.2	34
1995	29	1.6	9	3.0	19	2.3	14	5.5	33
1996	42	8.3	39	8.0	38	7.7	34	8.9	41
1997	50	8.5	32	8.8	36	9.2	36	13.7	53
1998	31	5.3	28	5.6	32	5.0	26	10.2	58
1999	36	6.6	37	4.2	25	3.7	20	11.0	62
2000	25	3.7	29	3.2	22	4.6	33	9.6	70

[1] Runoff Volume is MAF (million acre feet) of water in Snake River above Lower Granite Dam over the January to July period.

[2] Spill Total is the total volume (MAF) of water passed over spillway during the spring spill period defined as April 3 to June 20 in the Snake River.

[3] Avg % Spill is the average of the percentage of daily average flow (kcfs) being spilled over the spring spill period.

Columbia River basin

		McNary Dam		John Day Dam		The Dalles Dam		Bonneville Dam	
Year	Runoff volume[1]	Spill total[2]	Avg % spill[3]	Spill total	Avg % spill	Spill total	Avg % spill	Spill total	Avg % spill
1994	75	3.0	9	1.1	3	6.6	21	12.7	40
1995	104	15.1	36	1.4	3	20.2	47	13.7	33
1996	139	23.1	56	13.4	22	33.4	57	28.4	47
1997	159	43.0	59	23.1	29	43.5	58	37.2	49
1998	105	18.4	38	14.1	28	20.5	42	16.6	34
1999	124	21.7	44	12.7	25	21.0	42	16.4	32
2000	98	15.4	38	12.4	31	15.1	38	14.5	35

[1] Runoff Volume is MAF (million acre feet) of water in Columbia River above The Dalles Dam over the January to July period.

[2] Spill Total is the total volume (MAF) of water passed over spillway during the spring spill period defined as April 10 to June 30 in the lower Columbia River.

[3] Avg % Spill is the average of the percentage of daily average flow (kcfs) being spilled over the spring spill period.

Sample sizes

One difficulty with the earlier years of PIT tag data was the extremely small sample sizes for the 1994 to 1997 adult returns (Table 3.14). This makes it virtually impossible to make any definitive statements regarding this information. However, some trends can be noted in the data, with C_0/C_1 survival ratios greater than 1.0 in 1994–1998 and close to 1.0 in 1999–2000.

Table 3.14. Estimated Lower Granite Dam PIT tagged wild spring/summer chinook population and associated number of adults returning per study category.

Migration year	Estimated LGR population	Study category	Adult number	CJS survival	C_0:C_1 survival
1994	15,250	C_0	5	0.28 (0.06-0.56)	3.1
		C_1	4	0.09 (0.02-0.19)	
1995	20,203	C_0	10	0.37 (0.15-0.63)	1.48
		C_1	36	0.25 (0.17-0.33)	
1996	7,868	C_0	5	0.26 (0.15-0.50)	1.52
		C_1	9	0.17 (0.08-0.29)	
1997	2,898	C_0	16	2.35 (1.30-3.67)	2.53
		C_1	18	0.93 (0.53-1.43)	
1998	17,362	C_0	42	1.36 (0.96-1.80)	1.25
		C_1	133	1.08 (0.90-1.26)	
1999	33,662	C_0	95	2.13 (1.71-2.59)	1.12
		C_1	497	1.90 (1.73-2.08)	
2000	25,047	C_0	154	2.37 (2.00-2.75)	1.02
		C_1	392	2.33 (2.10-2.57)	

Changes in PIT-tag detection capability

Another complication affecting our ability to analyze the data is that full bypass detection history through all six dams equipped with PIT tag detectors between Lower Granite and Bonneville dams has only been available for fish migrating in 1998 and beyond. Prior to 1998, there was very limited PIT tag detection capability at John Day Dam (1–2 gatewell slots out of 48 gatewell slots present at the dam) and very low numbers of PIT tagged fish being detected at Bonneville Dam. Since the following analysis was geared toward those PIT tagged smolts that were known to survive to adulthood, the numbers of these smolt detected below McNary Dam was negligible.

Overall patterns of detection rates and spill

Table 3.15 compares the PIT tagged wild spring/summer chinook smolts in Category C_0 that survived to adulthood relative to their detection history at McNary Dam across the migration years 1994 to 2000. The goal would be to compare data from the low spill years of 1994 and 1995 with the higher spill years of 1996 through 2000. However, prior to 1997 the C_0 group had no detections at McNary Dam, and after 1997 about 30% of the C_0 group was detected at McNary Dam. This is a change in the makeup of the C_0 group that appears related to spill volumes, but small sample sizes prevent further analysis.

Table 3.15. Number of PIT tagged wild spring/summer chinook returning as adults that were detected as smolts at McNary Dam during migration years 1994 to 2000.

	Category C_0 PIT tagged wild chinook smolts that survive to adulthood		
Year	Total Number	Number detected at McNary Dam	Percent detected at McNary Dam
1994	5	0	0.0
1995	9	0	0.0
1996	4	0	0.0
1997	17	5	29.4
1998	46	15	32.6
1999	93	26	28.0
2000	154	45	29.2

In general, the higher spill at the Snake River projects from 1996 to 2000 resulted in PIT tagged smolts being detected fewer times, on average, in the Snake River post 1997 than pre 1997. Category C_1 fish (detected at 1 or more Snake River collector dams) had a greater chance of passing into a bypass system pre 1997 with the lower spill volumes. Category C1 smolts that survived to adulthood were detected, on average, 1.3, 1.7, 1.6, and 1.8 times in the Snake River during 1994, 1995, 1996, and 1997, respectively. These fish continued through the lower river and conceivably could have passed 1 to 3 more bypass systems, thus increasing the average number of bypasses they encountered.

As spill in the system increased over the years the number of bypasses experienced by the C_1 group would likely have decreased because the probability that they passed in spill increased. For example, the average number of bypasses experienced by the C_1 group in later years has decreased relative to the earlier years of data (about the same number of detections, but with 6 primary detection sites in later years versus 4 primary detection sites in earlier years). In addition, as shown in Table 3.16, the number of bypasses used in the downstream migrations of 1998 to 2000 by Category C_1 and C_0 smolts that survived to adulthood differed by only one bypass on average. These two observations may explain why the patterns for SARs have changed over the years.

Table 3.16. Average number of bypasses at which PIT tagged wild spring/summer chinook in study categories C_0 and C_1 were detected in migration year 1998 to 2000.

Year	C_0	C_1
1998	0.5	1.7
1999	0.8	1.9
2000	0.6	1.8

Conclusions:

In conclusion, although some inferences can be made from the data as to why C_0 and C_1 detections may have changed over the years, the CSS study was not structured to specifically address the question of the effects of bypass passage on SARs. Trying to address this question by conducting an analysis based on hindsight is proving to be difficult. The use of the C_0 and C_1 groups from the 1994 through 2000 data set has two inherent problems:

1. Sample sizes for the early years are very small.
2. The full 6-dam detection history was not available until 1998.

However, within the limitations described above, inferences can be made from trends in the data as to why there may have been a change over the years in the pattern of SARs between smolts in categories C0 and C1, but again no conclusive reasons can be developed. An alternate way to address the question might be to conduct an analysis of data from 1998 and beyond, and group all of the juvenile data by the number of bypass detections. This would lead to groups with from one to six detections, and the adult returns from these data could be compared. This would be a cleaner analysis, but was beyond the scope of this CSS assignment. It is something that could be addressed at some point in the future if sample sizes are determined to be sufficient.

4.0 Effects of Hydrosystem Stress

Subgroup B (see Appendix B) was charged with evaluating evidence relating specifically to Hypothesis 2.3.1: *Smolt passage routes through or around the hydrosystem cause various types of stress on smolts that increase vulnerability to mortality factors.*

In addition to evaluating the more general evidence relating stress to indirect mortality, Subgroup B assessed the value of evidence linking the four specific stress-induced mechanisms hypothesized as causing delayed mortality:

2.3.1.1 *Amount or extent of passage through or around the hydrosystem increases vulnerability to horizontal transmission of pathogens.*

2.3.1.2 *Passage through or around the hydrosystem reduces growth rates or condition of smolts.*

2.3.1.3 *Passage through or around the hydrosystem increases vulnerability to predation.*

2.3.1.4 *Passage through or around the hydrosystem results in reversal of, or incomplete smoltification.*

4.1 Evidence table[1]

Through consultation with the CSS Oversight Committee and experts in the fields of fish and stress physiology, the principal literature relating to stress was assembled for review by Subgroup B participants during and after the CSS Workshop. Relevant evidence (studies) for each hypothesis were classified based on the "Literature/supplementary," "Indirect," and "Direct" categories of evidence used in Budy et al. (2002)[1]. These studies were reviewed for evidence either for or against the main stress hypothesis and the four sub-hypotheses using the criteria outlined in Section 2.2. Table 4.1 presents the evidence by hypothesis and provides a brief summary of the stress indicators and general approach used in each study. Some studies may be applicable to multiple hypotheses, and therefore are listed more than once. Appendix F ("Application of Criteria for Evaluating Evidence") presents detailed narratives for the evidence summarized in Table 4.1.

[1] Direct: "Comparisons of overall survival of different groups of fish that experience different combinations of passage routes and transportation around the dams."
Indirect: "Retrospective comparisons of stock performance among regions and time periods provide indirect evidence of delayed mortality linked to hydrosystem experience." (Budy et al. 2002)

Table 4.1. Summary and evaluation of evidence relating to stress hypotheses. Relevant references are listed under each hypothesis (hypotheses are shown in bold). References listed in the second column allow cross-referencing of Tables 4.1 and 4.2. Section 6 includes references for evidence sources. Each of the three evidential criteria (applicability, clarity and rigor) were assessed on a 3-point scale, where '1' is best, and '3' is worst. Initials of Subgroup B participant undertaking a particular review are shown in the Reviewer column (or else 'ESSA' if primary review of paper done by ESSA Technologies).

Reviewer	Evidence/ source *	Indicator	Approach	Criteria **			Type of evidence	Comments/ uncertainties
				Appl.	Clarity	Rigor		
2.3 The hydrosystem indirectly affects smolt to adult survival by imposing stress on smolts.								
2.3.1 Smolt passage routes through or around the hydrosystem cause various types of stress on smolts that increase vulnerability to mortality factors.								
NB	Schreck et al. (1984)	Plasma cortisol Glucose, lactose Hepatic glycogen	Examined effects of acclimation temperature upon physiological responses & recovery resulting from an acute stress.	2	2	2	Direct	Supports the hypothesis
PW	Congleton et al. (2000)	Stress indices – increased plasma cortisol & glucose, decreased plasma chloride concentration	Wild and hatchery juveniles sampled after loading into fish-transport barges & after barge transportation. Chinook are more stressed by barge transportation than steelhead.	1	2	2	Direct	Supports the hypothesis
PB MM	Mazeaud et al. (1977)	Endocrine changes Blood glucose Plasmatic free fatty acid	Perturbations of biological parameters were investigated/reviewed to analyze & quantify stress. Discussion of primary & secondary effects of stress. Focused on the possibility of genetic selection of varieties of high or low response to stress.	3	2	3	Literature	Supports the hypothesis (weakly)
PW	National Marine Fisheries Service (2000e)		Synthesis of scientific information regarding transportation of salmonids through the hydrosystem. Empirical evidence is lacking to support speculation on whether transportation increases the susceptibility of salmonids to mortality from stress or disease.	1	2	2	Literature	Supports the hypothesis White paper. States that the white papers do not speculate about indirect effects that might occur as a result of hydrosystem passage.
PW	Levin and Williams (2002)	SAR El Nino-Southern Oscillation index	Examined survival rates of wild chinook and steelhead in the Snake River as a function of the number of hatchery steelhead released and climatic conditions. Chinook data was from out-migration years 1977 – 1997, steelhead from 1997 – 1994. Literature review.	2	3.5	2	Indirect.	Supports the hypothesis (weakly)

Reviewer	Evidence/ source *	Indicator	Approach	Criteria **			Type of evidence	Comments/ uncertainties
				Appl.	Clarity	Rigor		
NB	Congleton et al. (1995) Schreck et al. (1996) Congleton et al.(1996) {Project MPE-96-10}	Stress response	Examined stress response of s/s chinook and steelhead smolts exposed to multiple stressors simulating dam passage and barging events	2	2.5	2	Direct	Supports the hypothesis
NB	Schreck et al. (1992) Schreck et al. (1993) Schreck et al. (1994a) Schreck et al. (1995) {Project JTF-92-XX-3}	Stress response	Examined stress response of Snake River s/s chinook and steelhead during collection, loading and transport in barges	2	2	2	Direct	Supports the hypothesis
NB	Schreck and Stahl (2000a) Schreck et al. (2001a) Schreck et al. (2002a) {Project BPS-W-00-10}	Migration and survival rates	Acoustic tag detectors were used to evaluated behavior and survival of in-river and barged hatchery steelhead smolts below Bonneville Dam. Barged fish had higher mortality in estuary than ROR fish (consistent with D<1.0)	2	2.5	2	Direct	Supports the hypothesis
NB	Schreck et al. (1994a) {Project JTF-92-XX-3}	Stress response	Evaluated the impacts of collection and barging of smolts at McNary Dam	2	2	2	Direct	Supports the hypothesis

Reviewer	Evidence/ source *	Indicator	Approach	Criteria **			Type of evidence	Comments/ uncertainties
				Appl.	Clarity	Rigor		
NB	Schreck et al. (2000a) Schreck et al. (2000b) Schreck et al. (2001b) Schreck et al. (2002b) Schreck et al. (2003a) Schreck et al. (2003b) {Project TPE-00-1}	Post Bonneville survival rate; migration rates, saltwater preference	Used acoustic tags to evaluate differences in stress to and survival of ROR versus barged Snake River fall chinook and steelhead smolts	2	2.5	2	Direct	Supports the hypothesis (for fall chinook - equivocal for steelhead)
NB	Schreck et al. (1994b) {Project No. 88-160-3}	Stress indicators; migratory behavior	Evaluated stress responses of barged Willamette R. hatchery spring chinook smolts, and followed radio tagged smolts after release	2.5	2	2	Direct	Supports the hypothesis
MF	Monk et al. (1997)	Physiological indicators of gas bubble disease Reach survival rates	Measured GBD symptoms in juvenile steelhead following dam passage, compared survival rates of juvenile SH experimentally exposed to gas supersaturation. No significant differences in survival of exposed fish vs. controls.	3	3	3	Direct	Does not support the hypothesis (weakly)
2.3.1.1 Amount or extent of passage through or around the hydrosystem increases vulnerability to disease.								
PB MM	Wedermeyer (1970)		Literature review on the role of stress in fish disease.	3	3	2	Literature	Supports the hypothesis
PB MM	Congleton et al. (1984)	Direct Fluorescent Antibody Technique (DFAT)	Tested chinook smolts transported from hatcheries to MFS in Puget Sound & held in seawater to see if mortality due to BKD would increase following stresses of transportation. Survival was not correlated with BKD incidence.	1	2	3	Direct	Supports the hypothesis
MM	Raymond (1988)	SAR	Determined trends in abundance of spring/summer chinook & steelhead returning. Analyzed the % of adults returning from smolt out-migrations of 1962-1984. Used data from adult counts at dams, harvest data for river, and a method for obtaining relative annual indices of numbers of smolts starting seaward migrations.	3	3	2	Indirect	Supports the hypothesis (weakly)
MM	Maule et al. (1989)	Immune function Resistance to pathogen Cortisol	Exposed juvenile chinook to stress in lab and evaluated response.	2	2	1	Literature	Supports hypothesis

Reviewer	Evidence/ source *	Indicator	Approach	Criteria **			Type of evidence	Comments/ uncertainties
				Appl.	Clarity	Rigor		
PB MM	Mazeaud et al. (1977)	Endocrine changes Blood glucose Plasmatic free fatty acid	Perturbations of biological parameters were investigated/reviewed to analyze & quantify stress. Discussion of primary & secondary effects of stress. High concentrations of cortisol (due to stress) interfere with the immunological response to disease organisms.	3	2	3	Literature	Supports the hypothesis (weakly)
PB MM	Schreck et al. (2001c)	Cortisol	Literature review describing basic physiologic response of rainbow trout juveniles to stressors & consequences on fitness of broodfish. Reviews effects of stressor applied at different times during reproductive maturation. Stressed fish succumb to pathogens they would otherwise resist - a secondary effect of stress. Shows that time of stress is the most important thing, e.g., at time of reproduction. Matches up with patterns of R/S or Sp/Sp, not for SARs, T/Cs, D.	2	2	1	Literature	Supports the hypothesis
MM	Mesa et al. (2000)		Experimentally infected spring chinook with BKD and exposed them to multiple acute stressors. Saw no evidence that disease got worse or that those fish had higher mortality than fish that did receive the stressor.	2	3	1	Literature	Does not support hypothesis
2.3.1.2 Passage through or around the hydrosystem reduces growth and condition of smolts.								
JC MF	Rondorf et al. (1985)	Fatty acids	Model simulated energy budgets of smolts as a function of water temperature and flow regimes. Data from literature, lab & Columbia River basin.	1.5	1.5	2.5	Literature	Supports the hypothesis
PB MM	Williams and Mathews (1995)	Descaling, Relative survival	Migration rate, Upstream / downstream comparisons. Review of flow & survival relationships. Delayed mortality of spring-summer chinook smolts was correlated with degree of descaling.	1	2	2	Direct	Supports the hypothesis (weakly)
ESSA	Congleton et al. (2004) - Presentation at CSS workshop (Appendix G in this report)	Protein, lipids, cholesterol, swimming ability, condition factors, ATPase, Na+, K+,	Assessed condition of hatchery Snake River s/s chinook moving through the hydrosystem. Nutritional status (condition) decreased dependent on time in the hydrosystem and with later dates of migration. Nutritional indices for low-flow year smolts was comparable to fasted laboratory fish which showed diminished swimming and osmoregulatory abilities	1	2	2	Direct	Supports the hypothesis
2.3.1.3 Passage through or around the hydrosystem increases vulnerability to predation *								
ESSA	Congleton et al. (1984)	Relative predation rates; physiological stress response;	Exposed to crowding; measured phys. response to dam passage / transportation; compared predation on stressed / unstressed	1	2	2	Direct	Supports the hypothesis
ESSA	Mesa and Warren (1996)	Relative predation rates	Exposed to varying TGD levels and predation	2	2	1	Direct	Supports the hypothesis

Reviewer	Evidence/ source *	Indicator	Approach	Criteria **			Type of evidence	Comments/ uncertainties
				Appl.	Clarity	Rigor		
ESSA	Mesa et al. (1994)		Literature review	3	3	2	Literature	Supports the hypothesis
ESSA	Coutant (1973)	Relative predation rates	Measured differential predation on thermally shocked fish vs. control	2	2	1	Direct	Supports the hypothesis
ESSA	Mesa (1994)	Relative predation rates, physiological stress response	Lab experiments with treatments designed to simulate routine hatchery practices or dam passage.	2	2	1	Direct	Does not support the hypothesis
ESSA	Kruzynski and Birtwell (1994)	Relative predation rates	Fish exposed to sublethal concentration of toxics	3	3	1	Literature	Supports the hypothesis
DR	Columbia Basin Fish and Wildlife Authority (1991)		Literature review to provide the biological and technical justification for the flow proposal of the Columbia Basin Fish & Wildlife Authority. Goal to improve migration conditions to maximize survival. Discussion of relationship between water flows and predation. Focussed on residence time, temperature effects and water velocity. Insufficient water flows causes extended residence times of smolts. High temp. periods may severely exacerbate the predation problem.	3	2	3	Literature	Neither supports or opposes the hypothesis
ESSA	National Marine Fisheries Service (2000b)	Blood chemistry Increased descaling	Synthesis of scientific information focussing on passage of juvenile and adult salmonids through the Columbia River hydrosystem. Fish transiting bypass systems often have increased levels of stress. Some evidence suggests bypass induced stress may reduce the ability of juveniles to avoid predators.	3	2	2	Literature	Neither supports or opposes the hypothesis White paper. States that the white papers do not speculate about indirect effects that might occur as a result of hydrosystem passage.
DR	National Marine Fisheries Service (2000c)		Synthesis of scientific information focussing on passage of juvenile and adult salmonids through the Columbia River hydrosystem. The hydrosystem if believed to have increased the incidence of predation on salmonids over historic levels. The hydrosystem may increase stress and subclinical disease of juveniles increasing susceptibility to predation.	3	2	2	Literature	Neither supports or opposes the hypothesis White paper
DR	Mesa et al. (1998)	BKD, relative predation rates	Evaluation of vulnerability of BKD infected chinook juveniles to fish predators	1	2	2	Literature	Supports the hypothesis
DR	Ward et al. (1995)	Relative predation rates	Development of index of predation for Columbia, showed highest rates of predation by Northern Pikeminnow below Bonneville Dam	1	2	1	Direct	Supports the hypothesis
DR	Solazzi et al. (1991)	Relative Survival rates	Evaluated differential survival of juvenile salmon experimentally released at different locations (Bonnevllle Dam, estuary, off shore)	1	1	1	Direct	Supports the hypothesis
DR	Mesa et al. (2002)	Mortality, Relative predation rates	Exposed juvenile chinook to thermal stress. Evaluated if these stresses resulted in increased direct mortality or increased vulnerability to predation	3	1	2	Literature	Does not support the hypothesis

Reviewer	Evidence/ source *	Indicator	Approach	Criteria **			Type of evidence	Comments/ uncertainties
				Appl.	Clarity	Rigor		
ESSA	Olla et al. (1995)	Predator-evasion behavior, relative predation rates	Exposed chinook and coho smolts to handling stress. Evaluate vulnerability to predation by lingcod at variable times post handling.	2	2	1	Literature	Supports the hypothesis
DR	Petersen et al. (1994)	Differential predation on live/dead fish	Undertook experimental releases of live and dead salmon juveniles into Bonneville tail race to evaluate degrees of Northern Pikeminnow ingestion of dead fish	1	2	1	Direct	Supports the hypothesis
ESSA	Olla et al. (1992)	Plasma corticosoids, predator-evasion behavior	Coho juveniles were exposed to handling stress and then stress chemical levels and predator-evasion behaviors were evaluated at varied times post handling	3	2	1	Literature	Does not support the hypothesis
ESSA	Price and Schreck (2003)	Entry into saltwater	Exposed chinook salmon smolts to stress caused by exposure to simulated predators in lab setting. Evaluated ability to subsequently move into saltwater	2	2	1	Literature	Supports the hypothesis
ESSA	Marine and Cech, Jr. (2004)	Relative predation rates	Exposed chinook juveniles to high water temperatures and then evaluated vulnerability to predation by Striped Bass	2	3	2	Literature	Supports the hypothesis
ESSA	Gadomski et al. (1994)	Stress chemicals, Relative predation rates	Descaled chinook juveniles at levels of 10 and 20% descaled. Evaluated physiological changes and vulnerability to predation by Northern Pikeminnow	2	2	1	Direct	Does not support the hypothesis
ESSA	Handeland (1996)	Relative predation rates	Exposed Atlantic salmon juveniles to osmotic stress and then evaluated vulnerability to predation by Cod	2	2	1	Literature	Supports the hypothesis
NB	Clugston and Schreck (1992) Snelling and Schreck (1993) {Project No. 82-003}	Release behavior	Used radio tag tracking to compare behavior of stressed and unstressed (control) hatchery s/s chinook and steelhead smolts after release into the river	2	2	2.5	Direct	Supports the hypothesis
NB	Schreck et al. (1997) Schreck and Stahl (2000b) {Project MPE-95-3 and MPE-W-97-4}	Stress response, migration rates, predation rates	Evaluated stress responses of Snake River hatchery and wild s/s chinook at time of release, and migratory rates/behavior of ROR vs. barged smolts	1.5	2	2	Direct	Supports the hypothesis
NB	Stahl et al. (2000)	Stress response, outmigration behavior	Evaluated the behavior of stressed hatchery coho smolts at time of release in terms of increased vulnerability to avian predators	3	3	3	Direct	Neither supports or opposes the hypothesis

Reviewer	Evidence/ source *	Indicator	Approach	Criteria **			Type of evidence	Comments/ uncertainties
				Appl.	Clarity	Rigor		
2.3.1.4 Passage through or around the hydrosystem results in incomplete/delayed smoltification.								
NB	Schreck et al. (1997) Schreck and Stahl (2000a) {Project MPE-95-3 and MPE-W-97-4}	Stress response, migration rates, predation rates	Evaluated stress responses of Snake River hatchery and wild s/s chinook at time of release, and migratory rates/behavior of ROR vs. barged smolts	1.5	2	2	Direct	Supports the hypothesis
JC	Vanderkooi and Gale (2000)	Gill Na^+, K^+, ATPase, Cortisol, Glucose	Exposed subyearling and yearling spring chinook to electroshock or an acute handling stress & measured indicators at 3h, 25h & 7 days after exposure. No reductions in gill Na^+, K^+, or ATPase activity.	3	1	1	Literature	Does not support the hypothesis
JC	Patino et al. (1986)		Smoltification of coho was impaired or delayed by high rearing density and low water flow conditions.	3	1	1	Literature	Neither supports or opposes the hypothesis
JC	Mesa et al. (1999)	BKD, gill NA^+, K^+, ATPase	BKD disease progression in juvenile chinook caused increased stress response but no reduction in smoltification indices	2.5	2	1	Literature	Does not support the hypothesis
JC	Congleton et al. (2000)	Cortisol, glucose, electrolytes, NA^+, K^+, ATPase	Assessed effect of barging on smoltification indices for Snake R. s/s chinook and steelhead. No significant changes were evident.	1	2	2	Direct	Does not support the hypothesis
MF	Rondorf et al. (1989) Beeman et al. (1990) Beeman et al. (1991) Maule et al. (1994) Schrock et al. (1999) Schrock et al. (2000) {Project DE-A179-87BP35245}	Na+, K+, ATPase	The Assessment of Smolt Condition for Travel Time Analysis Project monitored attributes of smolt physiology in the Columbia and Snake River basins in multiple years. Goal was to relate levels of smolt development to migration rates through the hydrosystem.	2	2	2	Indirect	Neither supports or opposes the hypothesis

* Note that, in some cases, a group of papers (i.e., yearly reports from a multi-year report series) will have been summarized as a single evidence/source, and will have been evaluated as only **one** paper for the purposes of this assessment.

** If two individuals reviewed the same paper the criteria values presented here are the average of the reviewers' scores.

4.1.1 Interpretations from the evidence table

To assist in interpretation of the results presented in Table 4.1, we further condensed the evidence in two ways. First, we counted the number of papers in the three support categories (i.e., "support," "does not support," or "ambiguous" (provides evidence neither for or against the hypothesis)) for each hydrosystem stress-related hypothesis. We also assessed these categories of support based on whether the evidence was "direct," "indirect," or "literature /supplementary" (as in Budy et al. (2002)). These results are presented in Table 4.1.1. Secondly, we averaged the scores for the "applicability," "clarity" and "rigor" criteria (defined in section 2.2) across each support category for each hypothesis (Table 4.1.2). **Note** that these scores **are not** standardized across reviewers, in most cases there is only one reviewer per paper, thus these averages only represent a crude index of the available literatures' "value" for addressing a particular support category within a hypothesis. A final summary of literature support for the hydrosystem stress-related hypotheses (Hypotheses 2.3.1, 2.3.1.1, 2.3.1.2, 2.3.1.3 and 2.3.1.4) is presented in Table 4.1.3.

We use these two approaches to qualitatively summarize the level of support for each hypothesis in Table 4.1 in terms of the number of relevant papers, how directly related they were to the hypothesis, and their average "value". These results could conflict somewhat with expert opinion, which will also include a synthesis of information beyond than published. This is taken into consideration in Table 4.2 where results of this analysis are combined with expert opinions expressed at the workshop, to provide an overall synthesis of support for each hypothesis.

Subgroup B reviewed a total of twelve papers that addressed **hydrosystem stress (Hypothesis 2.3.1)** as a general mechanism for explaining delayed mortality (Table 4.1.1). Eleven of these papers provided some level of support for stress as an explanatory mechanism; seven of these providing direct evidence in support. Only one of the papers presented evidence that was counter to the hypothesis. In terms of their "value," as defined by the average score over the "applicability," "clarity" and "rigor" criteria, the average scores for the supporting studies were better (i.e., lower) than the scores for the one paper which did not support the hypothesis (Table 4.1.2). Thus the weight of available evidence strongly supports this hypothesis in terms of the number of papers, how directly the supporting papers addressed it and the average "value" of those papers.

Seven papers were reviewed for the **stress-disease hypothesis (Hypothesis 2.3.1.1)** (Table 4.1.1). Most of the papers (6) provided some level of support for the disease hypothesis, but the majority of these papers (4) were reviews and provided only conceptual support. One paper did not support the hypothesis. In terms of "value" the scores for the six supporting papers varied over the three criteria being better for "clarity," but worse for "applicability" and "rigor" relative to the one paper that did not support the hypothesis (Table 4.1.2). Thus, we conclude that weight of available evidence suggest a medium level of support for this hypothesis despite the larger number of supporting papers because the supporting evidence is not as direct as for hypothesis 2.3.1 and its average value is lower.

Only two published papers were found for the **stress-growth/condition hypothesis (Hypothesis 2.3.1.2)**, both of which support it (Table 4.1.1). We included Jim Congleton's presentation at the CSS workshop as an additional study in support of this hypothesis, although it is not yet published. The average criteria scores for these three studies were reasonably good ranging from 1.2 for "applicability" to 2.2 for "clarity" (Table 4.1.2). Based only on the proportion of papers that supported hypothesis and their relatively high "value," the weight of the available evidence tends to favor this hypothesis, but weakly since the few studies available for review make it difficult to draw strong conclusions at this stage. Greater confidence could be gained through a more thorough search for available information.

Twenty-three papers were reviewed for the **stress-predation hypothesis (Hypothesis 2.3.1.3)**, 15 of which provided some level of support for the hypothesis; eight of these papers provided direct support of the hypothesis (Table 4.1.1). Of the remaining papers, four did not support the hypothesis, and four were ambiguous (neither supported nor opposed the hypothesis). The average score for the papers that supported the hypothesis was better for "applicability" than those that either did not support it or were ambiguous (1.8 vs. 2.5 and 3 respectively) (Table 4.1.2). They scored slightly worse than those that did not support the hypothesis (2.1 vs. 1.8) on "clarity," but about the same "rigor" (1.4 vs. 1.3). They scored better for both "clarity" and "rigor" against the ambiguous studies (2.1 vs. 2.3 for clarity and 1.4 vs. 2.5 for rigor). This stress-predation hypothesis had by far the most information available for review of all the hypotheses. The weight of available evidence strongly supports it in terms of the number of papers in support and their "value." We conclude that this hypothesized mechanism for stress related impacts on delayed mortality has merit and should be pursued further.

Six papers were reviewed for the **stress-smoltification hypothesis (Hypothesis 2.3.1.4)**, only one of which supported it (Table 4.1.1). Three papers presented evidence counter to the hypothesis and two papers were ambiguous (neither supported nor opposed the hypothesis). Of the three papers counter to the hypotheses, only one addressed it directly, the remaining two were reviews. Of the two "ambiguous" papers, one was "indirect" and the other was a review. The three papers that did not support the smoltification hypothesis had a medium score for applicability (2.2), but reasonably good scores for clarity and rigor (1.7 and 1.3 respectively) (Table 4.1.2). Despite the fact that most of the papers did not support this hypotheses and those papers tended to be of good "value," we concluded that the weight of evidence is only weakly against this hypothesis because only six studies were available for review, only three of those did not support the hypothesis, and most of the studies did not address the hypothesis directly. Given the paucity of studies available to review for this hypothesis, it would be worth making a second pass to determine if more information relating to this subject is available than has yet been uncovered.

Table 4.1.1. Levels of support for each of the stress-related hypotheses based on the studies summarized in Table 4.1. Types of evidence are based on categories defined in Budy et al. (2002).

		Type of evidence		
Hypothesis	**Level of support**	**Direct**	**Indirect**	**Literature / supplementary**
Overall Stress (2.3.1)	Support	8	1	2
	Does not support	1	0	0
	Ambiguous	0	0	0
Disease (2.3.1.1)	Support	1	1	4
	Does not support	0	0	1
	Ambiguous	0	0	0
Growth/Condition (2.3.1.2)	Support	2	0	1
	Does not support	0	0	0
	Ambiguous	0	0	0
Predation (2.3.1.3)	Support	8	0	7
	Does not support	2	2	0
	Ambiguous	1	0	3
Smoltification (2.3.1.4)	Support	1	0	0
	Does not support	1	0	2
	Ambiguous	0	1	1

Table 4.1.2. Average scores over the Applicability, Clarity, and Rigor criteria. Scores are averages over the number of studies that either support ("Yes"), do not support ("No"), or neither support or not support ("Ambiguous") each hypothesis. The calculations use the scores presented in Table 4.1.

Hypothesis	Supports?	Applicability	Clarity	Rigor	N
2.3.1	Yes	1.9	2.3	2.1	11
	No	3	3	3	1
	Ambiguous				0
2.3.1.1	Yes	2.3	2.3	2.0	6
	No	2.0	3.0	1.0	1
	Ambiguous				0
2.3.1.2	Yes	1.2	1.8	2.2	3
	No				0
	Ambiguous				0
2.3.1.3	Yes	1.8	2.1	1.4	15
	No	2.5	1.8	1.3	4
	Ambiguous	3.0	2.3	2.5	4
2.3.1.4	Yes	1.5	2.0	2.0	1
	No	2.2	1.7	1.3	3
	Ambiguous	2.5	1.5	1.5	2

Table 4.1.3. Summary of hydrosystem stress-related hypotheses (Hypotheses 2.3.1, 2.3.1.1, 2.3.1.2, 2.3.1.3 and 2.3.1.4) — the majority of papers reviewed by Subgroup B appeared to support (to varying levels) each of the different hydrosystem-stress related hypotheses. The exception to this was the smoltification hypothesis, for which only one paper was found that supported this hypothesis.

Hypothesis	Number of papers reviewed	Number of papers supporting hypothesis	% supporting
Overall Stress (2.3.1)	12	11	92
Disease (2.3.1.1)	7	6	86
Growth/Condition (2.3.1.2)	3	3	100
Predation (2.3.1.3)	23	15	65
Smoltification (2.3.1.4)	6	1	17

Comments on Section 4.1.1 (*N. Bouwes*)

As was discussed before and during the workshop there is difficulty in interpreting studies that show "no significant" response. Because null hypothesis tests are often used in several studies, studies can only say whether they have rejected the hypothesis of no effect, or have failed to reject they hypothesis of no effect. A failure to reject the null is not the same as assuming the null is true. Such tests do not guard against committing a Type II error (accepting a false null) with nearly the same rigor as for a Type I error (rejecting a true null). In fact, it is likely that few of the studies reviewed at the workshop that failed to reject the null have evaluated the power of the statistical test used (although post-hoc power analyses have very limited value). Thus, a study that failed to show significant effects seems like it should at best be categorized as ambiguous (neither for or against) unless confidence intervals surrounding the difference in treatments was included in the paper and the reviewer made the call that the effects were not biologically significant.

4.2 Hypothesis table

Subgroup B participants were further asked to synthesize the existing information (based on the evidence presented and evaluated in Table 4.1, and their own expert knowledge) relevant to the overall hypothesis and each component link, using the three criteria outlined in detail in Section 2.2:

1. clarity;
2. mechanism; and
3. consistency with empirical evidence.

Table 4.2 presents this final assessment by Subgroup B participants as to whether each particular stress-related hypothesis was either:

i) **Likely:** the hypothesis seems plausible and is supported by the existing information reviewed in Table 4.1, as well as the synthesis of expert opinion expressed by Subgroup B participants.

ii) **Unlikely:** the hypothesis seems plausible but is not supported by the existing information reviewed in Table 4.1, nor does the synthesis of expert opinion expressed by Subgroup B participants suggest any support for the hypothesis.

iii) **Uncertain:** although the synthesis of expert opinion expressed by Subgroup B participants suggests that the hypothesis seems either likely or unlikely, given the lack of **definitive** supporting information in Table 4.1 an evaluation of the hypothesis is still considered speculative and requires further research.

iv) **Impossible to evaluate:** supporting information in Table 4.1 is currently extremely limited or non-existent and the synthesis of expert opinion expressed by participants in Subgroup B suggests no particular bias at this time.

Table 4.2. Summary and evaluation of hypotheses related to hydrosystem stress. Definitions for criteria are provided in Section 2.2.

	Evidence			Criteria		
Link	**Literature/ Supplementary**	**Indirect**	**Direct**	**Clarity**	**Mechanism**	**Consistency with Empirical Evidence**
2.3.1 Overall Stress	Mazeaud et al. (1977) National Marine Fisheries Service (2000e)	Levin and Williams (2002)	Schreck et al. (1984) Congleton et al. (2000) Project MPE-96-10 Project JTF-92-XX-3 Project BPS-W-00-10 Schreck et al. (1994a) Project TPE-00-1 Schreck et al. (1994b) Monk et al. (1997)	The hypothesis suggests that passage through the hydrosystem presents a variety of stress inducing events that may individually or cumulatively decrease smolt resistance to various mortality factors. Evidence of increased stress during hydrosystem passage is not sufficient alone to explain delayed mortality, unless some direct link can also be made between increased stress and increased smolt mortality. General evidence of increased stress during passage is, however, required as a necessary precursor before such links would be explored.	Stress induced by a suite of environmental factors smolts may encounter during hydrosystem passage (e.g., elevated water temperatures, pathogens, confinement, physical injury, gas supersaturation, etc.) could make them more susceptible to various mortality factors (e.g., disease, predation, osmoregulatory dysfunction, etc.) in the estuary and/or ocean.	There is strong body of evidence in the literature indicating that various routes of hydro system passage can cause multiple stresses to migrating smolts. Based on the weight of available evidence and the synthesis of workshop discussions the hypothesis that migrating smolts are experiencing various types of stress during hydrosystem passage, which increases vulnerability to mortality factors outside the hydrosystem, is **likely**. It is uncertain, however, whether the sum of hydrosystem stressors would be of sufficient magnitude to cause significant population level effects. It is difficult to make the jump from identification of localized stressor events to a statement that "increased stress due to passage through the hydrosystem increases delayed mortality" (i.e., mortality expressed after the hydrosystem). At this time it is not possible to unambiguously attribute such a possible large-scale effect to any particular stress mechanism(s).
2.3.1.1 Vulnerability to disease	Wedermeyer (1970) Maule et al. (1989) Mazeaud et al. (1977) Schreck et al. (2001c) Mesa et al. (2000)	Raymond (1988)	Congleton et al. (1984)	The hypothesis provides a reasonably clear description of one potential way in which passage experience leads to mortality. Because this hypothesis is related specifically to indirect/delayed mortality, the hypothesis could be more clearly stated as specifying that hydrosystem experience increases vulnerability to disease at a time and place removed from the experience itself. That is, cumulative effects of passage through the series of dam turbines or bypass systems increase vulnerability to disease in the estuary and ocean.	Stress can reduce immunoresponse, making fish more susceptible to pathogens. A fish exposed to continuing stress might ultimately succumb to disease outside the hydrosystem. BKD in particular requires a stressor (trigger) in order to become pathogenic.	There is a strong body of evidence in the literature (from laboratory studies on many animals) showing increased disease susceptibility as a result of stress. However, there has been little clear documentation of migrating smolts succumbing to disease after stress events. Unfortunately fish in laboratory settings do not respond or behave the same as smolting fish in a river. Conceptually and based on supporting literature, Subgroup B considered this to represent a highly ranked stress hypothesis in terms of explaining delayed mortality. Smolts will pick up pathogens as they move through the system, which will only become active if stress increases (e.g., BKD). There is general support for the link based on the literature, but there is no direct support for the explicit hypothesis that hydrosystem passage increases vulnerability to disease. Stress, in some cases, can be positive and even increase immunoresponses. However, there are many cumulative stressors in the hydrosystem that are likely to have an overall negative impact. The body of evidence leads toward support of the hypothesis, but there is a need for properly designed field experiments to resolve this. Based on the weight of evidence and the synthesis of workshop discussions the hypothesis that hydrosystem-induced stress increases vulnerability to disease is **likely but uncertain**.

	Evidence			Criteria		
Link	**Literature/ Supplementary**	**Indirect**	**Direct**	**Clarity**	**Mechanism**	**Consistency with Empirical Evidence**
2.3.1.2 Decreased growth/ condition	Rondorf et al. (1985)		Williams and Mathews (1995) Congleton et al. (2004) – presentation in Appendix G of this report	The hypothesis provides a description of one potential way in which passage experience could lead indirectly to delayed mortality. Decreased growth and condition of smolts due to hydrosystem stress could ultimately decrease resistance to disease, increase susceptibility to predation, or cause reversal of, or incomplete smoltification. Because this hypothesis is related specifically to indirect/delayed mortality, the hypothesis could be more clearly stated as specifying that hydrosystem induced changes in smolt condition and growth results in increased mortality at a time removed from the experience itself.	Smolt energy reserves can be depleted due to passage delays, reduced water velocities, excessive water temperature, etc., with consequent negative effects on smolt condition/growth rates.	Evidence relating to this hypothesis is very weak as only two publications in the literature were uncovered that provided any evidence in this regard (and those only indirectly). Jim Congleton's presentation at the workshop provides much stronger evidence for this hypothesis, but this new work is as yet unpublished. Based on the weight of the evidence and the synthesis of discussions at the workshop the hypothesis that hydrosystem-induced stress reduces growth and condition, although certainly feasible, is currently **impossible to evaluate** (due to the limited body of published literature on this topic presently available for review)
2.3.1.3 Increased susceptibility to predation	Mesa et al. (1994) Kruzynski and Birtwell (1994) Columbia Basin Fish and Wildlife Authority (1991) National Marine Fisheries Service (2000b) National Marine Fisheries Service (2000c) Mesa et al. (1998) Mesa et al. (2002) Olla et al. (1995) Olla et al. (1992) Price and Schreck (2003) Marine and Cech, Jr. (2004) Handeland (1996)		Congleton et al. (1984) Mesa and Warren (1996) Coutant (1973) Mesa (1994) Ward et al. (1995) Solazzi et al. (1991) Petersen et al. (1994) Gadomski et al. (1994) Project No. 82-003 Project MPE-95-3 Project MPE-W-97-4 Stahl et al. (2000)	The hypothesis provides a reasonably clear description of one potential way in which passage experience leads to mortality. Because this hypothesis is related specifically to indirect/delayed mortality, the hypothesis could be made clearer by specifying that hydrosystem experience is hypothesized to increase vulnerability to predation at a time and place removed from the experience itself. That is, the cumulative effects of passage through the entire hydrosystem increases vulnerability to predation in the estuary and ocean.	Disorientation, depletion of energy reserve and incomplete smoltification as a result of hydrosystem passage could reduce smolts ability to evade predators in the estuary and/or ocean.	Conceptually and based on supporting literature, Subgroup B considered this to represent a highly ranked stress hypothesis in terms of explaining delayed mortality. There is a strong body of evidence in the literature showing increased predator susceptibility of fish as a result of stress. However this evidence is derived principally from laboratory studies: field predation studies have not been designed to test the link to stress. There is a body of field studies documenting predation on smolts by fish/birds (with particularly high predation rates at Bonneville tailout). Although predator impact studies undertaken in the laboratory have shown stress-induced increases in predator susceptibility, fieldwork on predation has not clearly shown this connection with stress. The most intriguing field evidence to date is the observation that smolts trapped in the estuarine saltwater/freshwater interface (i.e., as a presumed result of incomplete smoltification) appear to experience differential predation by terns and cormorants. Based on the weight of available evidence and the synthesis of workshop discussions the hypothesis that hydrosystem-induced stress increases vulnerability to predation is **likely but uncertain**.

	Evidence			Criteria		
Link	**Literature/ Supplementary**	**Indirect**	**Direct**	**Clarity**	**Mechanism**	**Consistency with Empirical Evidence**
2.3.1.4 Reversal of, or delayed smoltification	Vanderkooi and Gale (2000) Patino et al. (1986) Mesa et al. (1999)	Project DE-A179-87BP35245	Congleton et al. (2000)	The hypothesis provides a reasonably clear description of one potential way in which passage experience leads to mortality. Because this hypothesis is related specifically to indirect/delayed mortality, the hypothesis could be more clearly stated as specifying that hydrosystem experience causes incomplete or delayed mortality that increases mortality at a time and place removed from the experience itself. That is, cumulative effects of passage through the series of dam turbines or bypass systems interferes with normal smoltification processes required for successful entry into the estuary and ocean.	Early barging or, alternatively, delayed passage of smolts could result in incomplete/delayed smoltification. In such cases smolts may be physiologically/behaviorally unprepared for ocean entry.	There is no evidence from the literature that increased stress affects smoltification. However, the number of studies available for review was limited, and only one represents a field-based assessment of actively migrating smolts. There are other factors (beyond stress) that need to more clearly accounted for in studies of smoltification. Based on the weight of evidence and the synthesis of discussions at the workshop the hypothesis that hydrosystem-induced stress results in reversal of, or delayed smoltification is **unlikely but uncertain**.

4.3 Summary and recommendations

4.3.1 Summary of review of evidence

A qualitative analysis was used to summarize the level of support for each stress hypothesis in terms of the number of papers, how directly related they were to the particular hypothesis and their average "value." This was considered a qualitative analysis because the scores assigned to review criteria were not standardized across reviewers; in most cases there was only one reviewer per paper.

The majority of papers reviewed by Subgroup B appeared to support each of the different hydrosystem-stress related hypotheses (Table 4.1.3), with the exception of the smoltification hypothesis, for which no supporting evidence was uncovered. However, the number of papers available for review, how directly they addressed the hypothesis and their average "value" varied widely across the hypotheses, which modified our conclusions about the strength of the weight of evidence for and against them. We concluded that the weight of evidence evaluated in Table 4.1 provided strong support for the overall stress-survival hypothesis, strong support for the stress-predation hypothesis, medium-strength support for the disease hypothesis, and weak support for the stress-growth/condition hypothesis. The weight of evidence was against the stress-smoltification hypothesis, but only weakly.

A factor acknowledged at the workshop was that the review interpretations could include both reviewer and publication bias. The first source of bias could be addressed by having a randomly selected subset of the papers reviewed by multiple authors that are also selected randomly. The latter source of bias could be addressed by expanding the search for stress-related literature addressing each hypothesis, or through peer review of the reference list by experts not involved in the current process.

4.3.2 Summary of overall review of hypotheses

The qualitative evaluation of the review results presented in Section 4.1 was intended only to supplement and reinforce the expert opinion of workshop participants, who have knowledge of the subject beyond that found in the published literature. Therefore, Table 4.2 presents the overall integration of Table 4.1 evaluations with the expert opinion expressed at the workshop, providing an overall synthesis of the level of support for each stress hypothesis.

During the workshop, Subgroup B participants reviewed each stress-related hypothesis, making changes to ensure hypotheses were clearly stated and included reasonable mechanisms (summarized in Section 2.1.3). Subgroup B reviewed most of the literature summarized in Table 4.1 at the workshop and discussed the results at that time. Based on evaluations of the literature (both during and after the workshop) and discussions at the workshop, Subgroup B made the following overall assessments of the stress hypotheses:

- Hypothesis 2.3.1, stress-increases vulnerability to mortality factors: Likely.
- Hypothesis 2.3.1.1, stress-disease: Likely, but uncertain.
- Hypothesis 2.3.1.2, stress-growth/condition: Impossible to evaluate.
- Hypothesis 2.3.1.3, stress-predation: Likely, but uncertain.
- Hypothesis 2.3.1.4, stress-smoltification: Unlikely, but uncertain.

Subgroup B discussions focused primarily on the hypothesized links between hydrosystem stress and increased risk or susceptibility to possible mortality factors (bottom portion of Figure 2.3), and not on the

higher level links suggested between those mortality factors and patterns in overall survival (top portion of Figure 2.3).

Discussion and review of the papers established that the general link between hydrosystem stress increased vulnerability to mortality factors appears likely, and that there are at least two highly plausible pathways through which this can occur: disease and predation. However, discussions and review did not establish the specific underlying mechanisms by which these effects would occur, or the possible magnitude of such effects.

Similarly, the subgroup discussions did not explore how these pathways could result in differential rates of delayed mortality between smolts with different life history experiences, or the spatial and temporal onset of delayed mortality. The pathway and mechanisms by which delayed mortality occurs may be different for smolts with different passage histories (e.g., transported vs. hydrosystem), different origins (e.g., wild vs. hatchery), or emigrating from different geographic regions (e.g., upriver vs. downriver).

As a specific example, Hypothesis 2.2a suggests that predation-mediated delayed mortality could be a more important factor for smolts that are transported earlier in the season when alternative prey items are in low abundance in the estuary below Bonneville Dam, or for hatchery fish throughout the migration period. Alternatively, stress-growth/condition mediated delayed mortality effects may be more of a factor for wild fish traveling in-river. Additionally, there may be interactions of varying strength between the different factors. Hiram Li and Carl Schreck began development of a preliminary conceptual modeling framework at the workshop (see Section 5) through which these multiple factors could be explored.

4.3.3 Recommendations

Recognizing the limitations of the available evidence for linking stress to delayed mortality, Subgroup B participants made recommendations for additional field/lab research projects to clarify the relationships between the effects of hydrosystem stress and delayed mortality, and the pathways by which this might occur (Table 4.3).

Table 4.3. Subgroup B recommendations for directed field/lab studies to address existing uncertainties and better identify effects of hydrosystem stress on delayed mortality.

Hypothesis	Recommendations
2.3.1 (Overall Stress)	1. There is a need to undertake greater synthesis of current work and design/undertake controlled lab/field experiments to link stress responses in the field to subsequent stress-related mortality outside of the hydrosystem.
2.3.1.1 (Vulnerability to disease)	1. Continue to gather information on other potential disease pathogens in the hydrosystem (i.e., Vibrio and Whirling Disease) 2. Undertake small pairwise comparisons of stress and disease (linked lab and field studies), improving on initial efforts in this regard undertaken by NOAA fisheries scientists (Galbraith). However, past criticisms of this approach described in FPC/CSS memos will have to be accounted for. 3. Use PIT tags to follow cohorts with different passage histories and assess BKD levels as smolts move down the hydrosystem, with additional trawling for tagged fish in the estuary to assess disease progression. To track pathogen levels will require development of new analytical techniques that could allow non-lethal detection of BKD infection levels, and not just BKD incidence.

Hypothesis	Recommendations
2.3.1.2 (Decreased growth/condition)	1. Extend literature review to determine if any additional supporting information currently exists for this hypothesis. 3. Continue and extend current studies (e.g., Jim Congleton's) examining the affect of stressors during hydrosystem passage on smolt condition and growth, and how this could relate to eventual survival beyond the hydrosystem. PIT tagging of fish could allow assessment of smolt condition, growth rate and survival as fish groups with different transport histories move through the hydrosystem and beyond. 3. Design specific field/lab experiments to identify stressor events and their impact on overall condition and subsequent survival.
2.3.1.3 (Increased susceptibility to predation)	1. Use PIT tag data to examine differential predation rates of smolts by avian predators based on transport history. 2. Design field experiments to test the hypothesis of differential stress-mediated predation.
2.3.1.4 (Reversal of, or delayed smoltification)	1. There is a need to better monitor smoltification indices (e.g., ATPase) during hydrosystem passage. Use of PIT tagging should allow sampling of distinct fish groups and allow examination of ATPase activity at different points in the hydrosystem for fish undergoing different passage routes. 2. Design field experiments to better identify if stressor events can affect smoltification with subsequent consequences for survival.

5.0 Towards a Holistic Model of Basin Interactions

Discussions at the CSS workshop lead to exploration of approaches for identifying and understanding the complex web of interacting factors that influence annual variations in smolt condition and survival. A preliminary conceptual model of smolt condition and migration timing variability (incorporating watershed, hydrosystem, and estuarine interactions influencing smolt survival) was developed at the workshop by Hiram Li and Carl Schreck. This conceptual model has not been peer reviewed other than by workshop participants' reviews of the draft report; it is meant to stimulate further thinking on potential causal mechanisms and interactions.

5.1 Sources of variability in patterns associated with smolt survival, SARs and migration *(H. Li and C. Schreck)*

Interpretations of hydrosystem affects on delayed mortality may be confounded by factors influencing mortality that are operating before salmonids enter the hydrosystem. These factors could influence variation in phenotypic frequency, phenotypic expression and physical fitness of salmonids that form the population sampled at collection facilities and barges. As there is no current tracking of these factors, patterns of delayed mortality could exhibit considerable interannual variability and it may be difficult to ascribe observed patterns to management practices in the hydrosystem itself. Figure 5.1 illustrates this hypothesized scenario.

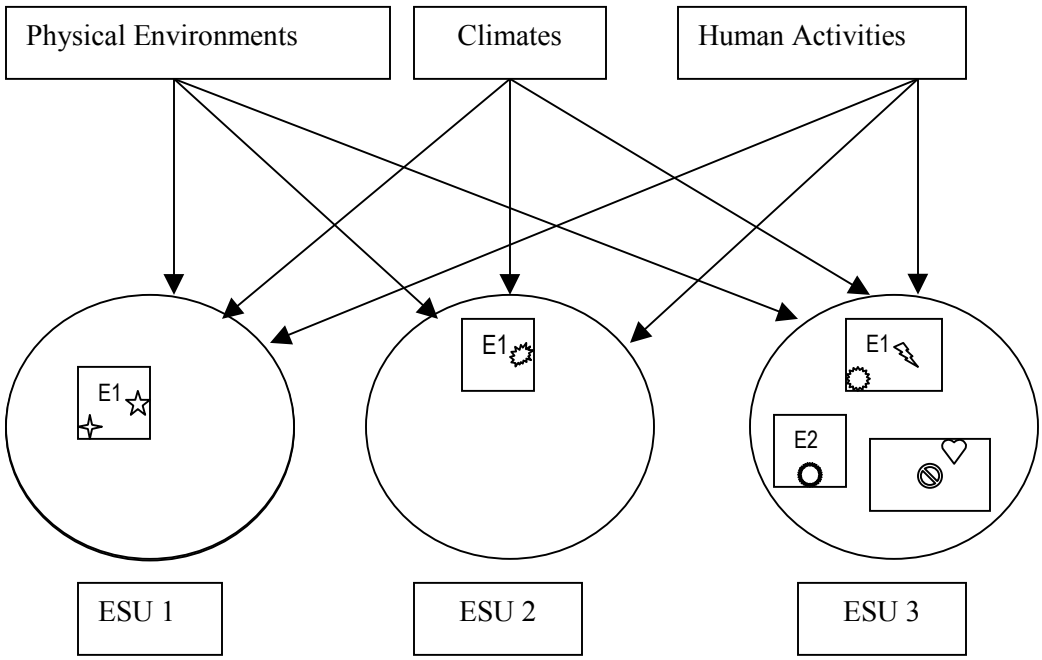

Figure 5.1. Interaction of multiple factors with catchment basin ESUs.

In Figure 5.1 each ESU inhabits a catchment basin with a different set of constraints: physical environment, climate, and anthropogenic impacts. These combinations create patches within the watershed and different phenotypes (as expressed by the different symbols) that are the result of genetic and environmental influences, as well as the interactions between these two influences. The capacity and behavior of each phenotype responds differently to the suite of physical conditions. In addition, perturbations (drought, deluge, fire) and human disturbances (dewatering, channelization, pesticides) and their interactions impose stresses upon and affect energy reserves and therefore the physical fitness of individuals. The survival and physical fitness of the different phenotypes will vary from year to year depending upon the local environmental dynamics of the watershed. The biologist trying to determine causes of delayed mortality is therefore sampling from populations that are vastly different in composition from year to year, and this will confound the outcomes of management plans that view populations as averages rather than as relative compositions of different phenotypes.

Watersheds with different conditions can produce different phenotypes (shaped by different influences i.e., phenotype = genetics + environmental interaction. There is likely sympatry of stocks with different phenotypes. Phenotypes from different watersheds will move into the Columbia at different times; with run timing dependent to varying extents on genetics, stream conditions (e.g., temperature, discharge) and/or estuarine/ocean conditions (e.g., currents). Figure 5.2 represents a tentative model of the system interactions that might effect survival of early run chinook in a low flow year (for example). Table 5.1 shows the definitions of the acronyms used within the models.

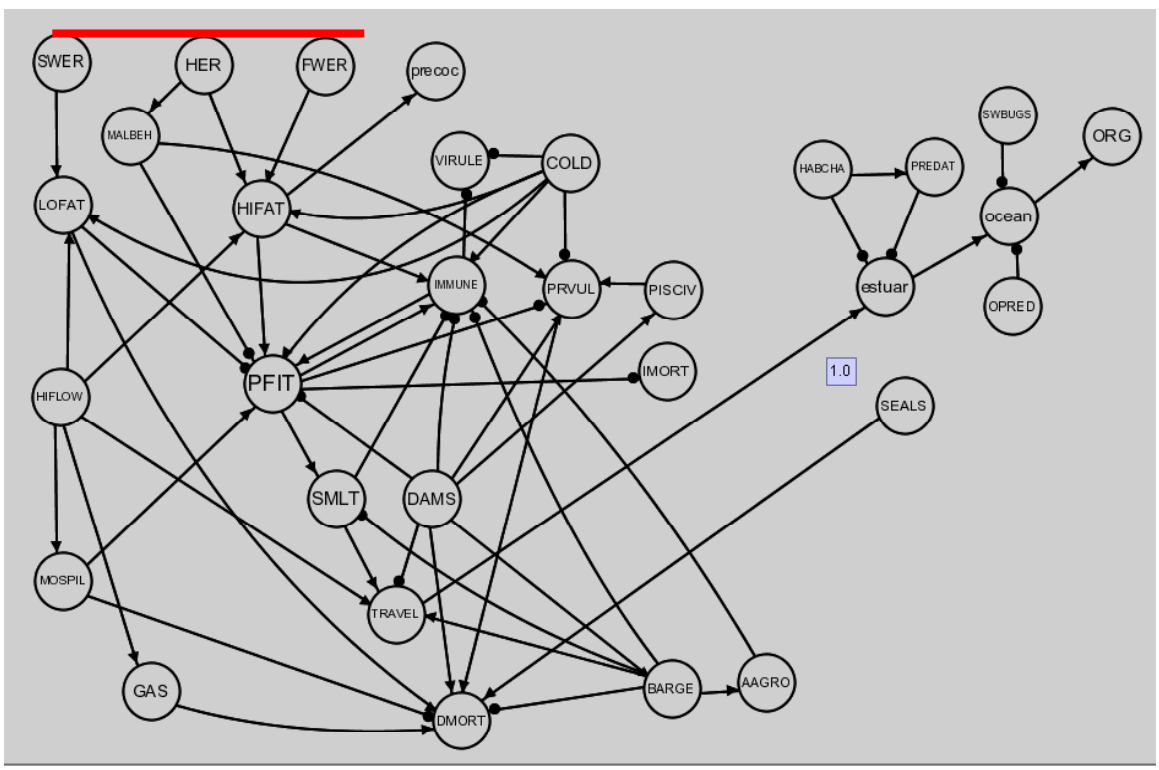

Figure 5.2. Example conceptual model for early run, spring chinook in a high flow year. Note that the sharply pointed arrow (→) denotes a positive influence from the source to its destination, whereas the blunt arrow (—•) denotes a negative influence.

The scenario presented in Figure 5.2 is as follows (commencing from the heavy dark line on the upper left of the figure). Early run stocks migrate to the Columbia River from three different sources: stressed

watersheds (SWER), functioning watersheds (FWER), and hatcheries (HER). Each environment has a different productivity influencing fat content: (LOFAT) and (HIFAT). The amount of fat influences physical fitness (PFIT) as well as the tendency to become precocial and residualize within the system. Physical fitness influences the state of the immune system (IMMUNE). Negative influences on the immune system are stresses, i.e., conditions at the dams (DAM), in the barge (BARGE), and agonistic behavior from steelhead on chinook (AAGRO). Immunosuppression increases virulence of pathogens (VIRULE). Factors that influence physical fitness influence indirect mortality because reductions in efficiency (energetic loads) increase susceptibility to risk, such as predation (PREDAT) or cumulative injuries from negotiating dam passage. Physical fitness has a direct bearing on developmental processes of smolting (SMLT). This process weakens the immune system, but also is necessary for migratory travel (TRAVEL).

In this example model the key physical factors are stream temperatures (COLD), flow (HIFLOW), spill (MOSPIL), nitrogen supersaturation (GAS), and dams (DAMS). As activity levels by predators and pathogens increase with temperature, cold stream temperature is an important mediator for early run stocks. Cold stream temperatures and high discharge (HIFLOW) have a positive energy sparing effect. HIFLOW effects more spill and that increases survival through the hydrosystem. However it also increases problems due to nitrogen supersaturation. The presence of dams favors both native and exotic piscivores (PREDAT), increases vulnerability of chinook salmon to predators by increasing contact time, necessitates transporting downstream migrants (BARGE) and, of course, kills fish directly in turbines, etc. Barging ostensibly reduces risks by decreasing travel time. During the early runs, however, it may contribute to indirect mortality by transporting chinook juveniles that are physically not ready to smolt and will arrive at the estuary prematurely. Other aspects of the model will depict interactions in the estuary. This aspect of the model has not yet been fully developed.

Table 5.1. Definitions for acronyms used in the Li and Schreck conceptual models.

Acronym	Definition
AAGRO	agonistic behavior
BARGE	transportation of smolts by barge
COLD	low water temperatures
DMORT	direct mortality
ESTUAR	estuary
FWER	fish from functioning watershed early run
GAS	nitrogen supersaturation
HABCHA	habitat change
HER	fish from hatchery
HIFAT	high body fat
HIFLOW	high discharge
HOT	high water temperatures
IMORT	indirect mortality
LOFAT	low body fat
LOFLOW	low discharge
MALBEH	maladaptive behavior
MOSPIL	water diverted to spill
OCEAN	ocean environment
OPRED	ocean predators
ORG	ocean rearing ground
PFIT	physical fitness
PRECOC	precocial fish
PREDAT	predator

Acronym	Definition
PRVUL	predator vulnerability
SEALS	marine mammals
SMLT	smolting
SWBUGS	saltwater pathogens
SWER	fish from stressed watershed early run
TRAVEL	passage through the Columbia
VIRULE	pathogen virulence

Figure 5.3 represents another example of these conceptual models; in this case presenting the interacting factors that could most strongly affect survival of late run, fall chinook in the second of two consecutively dry years.

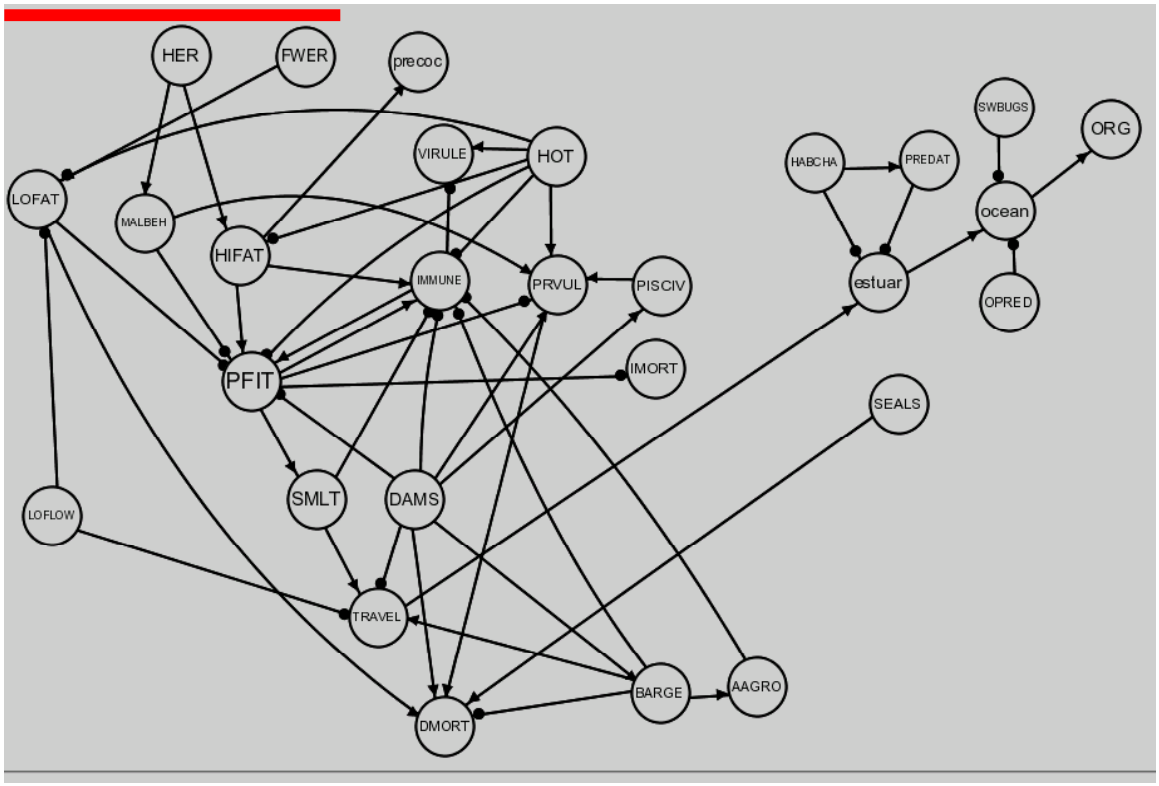

Figure 5.3. Example conceptual model for late run, fall chinook in the second of two low discharge years.

The scenario presented in Figure 5.3 is as follows (commencing from the heavy dark line on the upper left of the figure). Juvenile fall chinook from the stressed watershed (SWER) do not develop enough fat reserves to survive the winter in the watershed (and are excluded from the remainder of the model). Fishes from the functioning (FWER) watershed survive, but arrive at the mainstem with low fat reserves (LOFAT), whereas hatchery fish (HER) will likely have greater fat reserves (HIFAT) and should have better survival through the system. The stream temperatures are warm (HOT) and that increases disease virulence (VIRULE), prey vulnerability (PRVUL) and draws down fat reserves, and physical fitness (PFIT). As a result smolting (SMLT) may be delayed and travel times (TRAVEL) may also be delayed. Barging (BARGE) could increase smolt survival under these conditions.

The above examples are autecological perspectives. Li and Schreck intend to expand their modeling framework to a broader community-based perspective. Eventually the intent is to present the developing models as a series of nested subsystems. The conceptual models proposed by Li and Schreck at the CSS workshop will require continued refinement to make the proposed relationships and mechanisms more explicit. However, the initial models are a promising step towards a whole-system approach for more clearly understanding fish response to a range of naturally occurring and human-mediated impacts with the larger Columbia Basin.

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Appendix A.
Workshop Agenda

Comparative Survival Study Workshop
Bonneville Hot Springs Resort, Columbia River Gorge
Feb. 11–13, 2004

Workshop Objectives

1. synthesize the results of CSS and other research studies;
2. document and assess evidence relating to various factors that can affect survival rates over different life history stages, including hydrosystem passage, delayed mortality, time of ocean entry, and travel time;
3. produce a report synthesizing and assessing the evidence for and against hypothesized mechanisms for differential survival (hatchery-wild; upstream-downstream) and smolt to adult returns; and
4. provide the foundation for a series of publications in peer-reviewed journals.

Workshop Agenda

Wednesday, February 11th

Plenary Session

8:30 a.m. Introductions; Review of Workshop Objectives and Agenda (D. Marmorek)

8:45 a.m. Explanation of Impact Hypothesis and Weight of Evidence Approach, Briefing Document (D. Marmorek)

9:15 a.m. Discuss/Revise Preliminary Impact Hypotheses, Evidence, Criteria

10:15 a.m. BREAK

Brief presentations providing Overview of Problem, Evidence, Recent Analyses[3]

10:30 a.m. What is the Comparative Survival Study? How is it used? (N. Bouwes)

10:50 a.m. Effects of juvenile migration and ocean/climate factors on SARs and recruitment (C. Petrosky)

11:10 a.m. Effects of multiple stress events on physiological indices and fish behavior (C. Schreck)

11:30 a.m. Effects of downstream passage on fish energetics and physiology (J. Congleton)

12:00 noon General Discussion, including strategies for linking mechanistic studies with larger scale survival measurements

[3] 15 minutes for each presentation, followed by 5 minutes of questions

12:30 p.m. LUNCH

1:30 p.m. Review subgroup tasks; Break into subgroups:

Subgroup A will focus on the impact hypotheses in Figures 1 and 2 of the Workshop Briefing Document (pgs. 4 and 6), attempting to link evidence on the mechanisms shown in Figure 2 (i.e., changes in estuary hydrology / timing of entry into estuary) with evidence on overall survival patterns.

Subgroup B will focus on the impact hypotheses in Figures 1 and 3 of the Workshop Briefing Document (pgs. 4 and 7), attempting to link evidence on the mechanisms shown in Figure 3 (i.e., disease, reduced growth, increased vulnerability to predation, delayed smoltification) with evidence on overall survival patterns.

Subgroup Sessions

2 p.m. Review and assess impact hypotheses (See example in Section 3 of Briefing Document):

1. *Clarify impact hypothesis.* Subgroup reaches consensus regarding the structure of the impact hypothesis, and if necessary, restatement of the hypothesis or its associated linkages.
2. *Document / evaluate existing knowledge:*
   - 2a. whole Subgroup Assembles / clusters relevant evidence for or against the overall hypothesis (e.g., CSS studies), or for specific linkages (use Tables 1 and 2 in Briefing Document as a guide to potentially relevant evidence, add / delete material as required);
   - 2b. small groups evaluate most relevant evidence using *evidential* criteria (*applicability, clarity, rigor*; defined in Section 3.1.2 on pg. 30 of Briefing Document). Does each piece of evidence support the hypothesis, negate it, or is neutral / uncertain? **[Homework Wednesday night]**
3. Through an examination of all of the evaluated evidence in step 2, each Subgroup A*ssesses both the major links and the overall hypotheses* for which they're responsible, using overall criteria (clarity, mechanism, consistency with empirical evidence; defined on pg. 29-30 of Briefing Document)
4. Subgroup *develops conclusions about the major links and overall impact hypothesis* (e.g., likely, unlikely, uncertain, impossible to test) and recommendations on research, monitoring and evaluation to reduce remaining uncertainties. *Document differences of interpretation* of existing evidence and ways to resolve technical issues in the future.

3:15 p.m. BREAK

5:30 p.m. DINNER

Evening: Facilitators prepare a draft outline for the report (similar to Section 3 of the Briefing Document, but easily converted into published papers), and synthesize workshop discussions. Participants review literature, write up evaluations of evidence and draft conclusions on component hypotheses for circulation to other subgroup members for comment.

Thursday, February 12th

8 a.m. Subgroup Sessions (continued)

- review written material from yesterday
- continue review and assessment of impact hypotheses
- group's draft conclusions on component hypotheses
- group's draft conclusions on overall hypotheses

10 a.m. BREAK

12:30 p.m. LUNCH

1:30 p.m. Subgroup Sessions (continued)

- Write up, review and revise draft conclusions on hypotheses and evidence
- Outline steps to reduce remaining uncertainties (e.g., lab or field research, monitoring, Adaptive Management experiments)

3:15 p.m. BREAK

5:30 p.m. DINNER

Evening:

- Presenters or facilitators for each subgroup summarize conclusions for presentation on Day 3. Revise outline for workshop report, inserting draft pieces in their current form
- Circulate copy of draft report to all participants
- Participants mingle and exchange insights, becoming increasingly insightful with time, beer.

Friday, February 13th (morning only)

8 a.m. Plenary Session

Subgroup reports / discussion / cross-fertilization

10 a.m. BREAK

10:15 a.m. Subgroup reports / discussion / cross-fertilization, continued

11 a.m. Next steps / Draft Outline for Workshop Report / Writing Assignments / Workplan

12 noon Adjourn

Appendix B.
Participants in CSS Workshop and Subgroup Assignments

Subgroup A focused on Figures 2.1 and 2.2 of the Workshop Briefing Document (pgs. 4 and 6), attempting to link evidence on the mechanisms shown in Figure 2.1 (i.e., changes in estuary hydrology / timing of entry into estuary) with evidence on overall survival patterns.

Subgroup B focused on Figures 2.1 and 2.3 of the Workshop Briefing Document (pgs. 4 and 7), attempting to link evidence on the mechanisms shown in Figure 2.3 (i.e., disease, reduced growth, increased vulnerability to predation, delayed smoltification) with evidence on overall survival patterns.

Name & affiliation (alphabetical order)	Sub-group	Area of research relevant to workshop objectives
Tom Berggren, FPC	A	Understands methodology for juvenile and SAR survival estimates in CSS work
Nick Bouwes, Eco Logic	B	CSS work, review of physiological studies related to delayed mortality, differences in growth among different groups of fish
Phaedra Budy, Utah State	B	Overview of work related to delayed mortality components
Jim Congleton, U. of Idaho	B	Work in mainstem corridor on physiological indicators (lipids, energetics, protein catabolism) vs. juvenile travel time
Margaret Filardo, FPC	B	Environmental correlates of juvenile downstream survival
Steve Haeseker, USFWS	A	CSS work, decision analysis, modeling
Hiram Li, OSU	B	Effects of temperature on fish distribution and density, bioenergetics; inter-basin survival comparisons
Jerry McCann, FPC	A	Survival analysis of downstream juveniles and environmental correlates
Matt Mesa, BRD	B	Predator avoidance after stress, including gas supersaturation; timing of smoltification; effects of multiple stressors
Bill Muir	A	Evaluation of transportation, estuarine conditions, within-season variation in SARs
Charlie Petrosky, IDFG	A	Life cycle survival, SARs, CSS work
Dennis Rondorf, BRD	B	Radiotracking studies of survival through projects, growth & diet
Howard Schaller, USFWS	A	Overall life cycle survival of different stocks
Carl Schreck, OSU	A	Effects of transportation and other events on behavioral and physiological indicators of stress, and implications for fish
Chris Toole, NMFS	A	TRT, life cycle modeling assessments Hydrosystem operations and survival rates, SARs
Earl Weber, CRITFC	B	Mainstem passage, SARs, Weight of Evidence analyses
Paul Wilson, USFWS	A	Analyses of CSS, delayed mortality, survival rates, D
Workshop Facilitation and Reporting		
David Marmorek, ESSA	A	Lead Workshop Facilitator; Workshop Report; PATH facilitator
Ian Parnell, ESSA	B	Facilitator; Workshop Report; PATH analyst
Marc Porter, ESSA	B	Literature Review; Workshop Report

Appendix C.
Within-year changes in SARs and D for cohorts of in-river and transported chinook and steelhead that were tagged or marked during specific weeks at Lower Granite Dam
(from Williams et al. 2003)

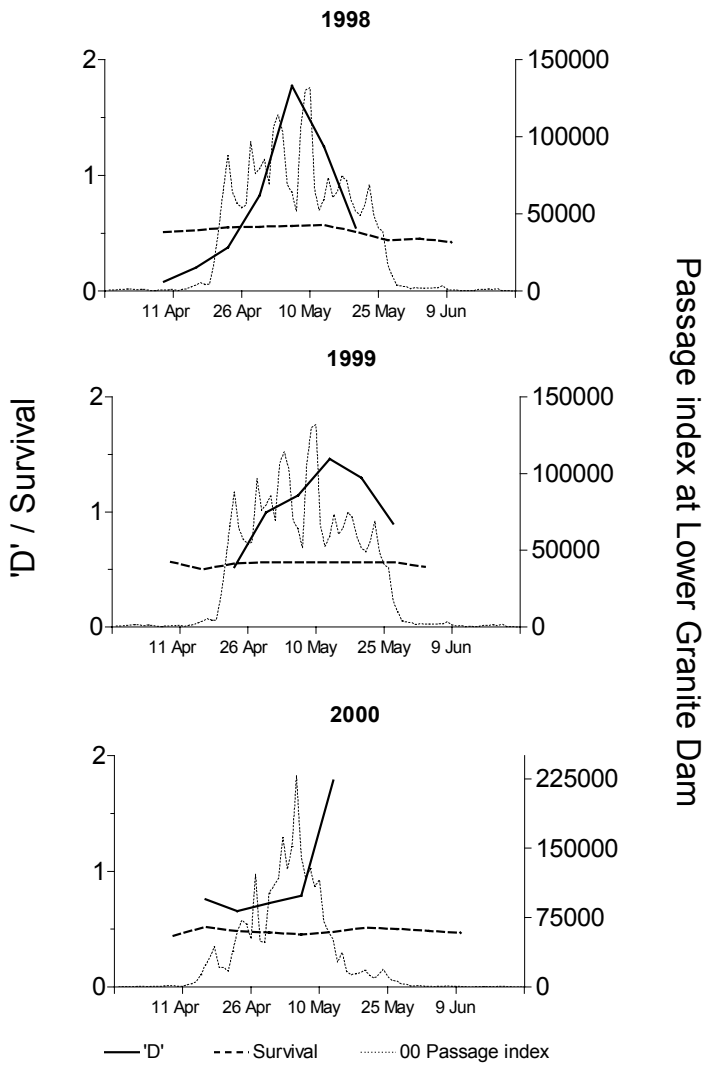
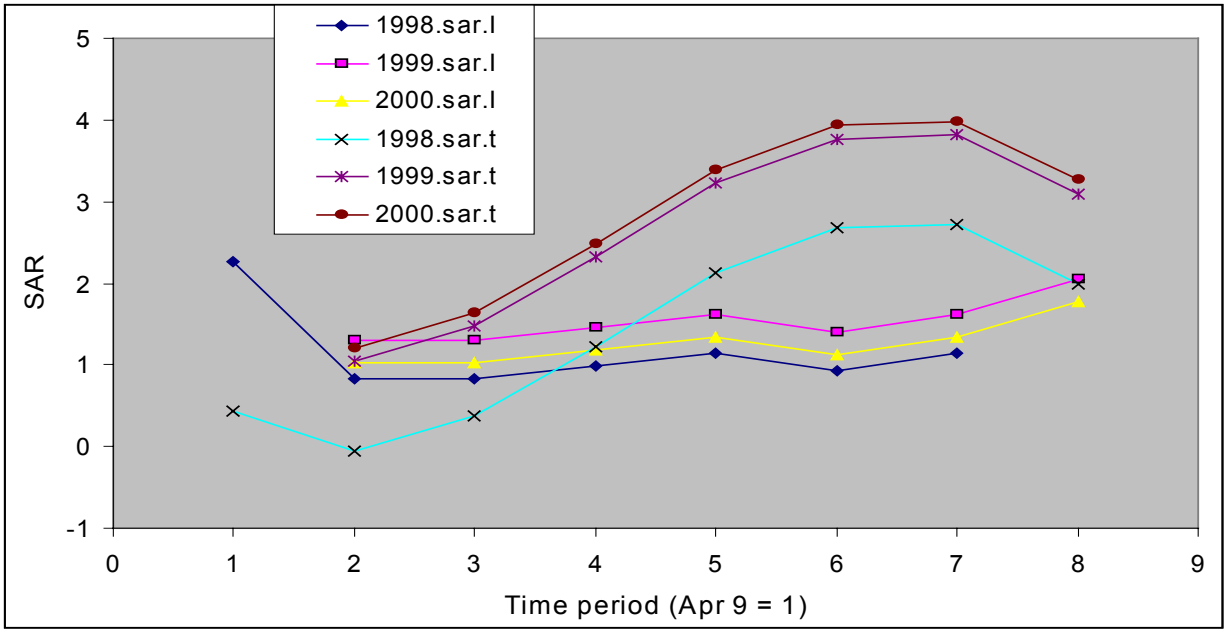


Figure C.1. Hatchery yearling chinook (YCS) tagged above Lower Granite (LGR) dam (Williams et al. 2003). Values are for 5-day running averages of SARs and D for daily cohorts of fish passing LGR dam on the dates indicated on the x-axis. An index of the number of smolts passing Bonneville Dam each day was obtained from the DART database (http://www.cqs.washington.edu/dart/). Smolt numbers included steelhead, yearling chinook salmon, coho salmon, and sockeye salmon (subyearling chinook salmon were excluded because of differences in size, timing, and behavior). Data are from Table 3.3 in this report.

a) General Pattern in SARs for Yearling Chinook.



b) General Pattern in D for Yearling Chinook.

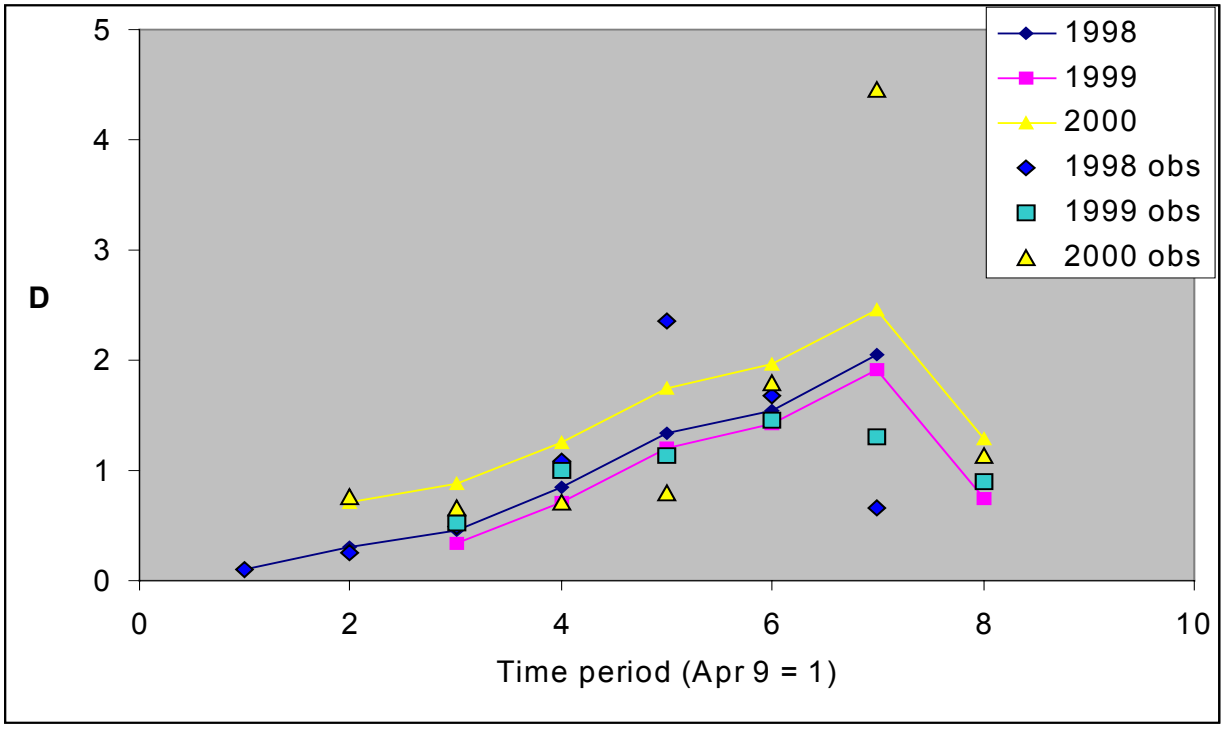


Figure C.2. Regression analysis of the data in Table 3.3 (graphed in Figure C.1), completed by (Steve Haeseker at the Feb./04 CSS workshop. General model used was $Y_i = \mu$ + passage year effect + period effect.

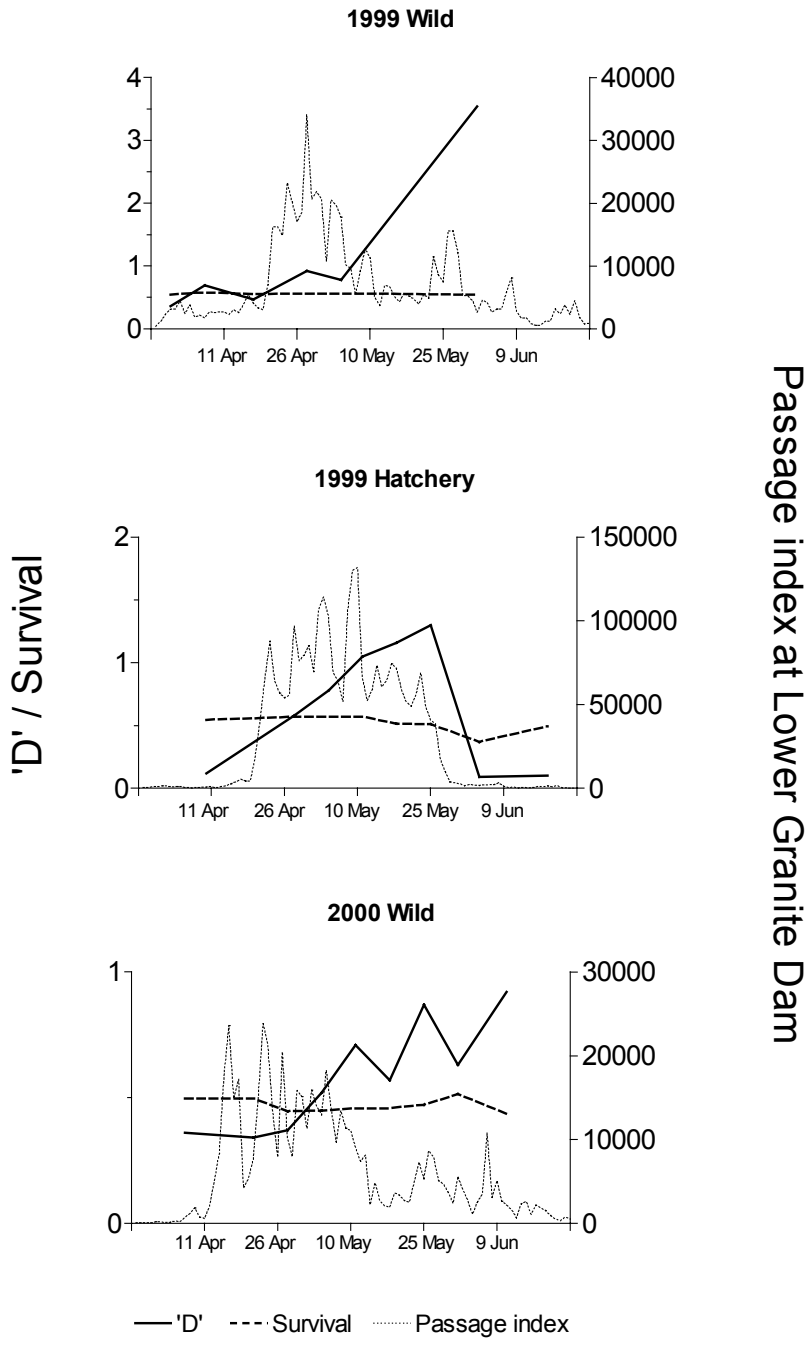


Figure C.3. Hatchery and wild yearling chinook marked at Lower Granite (LGR) dam.

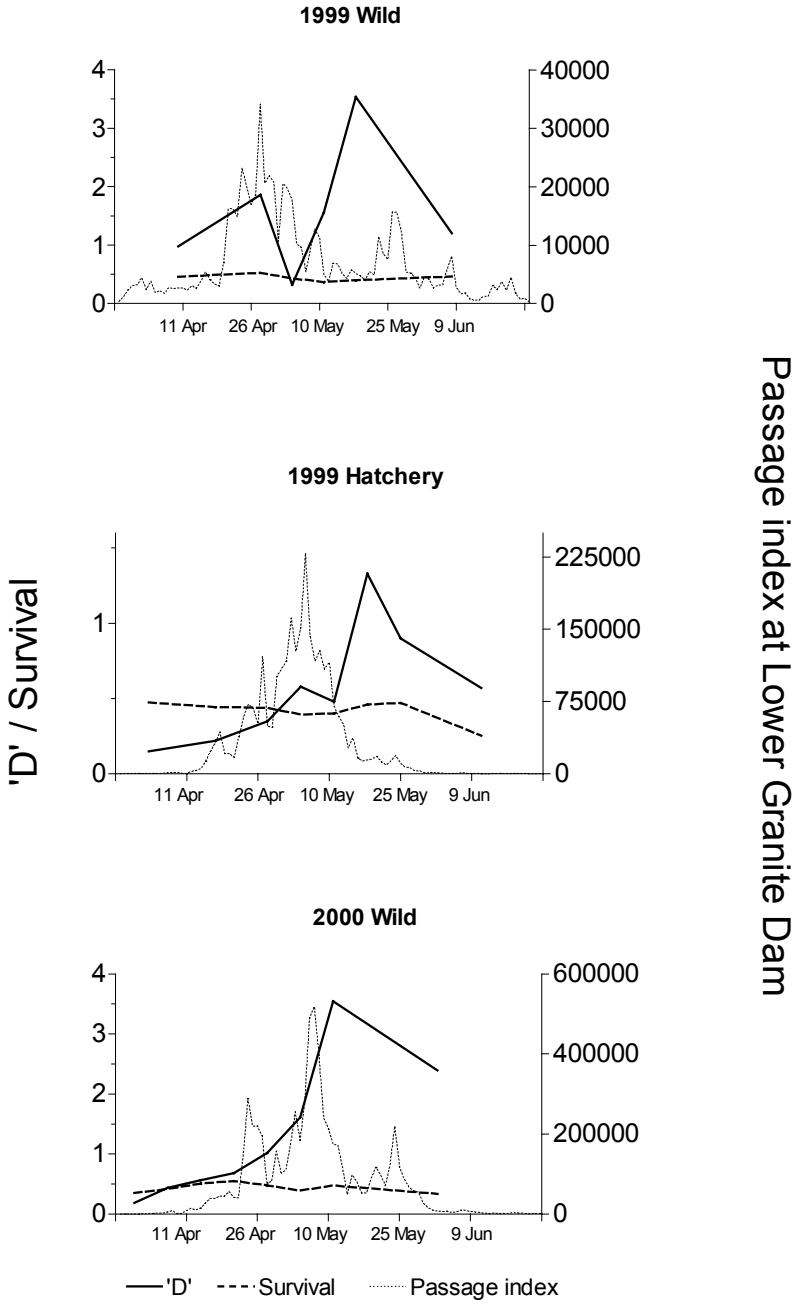


Figure C.4. Hatchery and wild steelhead tagged at Lower Granite (LGR) dam.

Appendix D.
Glossary of Terms Used in the Delta Model Analysis
(H. Schaller and C. Petrosky)

R/S (recruits/spawner): The number of mature fish returning to the point of recruitment (R) divided by the number of spawners in the parent generation (S). R is estimated indirectly from catch, upstream mortality estimates, % hatchery adults on spawning ground and escapement information (see Beamesderder *et al.* 1997). S is estimated from weir counts, or redd counts (sp/sum) or dam counts (fall chinook).

Residuals from graphs of ln(R/S) vs. S (RES): A residual is the difference between the observed and expected R/S at a given spawning density when the data are fit to a model of the form: ln(R/S) vs. S. Variation in residuals will influence the ability of a monitoring design to detect changes in R/S. Time-series patterns in residuals can also provide information about influences on a stock over time.

SAR: Smolt to adult survival rates (SARs) estimate survival rates of fish from the time they pass the upper-most dam as smolts to the time they return as adults. SARs and passage survival estimates (V_t , V_n) allow inferences on ocean survival. There is value in measuring SARs as well as R/S since R/S alone cannot differentiate between different life history stages.

T:C : The Transport: Control ratio is the ratio of transported fish survival to in-river fish survival from juveniles at the collection point to adults at the same point. T:C is estimated through tagging experiments.

$\mathbf{V_n}$: the direct passage survival of in-river juvenile fish, measured from the head of Lower Granite pool to the tailrace of Bonneville dam, including reservoir and dam survival at each project.

$\boldsymbol{\lambda_n}$ post-Bonneville survival factor for non-transported smolts. This factor will be very strongly affected by assumed D values as long as transportation is there. For spring-summer chinook, this variable is estimated indirectly, and depends on many other variables: the total mortality (*m)* including both passage and extra mortality; the direct mortality estimated from passage models (*M*); the fraction of fish below Bonneville which were transported (*P*); and *D*. For details see the PATH Preliminary Decision Analysis report (pg. A-92), or the Delta model description attached to the AFISH Appendix.

μ : the incremental total mortality between Snake River Basin and the John Day project in a specific year. This variable is estimated indirectly – see Deriso *et al.* 1996.

$\Delta\, \boldsymbol{\lambda_n}$: the change in the post-Bonneville survival factor for non-transported smolts after an action (i.e., $\lambda_{n,\ \text{after action}}$ / $\lambda_{n,\ \text{before action}}$). This variable is potentially useful for differentiating among extra mortality hypotheses

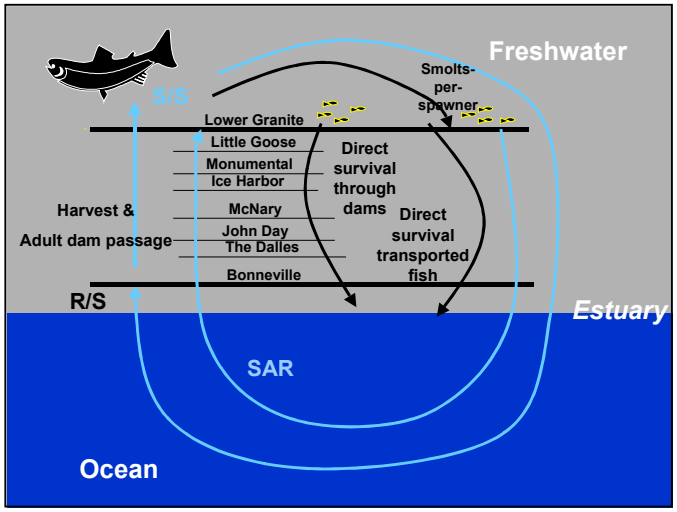
Table A-1. Key PATH uncertainties for spring/summer and fall chinook. Extra mortality hypotheses are more important at higher values of D.

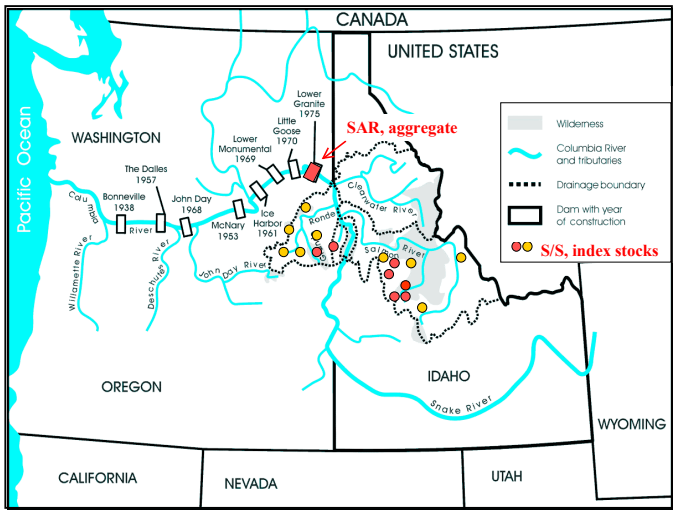
Spring Summer Chinook (from Table 2.2.4-1 in Marmorek et al. 1998.)	
Uncertainty	Alternative hypotheses
Relative post-Bonneville survival of transported and non-transported fish (D)	~0.3: FLUSH transportation model ~0.6: CRiSP transportation model ~0.8: NMFS AFISH Appendix (not yet run in models)
Extra Mortality	1 – Hydro (here to stay unless dams go) 2 – BKD (here to stay) 3 – Regime Shift 4 – Hatcheries 5 – Birds
Life-cycle models (existence of common year effects, and ability of downstream stocks to act as controls for upstream stocks)	Alpha (no common year effects) Delta (common year effects)
Length of Transition Period following drawdown	2 years 10 years
Equilibrated Juvenile Survival Rate through free-flowing reach following drawdown	0.85 (spring/summer chinook) 0.96 (spring/summer chinook)

Fall Chinook (Preliminary) [4]	
Relative post-Bonneville survival of transported and non-transported fish (D)	~0.1: life cycle model and (R/S) data ~0.2: 1995 PIT-tag data for Snake River fish and passage model estimates of in-river survival ~1.6: 1978-83 T:C studies for Hanford Reach fish and various in-river survival estimates
In-river Harvest	Base -50%
Ocean Harvest	-15%, 0%, +15% -50%, -75%
Extra Mortality	1 – Hydro (here to stay unless dams go) 2 – BKD (here to stay) 3 – Regime Shift 4 – Hatcheries 5 – Birds

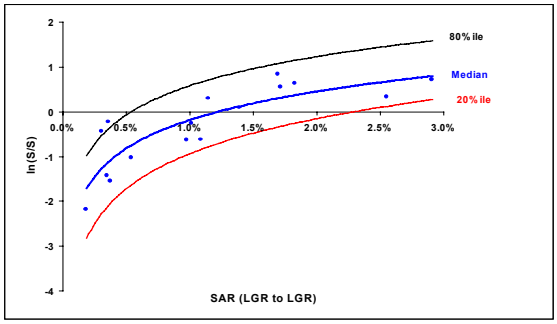
Appendix E.
Effects of juvenile migration and ocean/climate conditions on smolt-to-adult return rates and recruitment

(N. Bouwes, C. Petrosky, and H. Schaller - Presentation at CSS Workshop)



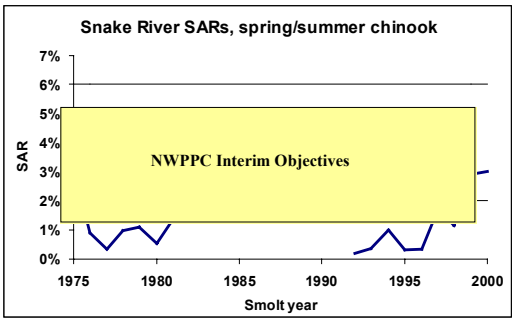


SARs vs. S/S needed for population persistence and recovery?



Snake River spring/summer chinook (16 index stocks), BY 1975-1997

Smolt to Adult Survival Rate (SAR) NWPCC Interim objective = 2-6%



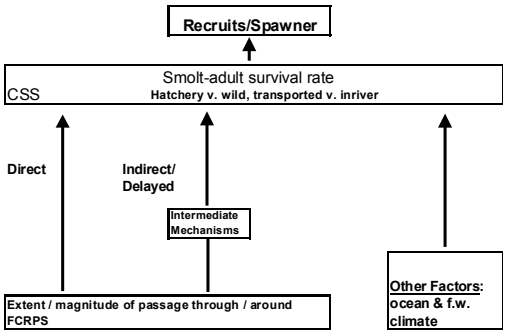


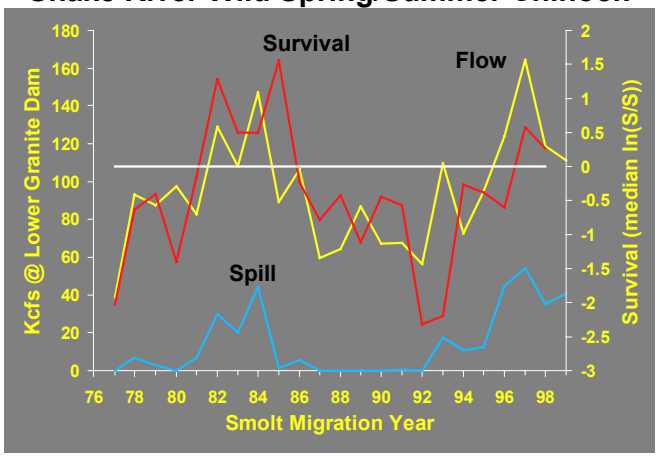
Figure 1. General Ha about hydrosystem effects on SARs

Why focus on flow or water travel time?

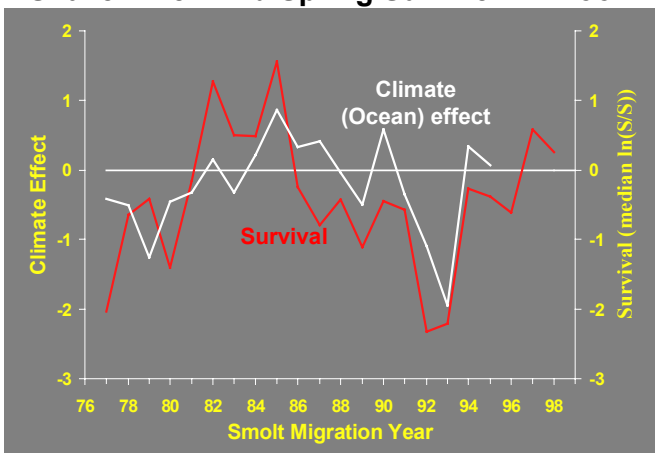
- **Management issues: BiOp flow targets, NWPCC amendments**
- **Mechanisms (see Workshop figs. 2 & 3):**
  Flow or WTT affects:
  - **Migration time to estuary;**
  - **Temperature exposure;**
  - **Energy reserves and stress;**
  - **Timing of salt-water entry;**
  - **Estuary plume.**

  Hypothesized direct and indirect mortality (fish condition)
- **Measurements:**
  - **Direct mortality (estimated by inriver or reach survival)**
  - **Delayed mortality (estimated from overall life cycle survival after accounting for sources of direct mortality and climate effects)**

Snake River Wild Spring/Summer Chinook



Snake River Wild Spring/Summer Chinook



Explanatory models for SAR & recruitment, Snake River salmon and steelhead

- Wild sp/su chinook SARs
- Wild steelhead SARs
- Wild sp/su chinook S/S

- Water travel time
- Spill proportion (2)
- Proportion transported
- Climate effect (Deriso et al. 2001; common year effect)

Multiple regression for all variables, best models from BIC; Supported by stepwise regression

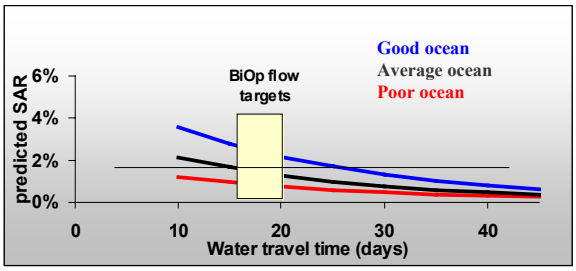
Juvenile migration & climate (ocean) conditions were both influential in explaining patterns:

- SAR spring/ summer chinook
- SAR steelhead
- S/S spring/ summer chinook

- Negative correlation with proportion transported;
- (excluding transport) WTT, climate
- WTT, WTT*spill, climate
- WTT, climate

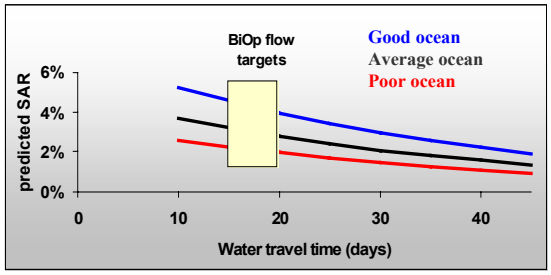
State, Federal & Tribal Anadromous Fish Managers. 2003. Comments on NWPPC draft mainstem amendments as they relate to flow/survival relationships for salmon and steelhead. http://www.fpc.org

Influence of Water Travel Time and Climate Effect on Spring/Summer Chinook SAR (predicted)



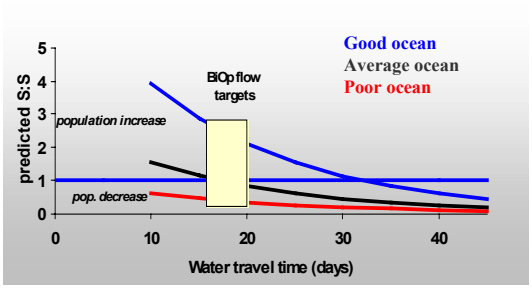
Snake R. spring/summer chinook

Influence of Water Travel Time and Climate Effect on Steelhead SAR (predicted)



Snake R. steelhead

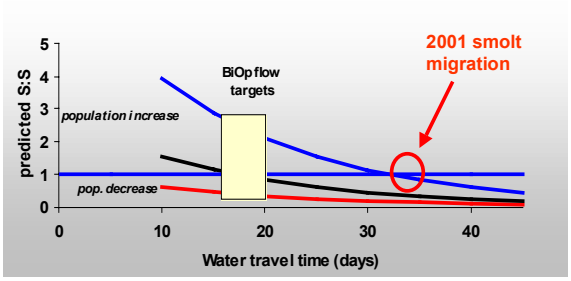
Influence of Water Travel Time and Climate Effect on Spring/Summer Chinook S/S (predicted)



Snake R. spring/summer chinook (7 PATH index stocks)

Retrospective to Prospective:

2001 smolt migration, poor flows but "good" ocean
Models predicted poor to mediocre returns from 2001, appear consistent with recent observations
Need for updating R/S analyses, climate effect, and Ha



Conclusions

- **Believe multiple lines of evidence show flow / survival relationship.**
  - **Juvenile survival evidence**
  - **Adult recruitment patterns**
  - **Theoretical / mechanistic information**
- **Need to consider large scale climate/ocean conditions.**
- **Given BIOP flow targets stocks are still at risk (average-poor climate/ocean conditions).**
- **Any degradation in flows will place stocks at higher risk.**
- **A need exists to assess hypotheses about the effect of Columbia River hydrosystem on salmon and steelhead survival, growth, behavior and physiology.**

Appendix F.
Application of Criteria for Evaluating Hypotheses and Evidence

Hypothesis 2.3.1

"Passage through or around the hydrosystem causes various types of stress on smolts which increases vulnerability to mortality factors"

1) Clarity

The hypothesis suggests that passage through the hydrosystem presents a variety of stress inducing events that may individually or cumulatively decrease smolt resistance to various mortality factors. Evidence of increased stress during hydrosystem passage is not sufficient alone to explain delayed mortality, unless some direct link can also be made between increased stress and increased smolt mortality. General evidence of increased stress during passage is, however, required as a necessary precursor before such links would be explored.

2) Mechanism

There are several potential mechanisms by which increased stress as a result of passage through or around the hydrosystem might increase vulnerability to mortality factors. Examples include:

- Increased stress increases vulnerability to and proliferation of pathogens
- Increased stress reduces growth rates or condition of smolts
- Increased stress increases vulnerability to predation
- Increased stress results in reversed or incomplete smoltification.

Evidence for increased stress during hydrosystem passage is summarized below.

3) Consistency with Empirical Evidence

<u>Evidence for the hypothesis:</u>

a) S/S chinook smolts exposed to multiple events designed to simulate stressors occurring during passage or barging past multiple dams (e.g., handling, high fish densities) showed elevated stress responses. Stress response of steelhead, however, was not correlated with increased steelhead densities (Congleton et al. 1995; Schreck et al. 1996; Congleton et al. 1996: Project MPE-96-10). – *Reviewer: Nick Bouwes*

Applicability (Score = 2)

This study is applicable in that it is conducted on Snake River hatchery and wild s/s chinook and steelhead and evaluates the impacts of downstream passage on stress. The paper provides evidence that stress increases through multiple stressors (e.g., migration past several dams) for s/s chinook, which is consistent with the hydrosystem causing chronic stress that has indirect impacts that may

manifest in mortality after migration (but did not measure mortality after release). However, stress was simulated by holding fish in a dipnet for 30 sec. rather than actual passage through a dam. This pattern did not hold up in 1995.

The paper also evaluates the effects of steelhead density on chinook and steelhead stress levels during barging, which is applicable to standard transportation procedures. Chinook stress was and steelhead stress was not correlated steelhead density. The paper does not actually measure the relationship between stress and subsequent mortality but that is the implication of the results.

This study also evaluated migration rates of barged and run-of-the-river smolts below BON dam. ROR always migrated faster than barged smolts. Because predation will be higher the longer smolts are in the hydrosystem, this may provide a mechanism by which transported fish suffer higher delayed mortality than ROR (i.e., D<1.0). However, no significant difference could be detected in mortality rates of both groups.

Clarity (Score = 2.5)

The intentions of the study were to evaluate stress during the downstream outmigration in-river and on barges. The study addressed multiple stress events on low-level chronic stress and evaluated the impacts of steelhead density on stress of chinook and steelhead. Differences between hatchery and wild were also evaluated. Several covariates that may also explain patterns were not measured. Results of multiple year studies in some cases did not corroborated each other, with little or no explanation for the conflicting results. It is uncertain whether changes in stress recorded result in mortality below the hydrosystem. This study supports the mechanism of how transportation and dam passage leads to stress that could lead to mortality, but mortality is not measured

Rigor (Score = 2)

Used comparative approach to evaluate relative differences in responses. Approach provides convincing evidence for differences in stress depending on the number of stressful event encountered. However, true controls cannot be used since even that treatment requires handling. Stress was also shown to be higher in smolts that were loaded with higher densities of steelhead. Several other variables that were not evaluated may also explain these patterns were not use as potential covariates. Not peer reviewed.

b) Stress response of Snake River s/s chinook and steelhead increased during collection and loading onto barges for transport. However, stress levels decreased during barging (Schreck et al. 1992; Schreck et al. 1993; Schreck et al. 1994a; Schreck et al. 1995: Project JTF-92-XX-3). – *Reviewer: Nick Bouwes*

Applicability (Score = 2)

This study is applicable in that it is conducted on Snake River s/s chinook and steelhead and evaluates the impacts of barging and collection on stress. The paper provides evidence that stress increases during collection and loading into barges for s/s chinook, which is consistent that barging has indirect impacts that may manifest in mortality after release (but did not measure mortality after release). However, stress levels decreased during barging. The affects of release from barges on stress were not observed. Migration behavior was observed using radio telemetry. The paper does not actually measure the relationship between stress and subsequent mortality but that is the implication of the results.

Clarity (Score = 2)

The intentions of the study were to evaluate stress and smoltification during the collection process, evaluate the impacts of steelhead density on stress of chinook, evaluate raceway procedures on stress, evaluate the level of BKD in collected smolts, and smolt behavior upon release. These goals were evaluated. Several covariates that may also explain patterns were not measured. Uncertain that changes in stress recorded results in mortality below the hydrosystem. This study supports the mechanism of how transportation leads to stress that could lead to mortality, but mortality is not measured.

Rigor (Score = 2)

Used comparative approach to evaluate relative differences in responses. Approach provides convincing evidence for differences in stress. However, true controls cannot be used since even that treatment requires handling. Understandably, several other variables that were not evaluated may also explain these patterns were not use as potential covariates. Not peer reviewed.

c) Run of the river Snake River hatchery steelhead smolts showed higher survival below Bonneville Dam than steelhead that were barged (in 2001 only, there were no differences in survival between ROR and barged fish in 2002) (Schreck and Stahl. 2000a; Schreck et al. 2001a; Schreck et al. 2002a: Project BPS-W-00-10) – *Reviewer: Nick Bouwes*

Applicability (Score = 2)

This study is applicable in that it is conducted on Snake River hatchery steelhead and evaluates the impacts of downstream passage on migration behavior and survival below BON dam. This study evaluated migration rates of barged and run-of-the-river smolts below BON dam. The study does not evaluate how delay mortality is related to the hydrosystem despite the implication from the title.

Clarity (Score = 2.5)

The intentions of the study were to evaluate behavior and survival during the downstream outmigration in-river and on barges. These goals were evaluated. However, the more general goal to evaluate delayed mortality (i.e., how stress from the hydrosystem results in mortality below the hydrosystem) between different groups was not directly evaluated. There were conflicting results between 2001 and 2002 where in 2001 survival was higher for run-of river (ROR) smolts than for barged fish but there were no differences in 2002. These contradictions were also observed from other studies. A discussion of these differences is warranted but little or no explanation for the conflicting results was provided. Several covariates that may also explain these patterns were not measured. Provides weak support that barging fish have higher mortality in estuary than ROR fish (this occurred in 1 of the 2 years of the study) which is consistent with D<1.0. Did not directly evaluate how delayed mortality is caused by the hydrosystem.

Rigor (Score = 2)

Used comparative approach to evaluate relative differences in responses. Acoustic tag detectors were placed in an array that had a high probability of detecting smolts with acoustic tags. Several other variables that were not evaluated may also explain these patterns were not use as potential covariates. Not peer reviewed.

Stress levels of Snake River s/s chinook and steelhead increased during collection and loading onto barges. Loading onto barges was the most stressful event in the process. Stress levels decreased somewhat during actual barge transport (Schreck et al. 1984: BPA project DE-A179-82BP34797). – ***Reviewer: Nick Bouwes***

Applicability (Score = 2)

This study is applicable in that it is conducted on Snake River s/s chinook and evaluates the impacts of barging and collection on stress at McNary Dam. The paper provides evidence that stress increases during collection and loading into barges for s/s chinook and that stress is cumulative, which is consistent that barging has indirect impacts that may manifest in mortality after release (but did not measure mortality after release). Loading into barges was the most stressful event in the process. Stress levels decreased somewhat during barging. The paper does not actually measure the relationship between stress and subsequent mortality but that is the implication of the results.

Clarity (Score = 2)

The intentions of the study were to evaluate stress during the collection process and barging process. These goals were evaluated. The ultimate goal to increase adult production was not evaluated. Does not evaluate whether stress leads to increase mortality. Uncertain that changes in stress result in mortality below the hydrosystem. This study supports the mechanism of how transportation leads to stress that could lead to mortality, but mortality is not measured.

Rigor (Score = 2)

Used comparative approaches to evaluate relative differences in response. Approach provides convincing evidence for differences in stress. However, true controls cannot be used since even that treatment requires handling. Understandably, several other variables that were not evaluated may also explain these patterns were not use as potential covariates. Not peer reviewed.

d) **Run of the river Snake River fall chinook smolts showed higher survival rates below Bonneville Dam than barged chinook smolts in all 3 years assessed. This was not the case for Snake River steelhead, in that barged steelhead survived better than ROR in 2001 and 2003 (the reverse was true in 2002) (Schreck et al 2000a; Schreck et al. 2000b; Schreck et al. 2001b; Schreck et al. 2002b; Schreck et al. 2003a; Schreck et al. 2003b: Project TPE-00-1). –** ***Reviewer: Nick Bouwes***

Applicability (Score = 2)

This study is applicable in that it was conducted on Snake River hatchery and wild fall chinook and steelhead and evaluates the impacts of downstream passage on migration behavior, survival from BON to the ocean, feeding ability, and saltwater preference. Did not measure other indices of stress and how this might explain differences in release groups.

This study also evaluated migration rates of barged and run-of-the-river smolts below BON dam. No differences in migration rates between ROR and barged fish or between hatchery and wild, for fall chinook and steelhead. Barged fall chinook had lower survival below BON than did ROR fish, which is consistent with the low D-values observed for fall chinook. Barged steelhead survived at higher rates below BON than did ROR in 2001 and 2003 but the reverse was observed in 2002. No differences observed between barged and ROR for feeding ability and saltwater preference for both species.

Clarity (Score = 2.5)

The intentions of the study were to study the downstream outmigration patterns of fall chinook and steelhead that previously migrated in-river or were transported on barges. Differences between hatchery and wild were also to be evaluated. These goals were evaluated. Several covariates that may also explain patterns were not measured. Results of multiple year studies and other studies conducted by the researchers in some cases did not corroborate each other, with little or no explanation for the conflicting results. Only measured survival and migration behavior and few indices that could be related to stress such as feeding ability and saltwater challenge tests. However, did not measure stress indices and resulting impact on survival and behavior. Survival results were different between the years and studies for steelhead but hypotheses for differences were not discussed or explored.

Rigor (Score = 2)

Used comparative approach to evaluate relative differences in migration behavior and survival between barged and ROR smolts. Acoustic tags were used which allow a much larger sample size than radio tags. Several other variables that were not evaluated may also explain these patterns and could be used as potential covariates. Not peer reviewed.

e) Hatchery spring chinook trucked downstream in the Willamette River showed elevated stress indicators after transport (Schreck et al. 1994a). – *Reviewer: Nick Bouwes*

Applicability (Score = 2.5)

This study is applicable in that it is conducted on spring chinook (however they used hatchery fish and was conducted in the Willamette) and evaluates the impacts of migration behavior and the impacts of transportation from hatchery on stress. The paper provides evidence that transportation in a truck is very stressful for s/s chinook, which is consistent that stress may indirectly be manifested in mortality after release for transportation trucks in the Columbia. The paper does not actually measure the relationship between stress and subsequent mortality.

Clarity (Score = 2)

This study is applicable in that it is conducted on spring chinook (however they used hatchery fish in the Willamette) and evaluates the impacts of migration behavior and the impacts of transportation from hatchery on stress. The paper provides evidence that transportation in a truck is very stressful for s/s chinook, which is consistent with the hypothesis that stress may indirectly be manifested in mortality after release for smolts transported in trucks in the Columbia. The paper does not actually measure the relationship between stress and subsequent mortality.

Rigor (Score = 2)

The effects of transportation on hatchery smolts were measured before and after. Conducted this study for 3 years and measured several other condition factors prior to transportation. Not peer reviewed.

f) Stress levels increased in Snake River s/s chinook and steelhead during barging. Stress levels were found to be higher in wild than in hatchery fish (Congleton et al. 2000) – *Reviewer: Paul Wilson*

Applicability (Score = 1)

This study is applicable in that it is conducted on Snake River s/s chinook and steelhead and evaluation of the impacts of barging on stress. The paper provides evidence that stress increases during barging for s/s chinook, which is consistent with the hypothesis that barging has indirect impacts that may manifest in mortality after release (but they did not measure mortality after release). They demonstrated that stress was higher for wild than hatchery chinook, which is consistent with empirical information that transportation SARs are higher for hatchery chinook than wild chinook, relative to their in-river counterparts. However, the study does not actually measure the relationship between stress and subsequent mortality, although that is the implication of the results.

Clarity (Score = 2)

The intentions of the study were to evaluate stress during the barging process and compare this between H and W, and to evaluate the impacts of steelhead density on stress of chinook and steelhead. These goals were evaluated. Several covariates that may also explain patterns were not measured. Also, the intent is to relate results to the observation that transportation not as beneficial as believed. Uncertain that changes in stress result in mortality below the hydrosystem. This study supports the mechanism of how transportation leads to stress that could lead to mortality, but mortality is not measured.

Rigor (Score = 2)

Used several response variables to corroborate each other. Approach provides convincing evidence for differences in stress. Understandably, several other variables that were not evaluated may also explain these patterns, but were not used as potential covariates.

h) Survival of wild salmonids may be influenced by the interaction between two potential risk factors: the number of hatchery fish and climatic conditions. Stress is proposed as an explanatory factor for negative relationship observed between steelhead hatchery releases and chinook SAR (Levin and Williams. 2002) – *Reviewer: Paul Wilson*

Applicability (Score = 2)

This is a correlative study of relationships between releases of hatchery steelhead and the smolt-to-adult return rates of naturally spawning steelhead and chinook in the Snake River. The authors tested the hypothesis that the survival of wild salmonids is a function of the interaction between two potential risk factors: the number of hatchery fish and climatic conditions. They include in the analysis a metric intended to serve as an indicator of climatic conditions. The juvenile hydrosystem migration is a plausible locus of posited effects of hatchery steelhead releases, and the study does investigate effects on two relevant species from the system of interest. However, applicability is limited because the analysis does not attempt to allocate any effect of hatchery releases on survival of wild fish between various mechanisms. Because of this, it does not provide evidence about effects on species not investigated (e.g., Snake River fall chinook). Stress is proposed as an explanatory factor for negative relationship observed between steelhead hatchery releases and chinook SARs.

Clarity (Score = 3.5)

The relevance of the study to management is not entirely clear. The authors suggest that an effect may be primarily the result of stress before or during bypass capture and barging. If so, the effect could be alleviated by eliminating smolt transportation. If, on the other hand, the effect of stress is primarily the result of interactions during the in-river migration, maximizing transportation may alleviate any effect. If stresses imposed by hatchery fish on transported wild fish were the primary mechanism of effect, then the correlation between SARs of transported fish and hatchery releases should be stronger than the correlation between extra mortality of in-river fish and releases. Although data on SARs can be estimated separately for transported and non-transported fish, the authors don't use these measures in their analysis.

If the effect were due to interactions on entry to the estuary or ocean, then the effect would not be due to experience in the hydrosystem, but would be exacerbated by hatchery steelhead releases in the Columbia basin outside the Snake River basin. Also, it's not clear how abundant, naturally produced steelhead would affect chinook survival rates in a recovered system absent large releases of hatchery steelhead.

Rigor (Score = 2)

The paper is an empirical investigation published in a peer-reviewed journal. However, the evidence presented is correlative and there are many potentially confounding factors not examined. Any effect of hatchery releases could occur either within the hydrosystem or below it.

i) Comparison of D and T/I ratios from PIT tagged Snake River steelhead and chinook suggests differential survival of transported and untransported fish. Stress is suggested as one possible mechanism explaining this pattern (National Marine Fisheries Service 2000e) – *Reviewer: Paul Wilson*

Applicability (Score = 1)

The paper summarizes research relating to transportation of salmon and steelhead smolts from the Snake and Columbia rivers available. A brief description of current (as of early 2000) uncertainties is also included. Estimates of *D* and T/I ratios for Snake River steelhead and yearling migrant chinook from PIT tag data are presented. Hypotheses and evidence for mechanisms that might cause differential survival between transported and untransported fish, including stress, are briefly summarized.

Clarity (Score = 2)

The mean *D* for 4 years of data for Snake River yearling migrant chinook was estimated to range from approximately 0.6 to 0.7, with annual 95% confidence bounds ranging from –0.69 to 2.72. Mean estimates of *D* for Snake River steelhead for the same years range from 0.5 to 0.6, with annual 95% confidence bounds ranging from -0.68 to 1.87. The methods which were used to make the estimates aren't completely detailed, and the presentation of negative values for confidence intervals suggest an inappropriate method was used to represent uncertainty in the estimates—other investigators have estimated confidence intervals for ratios of SARs with methods that exclude negative values.

Rigor (Score = 2)

The paper was not published in the peer-reviewed literature, but was a NMFS technical white paper in support of the 2000 FCRPS Biological Opinion. It is a review of literature and presented new analyses of the existence and magnitude of delayed, and reflects comments from other regional scientists. It provides evidence of delayed mortality due to transportation.

Evidence against the hypothesis:

a) Hatchery steelhead smolts experimentally exposed to supersaturated dissolved gases during transit showed no decrease in measured survival rates relative to control groups (Monk et al. 1997*)– Reviewer: Margaret Filardo*

Applicability (Score =3)

Steelhead were exposed to total dissolved gases (TDG) and then assessed as to whether survival rates were different due to treatment. There was no significant difference in survival of GBD-challenged steelhead than in control groups. More species and treatments would have made the study more applicable.

Clarity (Score = 3)

The study only addressed steelhead over a short period of time in the hydrosystem. Levels of TDG exposure were not developed to address possible exposure levels seen in the hydrosystem. No follow-up through adult returns was included in the analysis. Study was limited and changes may be confounded by stress related to dam passage (mechanical), rather than hydrosystem related spill.

Rigor (Score =3)

The study only addressed a short period of the migration after exposure. No direct evaluation of the hypothesis is possible. Published only as an annual report to Bonneville Power Administration (BPA). Not peer reviewed.

Hypothesis 2.3.1.1

"Passage through or around the hydrosystem increases vulnerability to proliferation of pathogens"

1) Clarity

The hypothesis provides a reasonably clear description of one potential way in which passage experience leads to mortality. Because this hypothesis is related specifically to indirect/delayed mortality, the hypothesis could be more clearly stated as specifying that hydrosystem experience increases vulnerability to disease at a time and place removed from the experience itself. That is, cumulative effects of passage through the series of dam turbines or bypass systems increase vulnerability to disease in the estuary and ocean.

2) Mechanism

There are several well-documented mechanisms that might explain how hydrosystem experience can lead to increased vulnerability to disease. Examples include:

- Physical injury sustained during passage through bypass/collection systems and turbines compromises immune function
- Delays, reduced water velocities, and increased water temperatures in reservoirs and forebays cause depletion of energy reserves in smolts, which compromises immune function
- Confinement of smolts at high densities in barges and collection systems can lead to higher rates of horizontal pathogen transmission.

Evidence for and against these mechanisms is summarized below.

3) Consistency with Empirical Evidence

<u>Evidence for the hypothesis:</u>

a) Comprehensive literature review suggests that across species there is a generalized decrease in disease resistance that follows non-specific stress. (Wedermeyer 1970) – *Reviewers: Phaedra Budy and Matt Mesa*

Applicability (Score = 3)

Generally applicable, as the author makes the link between the physiological or biochemical effects of stress and disease.

Clarity (Score = 3)

Confounded by review nature, and the fact that many different species were evaluated. Although, in general, it can be assumed that fish will respond to stress similarly to other animals. Supports the hypothesis but only in theory, direct evidence is not provided.

Rigor (Score = 2)

Literature review, but important for linking stress effects to increased vulnerability to disease. However, the papers cited are for mice (> 5), humans (2-3) or are reviews for which the animal is unknown. Only one example presented for fish (rainbow trout).

b) **Seawater survival of transported chinook smolts was not closely correlated with estimated incidences of BKD. However, almost all detected fish that died subsequently in seawater had typical symptoms of the disease (Congleton et al. 1984) – *Reviewers: Phaedra Budy and Matt Mesa***

Applicability (Score = 1)

Study examined the intensity of stress responses in spring and fall chinook smolts transported in barges with the Columbia River

Clarity (Score = 2)

Some confounding with BKD testing, but very weakly. BKD test was, perhaps, insensitive, but fish that died shared common symptoms.

Rigor (Score = 3)

Annual report to BPA and not in peer reviewed journal. However, report does have 6 authors, and replication (3 groups).

c) **Assessment of historical trends in returns of Columbia River chinook and steelhead suggests major problem in recent years has been mortality of smolts shortly after entry into the ocean. Activation of BKD by stresses encountered during downstream migrations, transportation, or transition to seawater is suggested as most likely cause (Raymond 1988) – *Reviewer: Matt Mesa***

Applicability (Score = 3)

Spring and summer chinook in the Snake River and Mid-Columbia River.

Clarity (Score = 3)

Study was assessment of run returns between 1962-1984. No direct measurements of disease induced mortality affecting the runs, but rather speculation that BKD activation is likely cause for high rates of smolt mortality.

Rigor (Score = 2)

Published in peer-reviewed journal.

<u>Evidence against the hypothesis:</u>

a) **Spring chinook experimentally infected with BKD in a laboratory situation showed no increase in pathogen proliferation or increased mortality following exposure to multiple acute stressors (Mesa et al. 2000) – *Reviewer: ESSA Technologies***

Applicability (Score = 2)

Experimental laboratory study evaluating response of BKD infected chinook salmon juveniles to acute stress events (designed to simulate those which migrating smolts might experience traveling through the Columbia River hydrosystem). BKD is a disease with high prevalence among Columbia River salmon, but the actual impact of BKD on survival of wild salmon is unknown as are the triggers for BKD pathogenesis.

Clarity (Score = 3)

Experiments evaluated response of pre-smolts in freshwater conditions. Results may not apply to actively migrating smolts or fish once they enter and reside in seawater. Study showed no increase in BKD infection levels or increased mortality levels in infected chinook exposed to multiple physical stressors. However study only deals with one disease and one type of stressor so does not represent the full suite of interactions between stressors (acute and chronic) and disease.

Rigor (Score = 1)

Evidence comes from specific, controlled experiments that have been published in a peer-reviewed journal

Hypothesis 2.3.1.2

"Passage through or around the hydrosystem decreases smolt condition and growth rates"

1) Clarity

The hypothesis provides a reasonably clear description of one potential way in which passage experience leads to mortality. However, the hypothesis is not related specifically to indirect/delayed mortality. The hypothesis could be more clearly stated as specifying that hydrosystem experience decreases smolt condition and growth rates, which leads to increased vulnerability to disease and predation and reversal of, or incomplete smoltification, which in turns leads to increased mortality at a time and place removed from the experience itself.

2) Mechanism

There are several well-documented mechanisms that might explain how passage through or around the hydrosystem could decrease growth rates or condition of smolts. Examples include:

- delays, reduced water velocities, and increased water temperatures in reservoirs and forebays cause depletion of energy reserves in smolts, which reduces smolt growth rates or condition;
- sudden and extreme changes in water pressures and velocities in bypass/collection systems and turbines cause harmful physiological changes in smolts, which affect smolt growth rates or condition;
- gas supersaturation during spill at high flows causes physiological damage to smolts passing through spillways, which affects smolt growth rates or condition; and
- physical injury sustained during passage through bypass/collection systems and turbines affects smolt growth rates or condition.

Evidence for and against these mechanisms is summarized below.

3) Consistency with Empirical Evidence

<u>Evidence for the hypothesis:</u>

a) **Developed a model simulating energy budgets of smolts as a function of water temperature & flow regimes. Data from literature, lab & Columbia River basin. (Rondorf et al. 1985) – *Reviewers: Margaret Filardo***

Applicability (Score = 2)

This paper is a development of a model describing the bioenergetics of fish migration, based on lab and field observations in the Columbia Basin. Lower score based on the fact that it was developed in 1983 and could be updated with empirical data collected since that time.

Clarity (Score = 2)

Authors conclude that starvation exerts a strong influence on the energy reserves of smolts and eventual survival in seawater challenges for lab tested smolts. Very indirect support of the hypothesis.

Rigor (Score = 3)

Evidence comes from field and lab observations prepared for annual report to Bonneville Power Administration. Not peer reviewed

b) **Delayed mortality (within 48 hrs) of bypassed spring- summer chinook smolts in the Columbia River was correlated with degree of descaling (Williams and Mathews 1995) – *Reviewers: Phaedra Budy & Matt Mesa***

Applicability (Score = 1)

Chinook salmon in the Snake River.

Clarity (Score = 2)

Evidence shows that descaling = delayed mortality, but not that dead fish were sick, etc. Link between descaling, and delayed mortality is made, link between descaling and actual cause of mortality (disease, predation, etc.) is not made.

Rigor (Score = 2)

Peer reviewed + review of stats, 2 groups.

c) **Hatchery Snake River s/s chinook showed decreased protein and lipid reserves with increased travel time through the hydrosystem. Depressed nutritional indices for low-flow year inriver smolts were comparable to fasted laboratory fish which showed decreased swimming and osmoregulatory abilities as a result of diminished nutritional status (Congleton et al. 2004 – Presentation CSS Workshop –Appendix G in this report) – *Reviewers: ESSA***

Applicability (Score = 1)

Examination of hatchery Snake River s/s chinook smolts. Directly addresses the question of whether travel time through the hydrosystem and date of passage can have measurable negative effects on smolt condition.

Clarity (Score = 2)

Monitored energy reserves (lipids and proteins) and nutritional blood chemistry indices of chinook smolts as they moved through Columbia hydrosystem. Extended travel time through the hydrosystem resulted in increased protein use. Additionally, although in all years compared lipid reserves were exhausted by Bonneville, in low flow years lipid reserves were depleted at points further upstream. This depletion of lipid and protein reserves did not seem to be counteracted by availability of food later in the season. Nutritional status of low-flow year smolts was comparable to that of fasted laboratory fish that showed decreased swimming and osmoregulatory abilities. Concluded that depletion of energy reserves is likely reason for low survival of migrating fish in the late season, and also likely reason why smolt-to-adult returns are lower in low-flow years than in higher-flow years. Results support continued transport of smolts in lower-flow years and later migrating fish in all years. However, study did not directly show with field data that nutritionally stressed fish showed increased delayed mortality post Bonneville (inferred, but not demonstrated).

Rigor (Score = 2)

Well-designed field and laboratory comparisons and experiments. However, not yet a published paper, as this was presented as preliminary results at the CSS workshop in Bonneville.

Evidence against the hypothesis:

No papers/reports were uncovered that presented evidence against this hypothesis.

Hypothesis 2.3.1.3

"Passage through or around the hydrosystem increases vulnerability to predation"

1) Clarity

The hypothesis provides a reasonably clear description of one potential way in which passage experience leads to mortality. Because this hypothesis is related specifically to indirect/delayed mortality, the hypothesis could be made clearer by specifying that hydrosystem experience is hypothesized to increase vulnerability to predation at a time and place removed from the experience itself. That is, passage through a dam turbine or bypass system may increase vulnerability to predation in the tailrace of that dam, or the cumulative effects of passage through the entire hydrosystem increases vulnerability to predation in the estuary and ocean.

2) Mechanism

There are several well-documented mechanisms that might explain how hydrosystem experience can lead to increased vulnerability to predation. Examples include:

Delays, reduced water velocities, and increased water temperatures in reservoirs and forebays cause depletion of energy reserves, and higher levels of aggregation, which makes smolts more vulnerable to predation (e.g., concentrates predators, reduces smolt's ability to evade).

Disorientation of smolts upon exiting bypass and collection systems can cause changes in behavior, which makes smolts more vulnerable to predation (e.g., surface orientation exposes smolts to avian predators). Similarly, smolts that arrive via barge at the estuary before smoltification is complete may congregate at the water surface (where salinity is lower), making them more vulnerable to avian predators.

Evidence for and against these mechanisms is summarized below.

3) Consistency with Empirical Evidence

<u>Evidence for the hypothesis:</u>

a) Underyearling chinook treated with a sublethal concentration of fungicide suffered up to 5 times higher rates of predation loss than untreated fish in a tank simulating estuarine conditions (Kruzynski and Birtwell 1994) – *Reviewer: ESSA Technologies*

Applicability (Score = 3)

The study provides general evidence for the hypothesis by quantifying the cumulative effects of sub-lethal stresses on vulnerability to predation. However, applicability is limited by the following factors:

- the study focuses on underyearling chinook in the Fraser River, B.C., and uses yellowtail rockfish as the predator.
- the stressor affecting vulnerability to predation in this case was a toxic chemical, which likely acts through different mechanisms than those involved in the effects of hydrosystem exposure on predation vulnerability.
- the study was conducted in a laboratory. There are likely different variables affecting predation vulnerability under natural conditions (e.g., condition of predators, availability of alternative food

items). Controlling for variability in these factors under laboratory conditions increases the clarity of the experiment, but reduces its applicability in describing the complex ecological interactions associated with predation in nature.

Clarity (Score = 3)

The study was conducted in a controlled laboratory setting, which removed several potential confounding factors. For example, all prey and predators had access to the same amount and type of cover, and all prey had similar body sizes and were subjected to similar rearing conditions.

Predation losses were measured five days after the chinook were released into the predation tank. Differential predation of treated chinook could have occurred anytime throughout this time period. If the largest differential losses occurred immediately after release, this would weaken the evidence for delayed effects of stress on predation vulnerability, as postulated in the hypothesis.

Observations of prey and predator behavior during the predation trials were limited to avoid causing disturbances that would affect behavior. This removed potential confounding due to observation disturbances, but also limited the ability of the study to identify specific behavioral changes in the toxic-stressed chinook that might explain their higher rate of predation loss.

Rigor (Score = 1)

The evidence comes from specific, controlled experiments that have been published in a peer-reviewed journal.

b) A review of predator-prey experiments using substandard (i.e., exposed to toxic, thermal, physical stressors) prey shows that stressed fish suffered higher predation losses than untreated prey in 27 of the 37 experiments. (Mesa et al. 1994) – *Reviewer: ESSA Technologies*

Applicability (Score = 3)

The study is a literature review of predator-prey experiments, some but not all of which focused on predation on Pacific salmon species. The purpose of the review was to examine predator-prey relationships in the broad context of ecological theory, rather than in the context of exploring possible causes of delayed effects of various stressors. In addition, almost all experiments reviewed were conducted in artificial conditions. Therefore, this paper on its own is not directly applicable to the hypothesis. However, the fact that a substantial majority of the literature reviewed showed higher predation losses in stressed fish provides some support for this hypothesis.

Clarity (Score = 3)

The paper has a broad context and therefore was not intended to provide clear evidence for or against the effects of stress on vulnerability of salmon juveniles to predation. The paper discusses potential mechanisms underlying increased vulnerability of stressed prey, but only in a general context because (as the authors point out) experimental evaluations of possible mechanisms were rare in the reviewed literature.

Rigor (Score =2)

The paper is a literature review and thus provides no new direct evidence for the hypothesis. However, it is published in a peer-reviewed journal.

c) Juvenile chinook exposed to high levels of total dissolved gas had significantly higher vulnerability to predation than unexposed fish. (Mesa and Warren 1996) – *Reviewer: ESSA Technologies*

Applicability (Score = 2)

The study was conducted on Columbia River chinook salmon, using northern pikeminnow (the predominant predator of juvenile chinook in the Columbia River) as the experimental predator. Exposure to high levels of total dissolved gas is a problem known to exist in the Columbia River hydropower system. Therefore, this study is directly relevant to the hypothesis.

The study was conducted in a laboratory and is thus unable to fully replicate natural conditions. For example, the supersaturation tanks were shallow and did not allow fish to compensate for high levels of TDG by moving to deeper depths. In addition, there are likely different variables affecting predation vulnerability under natural conditions (e.g., condition of predators, availability of alternative food items). Controlling for variability in these factors under laboratory conditions increases the clarity of the experiment, but reduces its applicability to describing the complex ecological interactions associated with predation in nature.

Clarity (Score = 2)

The study provides a relatively clear demonstration of the effects of high levels of TDG on predation vulnerability. Laboratory conditions allowed for control over potentially confounding factors such as body size of predator and prey and predator condition, and data were standardized to avoid potential biases in their statistical tests associated with small sample sizes and changes in prey availability.

Predation losses were measured up to three hours after treated and control groups of chinook were released into the predation tanks. This may not be long enough to derive any conclusions about the long-term delayed effects of TDG stress.

Fish exposed to TDG levels of 130% had predation losses that were significantly higher than control (unexposed) fish, and higher than groups of fish exposed to lower levels of TDG. 130% TDG occurs commonly in the Columbia River (during periods of uncontrolled spill), but fish may avoid or minimize exposure to these levels through vertical migration or other mechanisms. Therefore, the experimental conditions represent a potential worst case, which may or may not represent conditions commonly experienced by fish as they migrate through the hydropower system.

The study identified several potential physiological mechanisms to explain the link between high TDG and increased vulnerability. First, at 130% TDG gas bubbles were observed to be occluding the lateral line, an organ associated with predator detection. Fish exposed to 130% TDG also had damage to the gills, which could affect swimming performance and predator avoidance ability. In contrast, fish exposed to lower TDG levels (112%) had severely blistered fins, but did not show increased vulnerability to predation. The study thus provides some indication of specific physiological / behavioral mechanisms for increased vulnerability of fish exposed to high TDG conditions.

Rigor (Score = 1)

The evidence comes from specific, controlled experiments that have been published in a peer-reviewed journal.

d) Thermally shocked juvenile chinook salmon were selectively preyed upon by larger rainbow trout relative to control (unshocked) groups. (Coutant 1973) – *Reviewer: ESSA Technologies*

Applicability (Score = 2)

The experiment was conducted with Columbia River chinook salmon, using adult rainbow trout as the predator. The study was designed to explore the effects of exposure to high temperatures as fish pass through thermal discharges from the Hanford nuclear reactor near Richland, Washington. Therefore, the study directly addresses potential effects of stress encountered by mid- and upper Columbia stocks of Columbia River salmon. Similar stresses may be encountered by other Columbia River stocks due to localized thermal conditions (e.g., fall-run chinook rearing in the mainstem of the Snake River).

The study was conducted in a laboratory and was thus unable to fully replicate natural conditions. For example, the study exposed treatment groups to sustained high water temperatures for up to 12 minutes, whereas in nature fish are exposed to abrupt fluctuations between normal and high water temperatures as they pass through areas with differing local thermal and hydraulic conditions. Such simplifications are necessary for obtaining clear experimental results, but detract somewhat from the applicability of the study to explaining effects of thermal stress observed in nature.

Clarity (Score = 2)

The study provides a relatively clear demonstration of the effects of thermal shock on predation vulnerability. Laboratory conditions allowed for control over potentially confounding factors such as body size of predator and prey and predator condition. Predator-prey interactions were observed throughout the study. Fish exposed to thermal stress showed differences in behavior including disorientation, erratic swimming activity, unnatural position, and unresponsiveness. All of these likely contributed to reduced ability to avoid detection and capture, and obviously disoriented prey were observed to be the first to be eaten. These observations provide relevant information for discerning mechanisms by which thermal stress affects vulnerability to predation.

The study also observed that a fish's ability to recover from thermal stress depends on exposure time. Fish exposed to high temperatures for short periods of time but allowed to recover in cooler water before exposure to predators showed similar vulnerability to fish that had never been exposed to high temperatures. Conversely, fish that were exposed for long periods of time showed similar increases in vulnerability relative to control groups regardless of whether they were allowed a recovery period. This suggests that longer exposure to high temperature may lead to more permanent thermal damage, which would affect predation vulnerability well after exposure occurs. This provides evidence for the hypothesized delayed effects of stress on predation vulnerability.

Rigor (Score = 1)

The evidence comes from specific, controlled experiments that have been published in a peer-reviewed journal.

e) Juvenile chinook salmon exhibited physiological signs of stress (e.g., elevated plasma cortisol levels) after being experimentally exposed to crowding, after passing through dam bypass systems, and after collection for transport. In a subsequent experiment, fish that were exposed

to crowding experienced higher rates of predation than control fish, and there was a significant correlation between plasma cortisol levels and rates of predation. (Congleton et al. 1984) – *Reviewer: ESSA Technologies*

Applicability (Score = 1)

The study was conducted with hatchery-raised Columbia River chinook salmon. Part of the study was conducted in laboratory conditions (physiological response to crowding, differential predation on stressed and control fish), while measurement of physiological responses to hydrosystem passage and collection was done on site. The study is thus directly relevant to the hypothesis.

Clarity (Score = 2)

The study indicates a relatively clear link between hydrosystem passage and transport, physiological indicators of stress, and increased vulnerability to predation. The study noted that physiological recovery from stress was likely after 24 hours in sea water, but was incomplete after 72 hours in freshwater. This suggests the possibility that stress conditions can continue for some period after exit from the hydropower system, particularly in the estuary where water is of mixed salinity.

The authors note that many of the fish exposed to crowding conditions exhibited clouding or degeneration of the eye lenses. This suggests a possible mechanism for effects of stress on predation vulnerability, although the link between eye pathology and physiological indicators of stress such as plasma cortisol levels was not investigated further.

Clarity of the evidence from this study is partially reduced by the use of hatchery-raised fish. While this was necessary for experimentation, the potential confounding of using fish raised in hatchery conditions creates uncertainty about the applicability of the results to wild stocks. It is conceivable that fish raised in hatcheries have different physiological responses to stress than wild fish — perhaps more sensitive to stress because of higher incidence of disease in hatchery conditions, or perhaps less sensitive because they are more accustomed to crowded conditions than wild fish. The differences in physiological response to stress between hatchery and wild fish are a key uncertainty when assessing the strength of this evidence.

Rigor (Score = 2)

The evidence comes from specific, controlled experiments. Publication is in the form of a contractors report to BPA. The study may have been published subsequently in a peer-reviewed journal, but we have not found a reference (would have a score of 1 if published in a journal).

f) Juvenile chinook experimentally infected with Rs (causative agent of BKD disease) showed increasing levels of plasma cortisol and lactate as the disease progressed. Rs-challenged fish also showed increased vulnerability to predation by either northern pikeminnow or smallmouth bass in controlled laboratory experiments. (Mesa et al. 1998) – *Reviewer: D. Rondorf*

Applicability (Score =1)

The authors describe a predator-prey interaction that may result from pathogen interaction related to the effect of *Reinibacterium salmoninarum* (Rs). This may be especially important for spring chinook salmon because of the incidence of the pathogen in that run. The paper does not specifically address how the hydrosystem might cause indirect/delayed mortality below Bonneville Dam, but that seems plausible given the attributes of BKD.

Clarity (Score = 2)

The evidence presented in the paper is clear and the approach is appropriate. The laboratory experiments were not specifically designed to address the question of indirect/delayed mortality as described in the hypothesis 2.3.1.3. However, the experiments do address differential predation on test and control groups with different levels of antigen describing the prevalence and level of severity of the pathogen. The progression of BKD after ocean entry by juvenile chinook salmon and the sensitivity of chinook to stress, especially in advanced stages of BKD suggest this is a possible mechanism for indirect/delayed mortality. In that case, predation would likely be only the proximate cause of mortality.

Rigor (Score =2)

The laboratory experiments are well designed with test and control groups. However, the authors do not provide supporting data from field experiments supporting the ecological significance of the disease, BKD.

g) A predation index developed to examine the relative magnitude of predation within the Columbia Basin showed that highest predation rates on juvenile salmonids occurred below the Bonneville Dam. (Ward et al. 1995) - *Reviewer: D. Rondorf*

Applicability (Score = 1)

The authors present the results of an index of predation to describe the relative magnitude of predation on juvenile salmonids. The study was conducted over a wide area of the Columbia and Snake River hydropower system. The findings indicate the index of predation was highest below Bonneville Dam. The results indicate potential significant impacts of predation below the hydrosystem. If the effects of the hydrosystem on salmonids are relatively short lived, then the area below Bonneville Dam may be a likely area of interest.

Clarity (Score = 2)

The study covered a wide geographic area: the Columbia River basin and the hydropower system. The results are the product of a long-term study with numerous supporting peer reviewed papers. The evidence is clear; the predation index is relatively high in an area immediately downstream of the hydrosystem, in an area where indirect/delayed mortality is likely to occur.

Rigor (Score = 1)

The authors address a difficult subject using a practical approach. The results are published in a peer-reviewed paper with numerous citations of supporting literature. The evidence is strong that significant predation occurs downstream of Bonneville Dam, and it was considered conclusive support for predation being a significant loss for juvenile salmonids. The paper is not conclusive support for indirect/delayed mortality caused by the hydrosystem.

h) Juvenile salmon were experimentally released at varied locations in the lower Columbia system, ranging from below Bonneville Dam to the offshore plume. Survival was found to be highest for juveniles released directly into estuarine waters. (Solazzi et al. 1991) – *Reviewer: D. Rondorf*

Applicability (Score = 1)

The experimental releases of juvenile salmon were based on observations in Sweden, Norway, and British Columbia that smolts released directly into estuarine waters had relatively high survival. The authors of this paper found that fish released at Tongue Point on the Columbia River near the head of the saltwater intrusion had relatively high survival compared to releases ranging from below Bonneville Dam to offshore of the Columbia River plume. The authors suggest that the survival "bottleneck" for hatchery coho salmon probably occurred in the lower Columbia River. They also speculated that the bottleneck might have been caused by the northern pikeminnow. The findings are applicable because the authors document differential survival and identified a bottleneck below Bonneville a location of interest for the indirect/delayed mortality hypothesis. The authors do not relate survival to any operation of the hydrosystem, as that was not among their objectives

Clarity (Score = 1)

The experimental design and the authors' interpretation of the results contribute to unambiguous results. Although the authors discuss mechanism that might have caused differences in survival and adult returns, identifying the mechanism was beyond the scope of the paper.

Rigor (Score = 1)

The authors used a test and control approach and the appropriate statistical tests to identify differences in survival of release groups. The paper is published in a peer-reviewed journal.

i) Field experiments conducted in the Bonneville Dam tailrace determined that predatory northern pikeminnow consumed greater relative numbers of dead vs. live juvenile salmonids. (Petersen et al. 1994) – *Reviewer: D. Rondorf*

Applicability (Score = 1)

Experimental releases of live and dead juvenile salmon were related to consumption of prey by northern pikeminnow. The significance of this paper is that it is one of very few examples describing the differential predation on prey by piscivorous predators. The mechanism of differential predation is key if predation is proposed as a mechanism to account for indirect/delayed mortality downstream of the hydropower system. An applicability score of "1" was assigned, even though the causes of differential mortality stemming from passage through the hydropower system may be much more subtle that the dead verses live condition of smolts used by the authors.

Clarity (Score = 2)

Field experiments described in the paper corroborated laboratory studies where northern pikeminnow were also found to select dead salmon (Gadomski and Hall-Griswold 1992). The results are clear and the study site below Bonneville Dam is applicable to the predation hypothesis. The clarity score was relatively high because the experiments were conducted under field conditions and the design included a test and control groups. Furthermore, the condition of the test and control groups was established based on observations on the operation of the hydropower system and the resulting questions.

Rigor (Score = 1)

The rigor of this paper was ranked high because observations in laboratory experiments were used to develop design for field experiments below Bonneville Dam, the design included test and control groups, and the results were tested with statistics (Chi-square). The results were published in a peer-reviewed journal.

j) Coho and chinook smolts experimentally exposed to handling stress were selectively preyed upon by lingcod relative to control groups up to 4 hours post handling. (Olla et al. 1995) – *Reviewer: ESSA Technologies*

Applicability (Score =2)

Laboratory study of the effects of handling stress on non-predatory mortality, predator evasion and physiological stress indicators using chinook and coho salmon smolts. The predator used for the study was lingcod. Stressed chinook and coho smolts (as indicated by elevated cortisol levels) showed significantly increased vulnerability to predation by lingcod at 4 hrs after handling. But both species showed recovery of predator-evasion behavior 24 hrs after handling (as indicated by no increased vulnerability to predation after this period of time). Coho salmon showed greater susceptibility than chinook to non-predatory mortality simply as a result of handling.

Clarity (Score = 2)

Study showed that there may be significant differences among species/stocks of salmon in their physiological response to stress, but would suggest (in conjunction with other studies) that predator-evasion behaviors for salmon could recover within 1.5 to < 24 hr of incurring an acute stress. This study did not evaluate the effects of multiple (cumulative) stressors, and did not attempt to simulate the more intense stressors that smolts might experience in the Columbia during transport or outmigration.

Rigor (Score = 1)

Evidence comes from specific, controlled experiments that have been published in a peer-reviewed journal

k) Juvenile chinook smolts experimentally stressed by simulated predator chasing showed a significantly decreased saltwater preference relative to controls, at a time when chinook salmon should otherwise select full-strength saltwater. (Price and Schreck 2003). *Reviewer: ESSA Technologies*

Applicability (Score =2)

Laboratory study evaluating the effect of stress (induced by simulated fish and avian predators) on timing of saltwater entry by chinook salmon smolts.

Clarity (Score = 2)

Experiments showed that mild or severe stressors decreased the willingness of juvenile chinook to remain in saltwater, at a time when unstressed fish prefer salt to fresh water. Results suggest that stress may cause an electrolyte imbalance that forces the juveniles to avoid salt water. If juvenile

chinook are stressed during the estuarine phase of outmigration, their movement into saltwater may be compromised. It is conceivable that severely stressed fish might avoid saltwater altogether. Such behavior (short or long term) could expose fish to increased predation risk from avian predators, as they could be trapped on the less dense freshwater at the surface of the fresh-saltwater interface. Additionally, an efficient osmoregulatory shift from fresh to salt water may be a critical factor in determining early ocean survival for salmon.

Rigor (Score = 1)

Evidence comes from specific, controlled laboratory experiments that have been published in a peer-reviewed journal.

l) Juvenile chinook reared at a high water temperature regime (21-24°C for >60 days) showed significantly decreased growth rates, impaired smoltification indices and increased vulnerability to predation compared with control groups reared at cooler temperatures. (Marine and Cech, Jr. 2004) – *Reviewer: ESSA Technologies*

Applicability (Score =2)

Laboratory study on the effects of increased water temperatures on chinook salmon juveniles. Experimental water temperatures were designed to mimic temperature regimes (low to high) that fish might experience in the Sacramento River, which may not be comparable with conditions in the Columbia River. Predator evaluated was Striped Bass, a major introduced predator in the Sacramento system, but not in the Columbia.

Clarity (Score = 3)

Laboratory experiments showed increased vulnerability of heat stressed chinook juveniles to predation by striped bass. However, design did not allow clean separation of the effects of temperature from that of fish size, as fish raised at higher temperatures were significantly smaller than fish raised at cooler temperatures.

Rigor (Score = 2)

Evidence comes from specific, controlled laboratory experiments that have been published in a peer-reviewed journal. Confounding with fish size weaken the interpretations.

m) Atlantic salmon smolts osmotically stressed by variable length exposure times to full strength seawater showed differential vulnerability to predation by cod. Groups of smolts exposed to seawater for only 12 and 24 h, experienced significantly higher mortality than control fish (freshwater) or groups full acclimated to seawater. (Handeland et al. 1996) – *Reviewer: ESSA Technologies*

Applicability (Score =2)

Laboratory experiments examining interaction between osmotically stressed (as indicated by elevated plasma chloride levels) Atlantic salmon and predation by Atlantic cod. Neither species occurs in the Columbia. However, issues of predation vulnerability likely apply similarly to salmon smolts in the Columbia as they make the osmotically stressful transition to seawater.

Clarity (Score = 2)

Results showed that fish in transitional stage of freshwater to seawater transfer are behaviorally more at risk (i.e., reduced escape distances and schooling behavior) and suffered significantly higher mortality than fully acclimated fish. It seems likely that fish that are impaired in their ability to make a smooth transition from freshwater to the sea will be physiologically stressed and may be exposed to increased predation risk as a consequence of less effective antipredator behavior. However, applicability to natural state may be limited as test tanks used represented an open habitat with little cover and opportunity for antipredator behavior.

Rigor (Score = 1)

Evidence comes from specific, controlled experiments that have been published in a peer-reviewed journal. However, applicability to natural state may be weakened as test tanks used represented an open habitat with little cover and opportunity for antipredator behavior.

n) Stressed S/S chinook and steelhead smolts were twice as likely to hold in low flow areas (areas often preferred by northern pikeminnow) than unstressed (control) fish (Clugston and Schreck 1992; Snelling and Schreck 1993: Project N0. 82-003). – *Reviewer: Nick Bouwes*

Applicability (Score = 2)

This study is applicable in that it is conducted on s/s chinook and steelhead (however they were hatchery fish) and evaluates the impacts of stress on migration behavior and relates this to risk to predation. Stress was simulated in holding tanks and may not be representative of stress in the hydrosystem. The paper provides evidence that increases stress for s/s chinook and steelhead upon release results in greater holding in areas that have high concentrations of predators, which is consistent with the hypothesis that stress may indirectly be manifested in mortality after negotiating a dam. The paper does not actually measure the relationship between stress and subsequent mortality but that is the implication of the results.

Clarity (Score = 2)

The intentions of the study were to evaluate the behavior of smolts upon release at two sites after being stressed (treatment) or not being (stressed). These goals were evaluated, however this is somewhat anecdotal since a small sample of radio tagged fish were followed upon release. Provides little evidence that stress results in higher mortality. Uncertain that changes in stress recorded resulted in greater mortality below the hydrosystem.

Rigor (Score = 2)

Used radio tagged fish to observe the behavior of stressed and non-stress migrating smolts. Approach provides convincing evidence that stressed fish are more than twice as likely to hold in low flow areas, areas generally suitable for northern pikeminnows. However, true controls cannot be used since even that treatment requires handling and tagging (tags are put into stomachs with antenna hanging out the mouth). They suggest that mortality rates due to predators were higher for stress fish but based on very small sample size. Not peer reviewed.

o) Run of the river smolts from Snake River s/s chinook smolts (wild and hatchery) stocks always migrated faster below Bonneville Dam than barged fish (although no significant difference in mortality could be detected between the two groups. Additionally, smolts that had not completed smoltification remained on the freshwater lens in the estuary, making them more vulnerable to avian predators (Schreck et al. 1997 Project MPE-95-3; Schreck and Stahl 2000b: Project MPE-W-97-4.). – *Reviewer: Nick Bouwes*

Applicability (Score = 1.5)

This study is applicable in that it is conducted on Snake River hatchery and wild s/s chinook and evaluates the impacts of downstream passage on stress and migration behavior. The paper provides evidence that s/s chinook are stressed at time of release, which is consistent with the hypothesis that the hydrosystem can cause stress that may have indirect impacts that manifest in mortality after migration (mortality was measured after release only to the estuary).

This study also evaluated migration rates and behavior of barged and run-of-the-river smolts below BON dam. ROR always migrated faster than barged smolts. Because predation will be higher the longer smolts are in the hydrosystem, this may provide a mechanism by which transported fish suffer higher delayed mortality than ROR (i.e., D<1.0). However, no significant difference could be detected in mortality rates of between both groups.

In addition, these reports provide some of the earliest evidence linking smolt condition to avian predator vulnerability. Smolts appear to stay on the freshwater lens in the estuary if they have not yet completed smoltification. Because the lens becomes relatively shallow, these fish become vulnerable to avian predators. A higher proportion of radio tagged fish that were early in the smoltification process appeared to be consumed by predators.

ROR smolts appeared to prefer saltwater more than barged fish in the laboratory (not in the field). If this results in barged fish remaining in the freshwater lens for longer periods then ROR, the above result may provide a link to why D<1.0.

Clarity (Score = 2)

The intentions of the study were to evaluate stress and behavior during the downstream outmigration in-river and on barges. The objectives were clearly stated and evaluated. The overall objective is to provide suggestions on how to make transportation more effective. Because the main issue is timing of estuary entry, it is difficult to determine how barging will be altered to address the issue. Weakly supports the idea that dam transportation system stress results in delayed mortality. Uncertain that changes in stress result in mortality below the hydrosystem. This study supports the mechanism of how transportation and dam passage leads to stress that could lead to mortality, but mortality is not measured.

Rigor (Score = 2)

Used comparative approach to evaluate relative differences in responses. Approach provides convincing evidence for differences in stress depending on the number of the event type encountered. However, true controls cannot be used since even that treatment requires handling. Not peer reviewed.

Evidence against the hypothesis:

a) **Juvenile chinook salmon subjected to stressors simulating routine hatchery practices or dam passage experienced higher initial (i.e., < 1 hour after release into the predation tank) rates of predation loss to northern pikeminnow predators than untreated chinook (Mesa 1994). However, the study showed no long-term (> 1 hour) effects of stress on predation rates, suggesting that effects of this stress on predation vulnerability are short-lived and not likely to explain differential mortality rates of fish in the estuary and ocean. (Mesa 1994) – *Reviewer: ESSA Technologies***

Applicability (Score = 2)

The study was conducted on Columbia River chinook salmon, using northern pikeminnow (the predominant predator of juvenile chinook in the Columbia River) as the experimental predator. Treatments were designed to emulate stresses typically encountered in Columbia River hatcheries (treated fish were netted, exposed to air, then returned to the tank) and dams (fish were repeatedly dumped from one bucket to another from a height of 1 m).

The study was conducted in a laboratory. There are likely different variables affecting predation vulnerability under natural conditions (e.g., condition of predators, availability of alternative food items). Controlling for variability in these factors under laboratory conditions increases the clarity of the experiment, but reduces its applicability to describing the complex ecological interactions associated with predation in nature.

Clarity (Score =2)

The study was conducted in a controlled laboratory setting, which removed several potential confounding factors. For example, all prey and predators had access to the same amount and type of cover, and all prey had similar body sizes and were subjected to similar rearing conditions.

The experiment explored mechanisms for possible delayed effects of stress. For example, behavior of prey and predators was observed throughout the experiment. Treated prey were initially lethargic and disoriented, but were able to participate in normal anti-predatory (schooling) behavior within an hour of release. The study also monitored physiological stress indicators (e.g., plasma cortisol and glucose concentrations) over time in both treated and control fish, and found that physiological stress indicators had little correlation with predator avoidance behavior (plasma cortisol concentrations generally remained high in treated fish after predator avoided behavior had resumed).

Clarity of the study is reduced by several factors:

- The treatments may or may not be a true representation of the degree of stress associated with hatchery or dams. For example, treatments representing dam passage were applied over a matter of hours, whereas in nature these stresses are experienced over a period of days or weeks.
- Changes in predation losses over time could have been due to accumulating error as sample sizes were reduced due to predation losses.
- The study did not monitor long-term effects of treatments, and did not monitor cumulative effects of multiple treatment sessions.

Rigor (Score = 1)

The evidence comes from specific, controlled experiments that have been published in a peer-reviewed journal.

b) Juvenile coho experimentally exposed to handling stresses showed elevated corticosteroids throughout a 4-hour recovery period, but avoidance of predatory lingcod returned to control levels in less than 90 minutes. (Olla et al. 1982) – *Reviewer: ESSA Technologies*

Applicability (Score = 2)

This was a laboratory study evaluating the responses of physically stressed coho salmon juveniles to predation by lingcod. Handling stress was associated with a short-term (1 minute) increase in vulnerability to predation by lingcod. But behavioral abilities to avoid predation recovered rapidly (within 90 minutes). The study however does not attempt to mimic the more intense, longer exposure or multiple stressors that smolts would encounter during transport or outmigration

Clarity (Score =2)

Experiments showed that coho juveniles had significantly elevated plasma cortisol levels for extended periods after handling (up to 240 minutes). However, the fish showed recovered predator avoidance behavior within 90 minutes, even through stress indicators were still elevated, suggesting that effects of such stressors on predation vulnerability are short-lived and not likely to explain differential mortality rates of fish in the estuary and ocean. The study however does not attempt to mimic the more intense, longer exposure or multiple stressors that smolts would encounter during transport or outmigration

Rigor (Score = 1)

The evidence comes from specific, controlled experiments that have been published in a peer-reviewed journal.

c) Juvenile chinook were subjected to acute thermal stressors in the laboratory comparable to that salmon might experience in the Columbia River's Hanford Reach. Thermally stressed chinook showed no direct mortality as a result of these stressors and no increase in vulnerability to predation by smallmouth bass. (Mesa et al. 2002) – *Reviewer: D. Rondorf*

Applicability (Score =3)

The paper is applicable to the hypothesis because thermal stress might be experienced in the hydropower system to a greater extent than for transported fish. An alternative hypothesis might be that transportation causes stress of juvenile salmon, particularly subyearling fall chinook, at a time when their scope to deal with additional stressors is very limited. If juvenile salmon experience such stressors in a different manner, then they may be more vulnerable to predation below Bonneville Dam. On the other hand, the authors did not find that thermal stress they subjected fish to in the laboratory significantly increased vulnerability to predation. Therefore, within the context of the limited applicability of the experiments the findings do not support the hypothesis that thermal experience could result in differential predation after leaving the hydropower system.

Clarity (Score = 1)

The evidence is clear and not confounded. Physiological attributes were used to characterize the condition of the smolts.

Rigor (Score =2)

The authors subjected experimental animals to a thermal experience that was based on observations in the Hanford Reach, Columbia River. The results are unequivocal, indicating the thermal experience did not increase mortality or vulnerability to predation. The authors reported the statistical power of the test supporting the conclusions. The paper was published in a peer-reviewed journal, adding rigor to the information.

d) Juvenile chinook experimentally descaled (10 and 20% of total body area) did not show increased vulnerability to predation by northern pikeminnow relative to control fish. Descaling did result in varied elevations of different stress chemicals, but all but plasma glucose returned to control levels within less than 24 hours. (Gadomski et al. 1994) – *Reviewer: ESSA Technologies*

Applicability (Score =2)

Laboratory tests examined the potential for increased predation and increased physiological stress on chinook salmon at descaling levels (10 or 20%) considered common among smolts passing Columbia River dams. The predatory fish used in the experiments were Northern Squawfish, the dominant predator on juvenile salmonids in the Columbia River.

Clarity (Score = 2)

Study was conducted in a controlled laboratory setting, which removed many potential sources of bias. Experiments did not show any significant effects of descaling in terms of increased predation, but descaling did elicit physiological changes (although these did not result in mortality or impaired severe osmoregulatory function).

Rigor (Score =1)

Evidence comes from specific, controlled experiments that have been published in a peer-reviewed journal.

<u>Ambiguous Studies (providing no strong evidence either for or against the hypothesis):</u>

a) Proposed Columbia Basin flows that increase river residence time of smolts could significantly increase exposure to predatory fish. Simultaneous exposure to periods of high water temperature could have the potential to severely exacerbate this predation problem. (*Columbia Basin Fish and Wildlife Authority 1991) – Reviewer: D. Rondorf*

Applicability (Score = 3)

The technical justification is a review of factors important to the proposal for selected flows in the Columbia River basin. The anonymous authors identified increased exposure time of juvenile salmon to predatory fishes as a concern. Discussion focused on residence time, temperature effects and water velocity.

Clarity (Score = 2)

Regional experts prepared the report, and it is now somewhat dated. The technical justification is reasonable, clear and addresses issues related to the flow proposal as intended. The technical justification, however, does not specifically address delayed/indirect predation mortality relevant to the hypothesis.

Rigor (Score = 3)

As a multi-agency position paper prepared by the fisheries management agencies the report embodies considerable expertise. On the other hand, the alternative positions are not presented and would not be expected in such a document. As a position paper it does not have the unbiased attributes expected of a research technical report or peer reviewed paper.

b) Avian predators in the Columbia estuary below Bonneville Dam consume large numbers of smolts. There is also the potential for considerable smolt predation from pinnipeds (National Marine Fisheries Service (2000c) - *Reviewer: D. Rondorf*

Applicability (Score = 3)

Although the title of this white paper promises considerable information on predation, the review does not provide much useful information to support or negate the hypothesis on predation as a mechanism for indirect/delayed mortality. The white paper does highlight the relatively large losses due to avian predators, perhaps as many as 10-30 million salmon smolts. The large losses to avian predators are of interest for this review because it occurs primarily in the estuary downstream from Bonneville Dam where differential predation may be important if it contributes to indirect/delayed mortality. In addition, the paper does recommend more study of pinniped predation on juvenile salmon.

Clarity (Score = 3)

The review is timid in its conclusions, summing the state of knowledge up as “little is known” regarding how the existence and operation of the Federal Columbia River Power System affects predation relations. Predation in the Columbia River has been the subject of a series of large field predation studies on northern pikeminnow and is the subject of numerous peer-reviewed papers.

Rigor (Score =3)

The review is widely available on the www as a white paper, but has not appeared as a peer reviewed paper to the best of my knowledge.

c) Vulnerability to avian predators of recently release hatchery coho smolts was found to be unrelated to stress levels at release. However, differences in stress levels between release groups were too small to allow for detection in vulnerability (Stahl et al. 2000) – *Reviewer: Nick Bouwes*

Applicability (Score = 3)

This study is applicable in that it is conducted on hatchery coho evaluating migration behavior and stress related to avian predation in Nehalem estuary, which is also a concern in Columbia River Estuary. No stress due to a hydrosystem could be evaluated. The paper does not provide evidence that stress results in greater vulnerability to predation, but treatments were release groups over different times of the season where the contrast in stress was negligible.

Clarity (Score = 3)

The intentions of the study were to evaluate downstream outmigration behavior and stress to vulnerability to avian predation. Some behavioral traits were observed that may lead to increase vulnerability to birds, such as increased residence time in freshwater near the estuary due to premature release; however, differences in stress levels between release groups were too small to allow for detection in vulnerability.

Rigor (Score = 3)

Used descriptive approaches to evaluate relative differences in vulnerability to predation. Although some comparisons were made between groups, groups differed in date released so one cannot determine whether differences are seasonal or aspects of juvenile condition. Several other variables that were not evaluated may also explain these patterns were not use as potential covariates. This was, however, a pilot study. Not peer reviewed. Neither supportive nor opposed to the idea that stress results in delayed mortality due to predators.

Hypothesis 2.3.1.4

"Passage through or around the hydrosystem results in reversal of, or incomplete smoltification"

1) Clarity

The hypothesis provides a reasonably clear description of one potential way in which passage experience leads to mortality. Because this hypothesis is related specifically to indirect/delayed mortality, the hypothesis could be more clearly stated as specifying that hydrosystem experience causes incomplete or delayed mortality that increases mortality at a time and place removed from the experience itself. That is, cumulative effects of passage through the series of dam turbines or bypass systems interferes with normal smoltification processes required for successful entry into the estuary and ocean.

2) Mechanism

There are several well-documented mechanisms that might explain how hydrosystem experience can lead to incomplete or delayed smoltification. Examples include:

- Exposure to stressors causes changes in smolts that lead to delayed or incomplete smoltification.
- Sudden and extreme changes in water pressures and velocities in bypass/collection systems and turbines cause harmful physiological changes in smolts, which leads to reversed or incomplete smoltification
- Increased freshwater residence times in reservoirs result in premature onset of physiological adaptations to saltwater environments
- Gas supersaturation during spill at high flows causes physiological damage to smolts passing through spillways, which leads to reversal of or incomplete smoltification

Evidence for these mechanisms is summarized below.

3) Consistency with Empirical Evidence

<u>Evidence for the hypothesis:</u>

a) **Run of the river smolts from Snake River s/s chinook smolts (wild and hatchery) stocks always migrated faster below Bonneville Dam than barged fish (although no significant difference in mortality could be detected between the two groups. Additionally, smolts that had not completed smoltification remained on the freshwater lens in the estuary, making them more vulnerable to avian predators (Schreck et al. 1997 Project MPE-95-3; Schreck and Stahl 2000a: Project MPE-W-97-4.). – *Reviewer: Nick Bouwes***

   Applicability (Score = 1.5)

   This study is applicable in that it is conducted on Snake River hatchery and wild s/s chinook and evaluates the impacts of downstream passage on stress and migration behavior. The paper provides evidence that s/s chinook are stressed at time of release, which is consistent with the hypothesis that the hydrosystem can cause stress that may have indirect impacts that manifest in mortality after migration (mortality was measured after release only to the estuary).

   This study also evaluated migration rates and behavior of barged and run-of-the-river smolts below BON dam. ROR always migrated faster than barged smolts. Because predation will be higher the

longer smolts are in the hydrosystem, this may provide a mechanism by which transported fish suffer higher delayed mortality than ROR (i.e., D<1.0). However, no significant difference could be detected in mortality rates of between both groups.

In addition, these reports provide some of the earliest evidence linking smolt condition to avian predator vulnerability. Smolts appear to stay on the freshwater lens in the estuary if they have not yet completed smoltification. Because the lens becomes relatively shallow, these fish become vulnerable to avian predators. A higher proportion of radio tagged fish that were early in the smoltification process appeared to be consumed by predators.

ROR smolts appeared to prefer saltwater more than barged fish in the laboratory (not in the field). If this results in barged fish remaining in the freshwater lens for longer periods then ROR, the above result may provide a link to why D<1.0.

Clarity (Score = 2)

The intentions of the study were to evaluate stress and behavior during the downstream outmigration in-river and on barges. The objectives were clearly stated and evaluated. The overall objective is to provide suggestions on how to make transportation more effective. Because the main issue is timing of estuary entry, it is difficult to determine how barging will be altered to address the issue. Weakly supports the idea that dam transportation system stress results in delayed mortality. Uncertain that changes in stress result in mortality below the hydrosystem. This study supports the mechanism of how transportation and dam passage leads to stress that could lead to mortality, but mortality is not measured.

Rigor (Score = 2)

Used comparative approach to evaluate relative differences in responses. Approach provides convincing evidence for differences in stress depending on the number of the event type encountered. However, true controls cannot be used since even that treatment requires handling. Not peer reviewed.

<u>Evidence against the hypothesis:</u>

a) Non-smolting juvenile chinook showed no reduction in gill NA^+, K^+ or ATPase activities after exposure to acute stressors in an experimental lab setting (Vanderkooi et al. 2000) – *Reviewer: Jim Congleton*

Applicability (Score = 3)

This study determined the effects of two different acute stressors (handling and electroshock) on gill Na^+, K^+–ATPase activities in the gills of spring chinook salmon. Gill samples were taken at 3 h, 1 d, and 7 d after exposure to the stressor. The study dealt with a species of interest (spring chinook salmon), but the fish were not smolts. An increase in gill Na^+, K^+–ATPase activities is characteristic of the parr-to-smolt transformation in juvenile salmonids: gill Na^+, K^+–ATPase activities may respond differently to stress in smolts than in parr.

Clarity (Score = 1)

The results were convincing because two age-classes (subyearling and yearling) were used in separate experiments, because two different acute stressors (electroshock and handling) were used, and

because sampling was extended to 7 d (which should have been long enough for any effect to become apparent). In none of the experiments was a significant (or nearly significant) effect on gill Na^+, K^+–ATPase activities observed. Results are convincing that acute stress does not result in reduced gill Na^+, K^+–ATPase activities in non-smolting juvenile chinook salmon. The applicability of this conclusion to fish undergoing smoltification is not known.

Rigor (Score = 1)

The experimental design and statistical analysis were adequate, although the data should have been analyzed by repeated measures ANCOVA (this would not, however, have altered the conclusions). The results were published in a refereed journal.

b) Juvenile chinook exposed to BKD showed elevated stress response as the disease progressed, but showed no changes in gill Na^+, K^+, or ATPase levels (Mesa et al. 1999)– *Reviewer: Jim Congleton*

Applicability (Score = 2.5)

This study investigated the effects of a chronic, progressive infection with the bacterium causing bacterial kidney disease (BKD) on selected smoltification indices. Progressively worsening BKD was associated with elevated cortisol concentrations, indicating that the disease elicited a stress response, but did not alter the normal changes in gill Na^+, K^+–ATPase associated with smoltification in juvenile chinook salmon. The study used a species of concern (spring chinook salmon) and was carried out during the period of parr-smolt transformation. Furthermore, the hypothesized mechanism—suppression of normal smoltification by bacterial kidney disease—is applicable to migrating smolts. As with the study by Patino et al. 1986, however, the results are applicable to the effects of chronic stressors on developmental changes in smoltification indices during captive rearing, but may not be applicable to the effects of BKD or other, acute stressors on already well-developed smoltification indices in migrating smolts. The results are of limited applicability to the hypothesis.

Clarity (Score = 2)

Replicated experiments were done in a laboratory setting. The results establish that bacterial kidney disease has little or no effect on developmental changes in smoltification indices during captive rearing, but applicability to the effects of BKD or other, acute stressors on already well-developed smoltification indices in migrating smolts is uncertain.

Rigor (Score = 1)

Results were published in a refereed, international journal. The experimental design and statistical analysis were adequate, although alternative statistical analyses would have been preferable.

c) Snake River s/s chinook salmon and steelhead smolts showed no changes in smoltification indices before and after transport in Columbia River barges (Congleton et al. 2000) – *Reviewer: Jim Congleton*

Applicability (Score = 1)

Stress indices (plasma cortisol, glucose, and electrolytes) and smoltification indices (gill Na^+, K^+, ATPase) were measured in yearling chinook salmon (1995) and steelhead (1996) before and after barge transportation from Lower Granite Dam to the lower Columbia River. Although stress indices

were elevated for some groups of fish, no correlations were observed between stress indices and gill Na^+, K^+–ATPase activities, and no differences were found between mean gill Na^+, K^+–ATPase activities for fish sampled before and after barge transportation. The results are directly applicable to the hypothesis

Clarity (Score = 2)

This field study used migrating Snake River spring/summer chinook salmon and steelhead smolts that were subjected to routine barge transportation procedures. Fish were sampled at six-day intervals on five or six different occasions each year. Sample sizes were adequate and statistical methods were appropriate. The major limitations of the study are that: (1) it was observational and did not include an experimental component, and (2) fish were not held for observation after transportation. This is the only published study that reports on gill Na^+, K^+–ATPase activities in barge-transported fish. The major uncertainty is that the possibility of a delayed effect of transportation on smoltification indices was not precluded, because fish were not held for observation after transportation. The fish were, however, subjected to collection, handling, and transportation procedures for two to three days prior to the last sampling.

Rigor (Score = 2)

The study was published in a refereed, internationally recognized journal. The conclusion re lack of a stress effect on gill Na^+, K^+–ATPase activities was not, however, confirmed experimentally.

<u>Ambiguous Studies (providing no strong evidence either for or against the hypothesis):</u>

a) Smoltification indices (Na^+, K^+ and ATPase) in coho salmon were significantly reduced when exposed to poor rearing conditions (high fish density, low water flow) during hatchery rearing (Patino et al. 1986) *Reviewer: Jim Congleton*

Applicability (Score = 3)

The study found that smoltification-related increases in Na^+, K^+ ATPase activities were suppressed by poor rearing conditions (high fish density, low water flow). The results are applicable to the effects of chronic stressors on developmental changes in smoltification indices during hatchery rearing, but may not be applicable to the effects of acute stressors on already well-developed smoltification indices in migrating smolts. The study dealt with the effects of chronic stressors rather than acute stressors, and with suppression of early smoltification in captive fish rather than with reversal of smoltification in migrating fish. The results are not directly applicable to the hypothesis.

Clarity (Score = 1)

The study was done with coho salmon, which although not a species of concern in the Snake River Basin, are closely related to and physiologically similar to chinook salmon. Experimental manipulations in the hatchery were replicated, and supplemental experiments were done in a laboratory setting. The study dealt with the effects of chronic stressors rather than acute stressors, and with suppression of early smoltification in captive fish rather than with reversal of smoltification in migrating fish.

Rigor (Score = 1)

Results published in a refereed, internationally recognized journal.

b) Inriver migration was found to play an important part in development of smoltification of migrating Columbia and Snake R. salmonids, as measured by gill ATPase levels and condition factor. Travel time analysis and seasonal smoltification profiles of juvenile migrants showed high variability among species, and between years, in both physiological characteristics and emigration performance. This variability is attributed to environmental variability (Rondorf et al. 1989; Beeman et al. 1990; Beeman et al. 1991; Maule et al. 1994; Schrock et al. 1999; Schrock et al. 2000 – Project DE-A179-87BP35245) – ***Reviewer: Margaret Filardo, ESSA***

Applicability (Score = 2)

The initial intent of the studies was to provide stock specific information on migration characteristics (physiological development parameters) that could then be used to relate to parameters like fish migration speed or travel time. It is uncertain at this point how, or if, the data could be used in an analysis looking for trends among years. The intent of the studies was to look at trends within years and the data is likely too variable for application to other hypotheses. However, the summary report does contain appendices of the annual smoltification indices, which could provide greater information if formally analyzed.

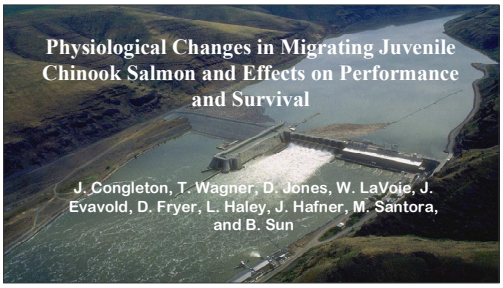
Clarity (Score = 2)

The studies solidified the notion that in-river migration played an important part in the development of smoltification, as measured by gill sodium, potassium ATPase levels and condition factor. A characteristic profile of low ATPase activities in the hatchery with increasing ATPase activity with increasing amount of time spent in river was documented. The absolute concentration of gill ATPase varies, but there is this relative increase within groups during their seaward migration.

Rigor (Score = 2)

Series of reports prepared for the Bonneville Power Administration between 1989 and 2000. Not published in a refereed journal.

Appendix G.
Physiological changes in migrating juvenile chinook salmon and effects on performance and survival
(J. Congleton et al. – presentation at CSS workshop)



Idaho Cooperative Fish & Wildlife Research Unit
U. S. Geological Survey University of Idaho

Energy Reserve Depletion Hypothesis

Snake River salmonids are adapted to natural (pre-development) migration conditions.

Snake River s/s chinook salmon are naturally adapted to undertake a downstream migration of two to five weeks. The migration is continuous, with limited foraging (unlike fall chinook), and without the "option" of residualization (unlike steelhead).

It is a "make or break" strategy.

Energy Depletion Hypothesis (2 of 4)

Migrating smolts are in a catabolic state

Migrating smolts are in a life-stage-specific metabolic state that involves the progressive mobilization of body carbohydrate, lipid, and (potentially) protein reserves.

This catabolic state is maintained throughout the period of downstream migration.

Energy Depletion Hypothesis (3 of 4)

Migration through the hydrosystem is extended for 3 to 5 weeks longer than under "natural" conditions, with possible adverse consequences.

If the migration if sufficiently protracted, lipid reserves will be exhausted, and body protein (including muscle protein and rate-controlling enzymes) will be used as a source of energy.

At some point, performance capabilities (e.g., swimming, osmoregulation) and viability will be adversely affected.

Energy Depletion Hypothesis (4 of 4)

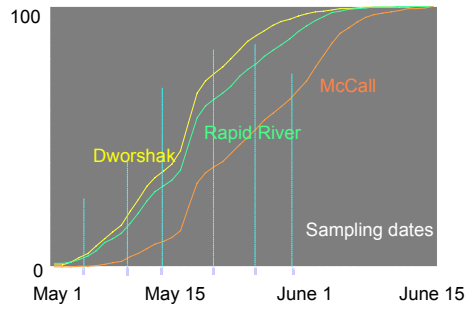
Food availability will affect the energy balance of migrating fish, and could be a mitigating factor

The rate of depletion of energy reserves will depend in part upon food availability. Food availability may trend upward during the migration season. As a result, depletion of energy reserves might be reduced in later-migrating fish.

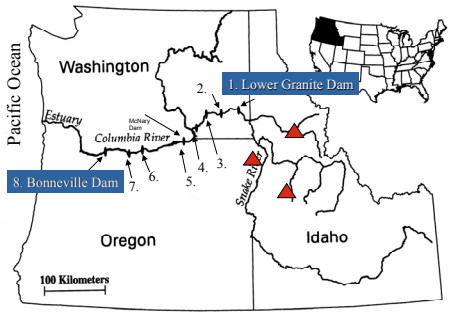
Methodology

- Juvenile s/s chinook salmon were PIT-tagged* at three Idaho hatcheries: Dworshak, Rapid River, and McCall.
- Computer-operated diversion systems at Lower Granite and Bonneville dams were programmed to divert fish from DW, RR, and MC at 6- to 7-d intervals throughout the migration.
- Energy reserves (lipid and protein), blood chemistry, and other physiological indices were determined for migrating fish.
- Laboratory experiments were done to determine if some blood-chemistry indices are useful indicators of nutritional status.

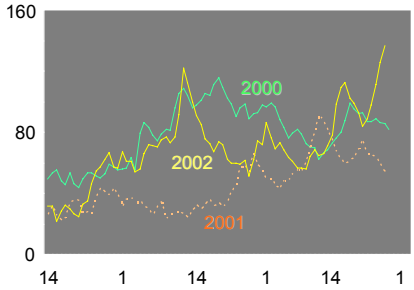
Example: Cumulative passage of Dworshak, Rapid River, and McCall fish (Lower Granite Dam, 2000)



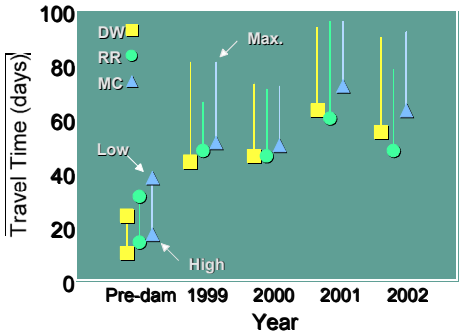
Snake-Columbia River Hydropower System



Snake River flows (kcfs), 2000-2002



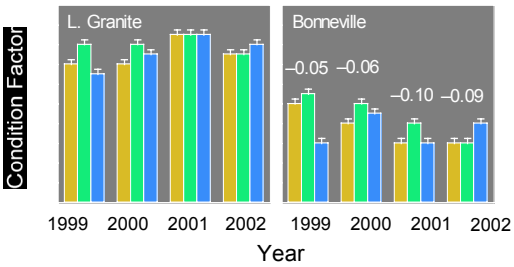
Chinook salmon travel times
(Rearing sites to Bonneville Dam)



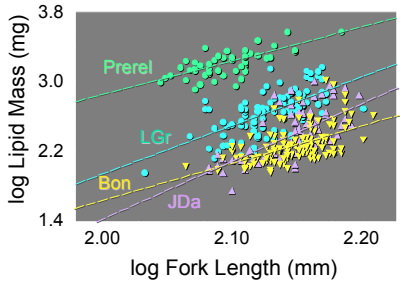
Results

Changes in energy stores (lipid and protein) during hydrosystem passage, 1999 - 2002

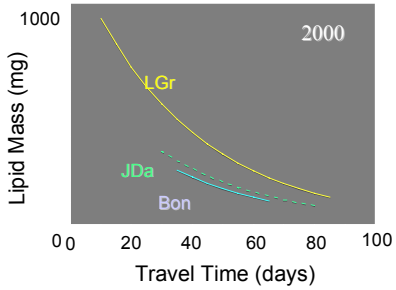
Condition Factor



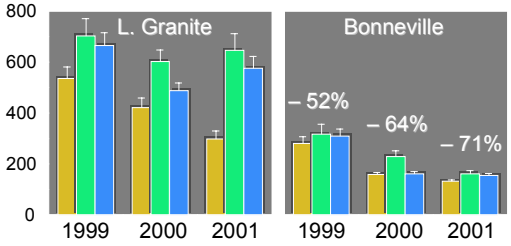
Example: log lipid mass versus log fork length regressions (all hatcheries, 2000)



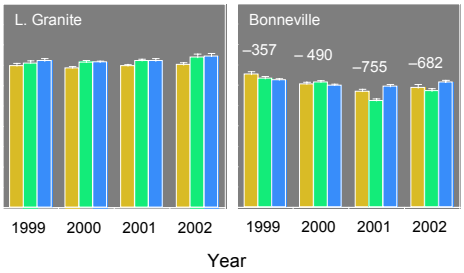
Example, ANCOVA model results: Effect of increasing travel time on standardized lipid reserves of McCall Hatchery fish



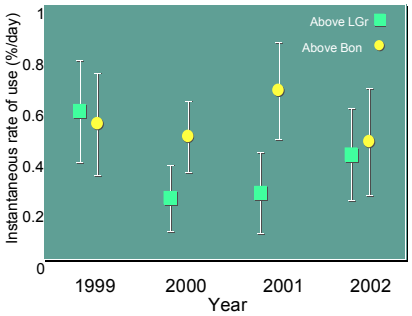
Standarized Lipid Mass (mg)



Standarized Protein Mass (mg)



Rate of Protein Use (mean ± 90% C.L.)



Conclusions

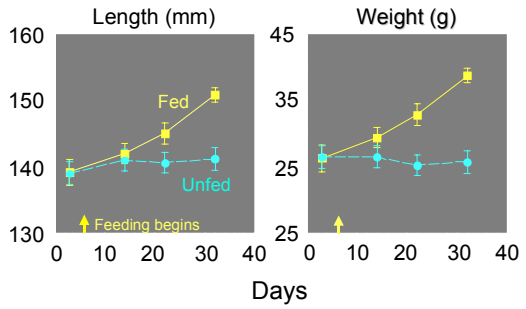
Use of energy reserves

- The rate of lipid use varied little between years; however, in lower-flow years lipid reserves were depleted at points further upstream.
- Lipid reserves were exhausted (<1% body weight) in fish reaching Bonneville Dam in all years.
- The rate of protein use increased after lipid was depleted.
- Protein use was greater in years when travel time was extended (i.e. 2001).

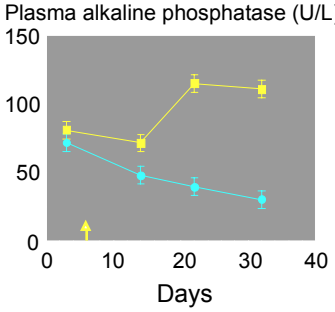
Results

Experiment to determine effects of food deprivation on blood chemistry indices in migrating smolts (captured at Lower Granite Dam and transported to the UI wet lab in 2001).

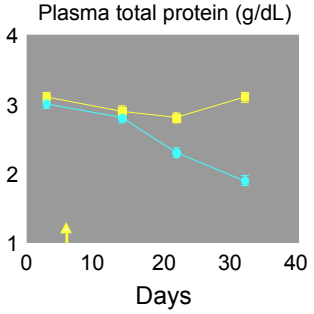
Food deprivation experiment 2001



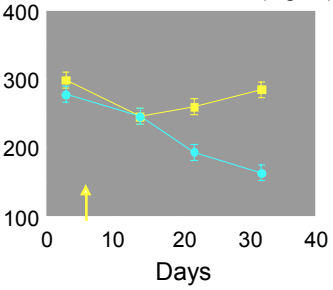
Plasma alkaline phosphatase (U/L)



Plasma total protein (g/dL)



Plasma total cholesterol (mg/dL)



Conclusions

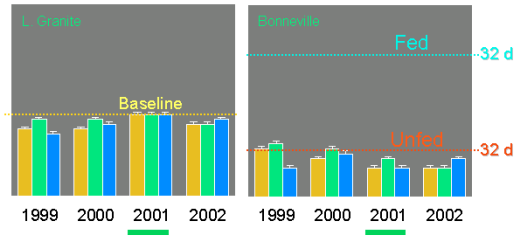
Food deprivation experiment

- Plasma alkaline phosphatase increased quickly in fed fish and decreased in unfed fish. This variable appears to be sensitive to food intake .
- Plasma total protein, cholesterol, and IGF-1 remained unchanged or increased in fed fish, but progressively decreased in unfed fish. These indices may respond to changes in energy stores.
- Plasma lipase and triglycerides also remained unchanged or increased in fed fish, but progressively decreased in unfed fish. These indices appear to be related to metabolism of lipid stores.

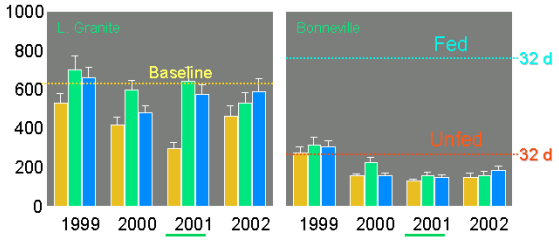
Results

Comparison of nutritional indices
in laboratory-fasted and fed fish
with
nutritional indices in migrating fish
sampled at L. Granite and Bonn. Dams

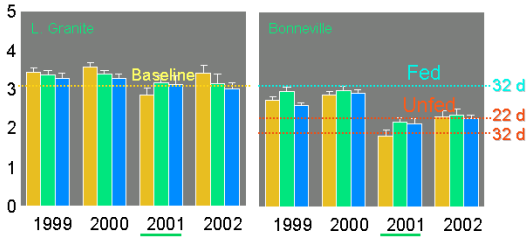
Condition factor



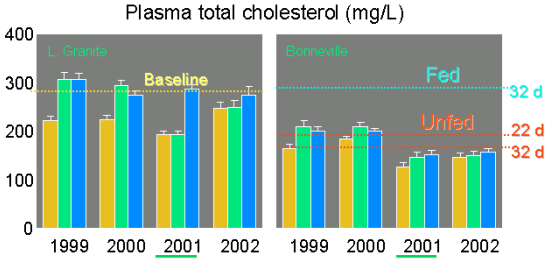
Body lipid mass (standardized, mg)



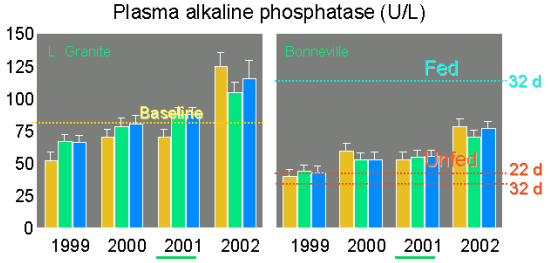
Plasma total protein (g/L)



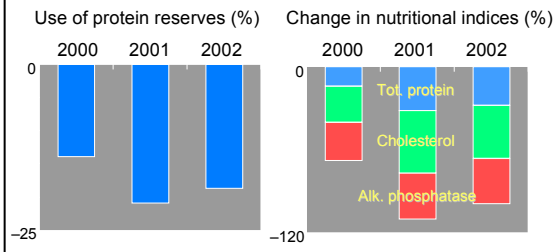
Plasma total cholesterol (mg/L)



Plasma alkaline phosphatase (U/L)



Changes in body protein reserves and in plasma nutritional indices during travel through the hydropower system (LGR to BON), 2000-2002



Conclusions

•Some nutritional indices (condition factor, lipid stores, cholesterol) declined to an even greater extent in migrating fish (30 d travel time to Bonneville Dam) than in laboratory-fasted fish (30 d in lab), suggesting (1) limited food intake by migrating fish and (2) higher energy costs than for fish held in the laboratory.

•Alkaline phosphatase was, however, somewhat higher in fish sampled at Bon than in fasted fish, indicating some feeding by migrating fish.

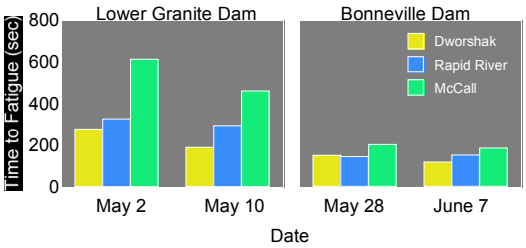
•The data did not indicate that increased food intake in lower-flow (warmer) years offsets the effects of longer migration times.

Results

Performance testing of fish before and after hydosystem passage

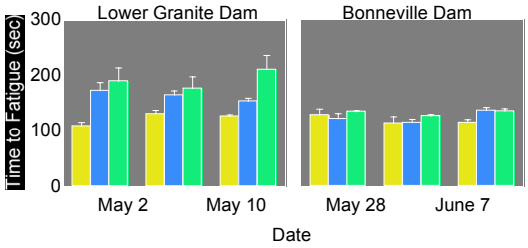
- •Swimming performance
- •Reponse to seawater challenge
- •Gill Na+,K+–ATPase activity

Mean Time to Fatigue in Fixed-Velocity Swimming Test, 2001



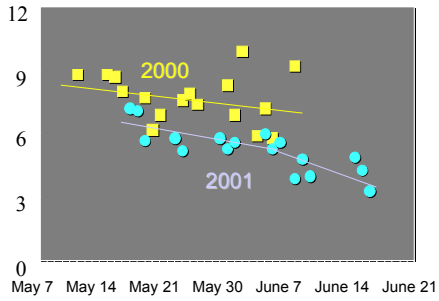
M.S. Thesis in progress, Derek Fryer, U.I.

Mean Time to Fatigue in Fixed-Velocity Swimming Test, 2002



M.S. Thesis in progress, Derek Fryer, U.I.

Gill Na^+, K^+ –ATPase activities in migrating fish sampled at Bonneville Dam in 2000 and 2001.



Conclusions (1 of 5)

- Body lipid reserves were depleted (< 1% body weight) in migrating fish in all years.
- Use of body protein reserves increased after lipid reserves were exhausted.
- Migrating fish used 10% of body protein reserves in 1999, 14% in 2000, 21% in 2001, and 18.6% in 2002.

Conclusions (2 of 5)

- Utilization of body protein may lower activities of rate-controlling enzymes involved in swimming, osmoregulation, and other critical functions.
- In fact, some performance capabilities did decrease during migration through the HP system:
  - Swimming ability (2001, 2002)
  - Gill Na^+,K^+–ATPase activities (and osmoregulatory ability (late-season 2001)

Conclusions (3 of 5)

- Blood-chemistry indices indicated low rates of food consumption by migrating fish.
- Depletion of lipid & protein reserves did not seem to be counteracted by increased food availability later in the season.

Conclusions (4 of 5)

- Depletion of energy reserves is likely the reason that the survival of migrating fish declines in the late season.
- …and also one of the major reasons that smolt-to-adult return rates are generally lower in lower-flow years than in higher-flow years.

Conclusions (5 of 5)

- Depletion of energy reserves would be most likely to adversely affect survival:
  - Of later migrating fish
  - In low-flow years.
  - In years when food availability is low in the marine environment.

Management Implications (1 of 2)

- Under present conditions (with the dams in service) these findings support continued transport of juvenile fish in lower-flow years, and of later-migrating fish in all years.

Management Implications (2 of 2)

•Improved methods for moving fish around dams (surface-bypass weirs) will not greatly reduce travel times, and so may not improve survival in low-flow years to the extent anticipated.

Do other data and observations support or discredit the hypothesis of a correlation between energy depletion and survival?

"All other things being equal" (we know they are not), we would predict that:

- Juvenile CS migrating through the HPS earlier in the season should survive better than those migrating later.
- Transportation should benefit later migrants more than earlier migrants.
- Fish migrating in higher-flow years should survive better than those migrating in lower-flow years.
- McCall & Rapid River fish should survive better than Dworshak fish.

Limitations & caveats

(1) Relationship between energy depletion and survival is speculative: At what point does depletion of energy reserves reduce survival, if at all? (Amenable to experimental approach).

(2) If energy-reserve depletion resulted in high delayed mortality, transportation should provide a larger benefit than observed.

(3) The energy-reserve hypothesis is applicable only to s/s chinook salmon.

(4) The applicability to wild s/s chinook salmon is uncertain.

Funding provided by:
U. S. Army Corps of Engineers

With special thanks to:

- Fish Passage Center
- Pacific States Marine Fisheries Commission
- National Marine Fisheries Service
- Many individuals

Idaho Cooperative Fish & Wildlife Research Unit
U. S. Geological Survey University of Idaho

Results

Multiple bypass effects:

- Multiple bypass on body lipid content.
- Multiple bypass on travel time.
- Length on multiple bypass (i.e., are smaller or larger fish more likely to be bypassed multiple times?)

Does body lipid decrease (on a length-controlled basis) with multiple bypasses?

Year	Site	*n*	*P*	Coefficient	
1998	JDA	54	0.42		No
1999	JDA	111	0.03	-12%/bypass	Yes
2000	JDA	78	0.71		No
2000	BON	120	0.09	+7.7%/bypass	No
2001	BON	145	0.71		No
2002	BON	73 (inc.)	0.72		No
2002	BON (W)	48 (inc.)	0.72		No
Overall					No

Does travel time increase with multiple bypasses?

Year	Site	*n*	*P*	Coefficient	
1998	JDA	54	0.02	+1.5d/bypass	Yes
1999	JDA	111	0.64		No
2000	JDA	124	0.31		No
2000	BON	210	0.35		No
2001	BON	279	0.80		No
2002	BON	301	0.52		No
2002	BON (w)	89	0.38		No
Overall					No

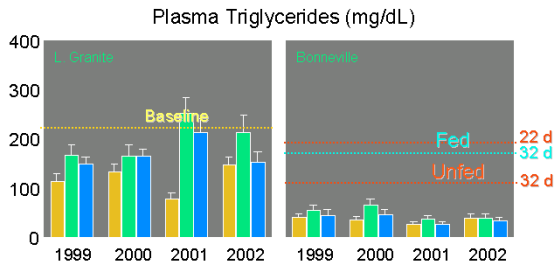
Conclusions

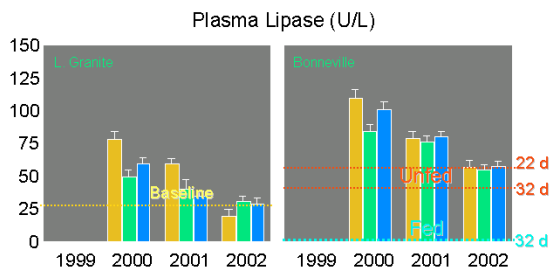
Performance Capabilities

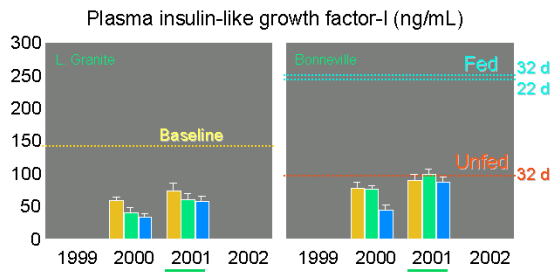
- Seawater readiness
  - Gill Na^+,K^+ ATPase declined (2001).
  - Ability to osmoregulate in seawater declined. (2001).
- Swimming ability
  - Time to fatigue declined (2001, 2002).

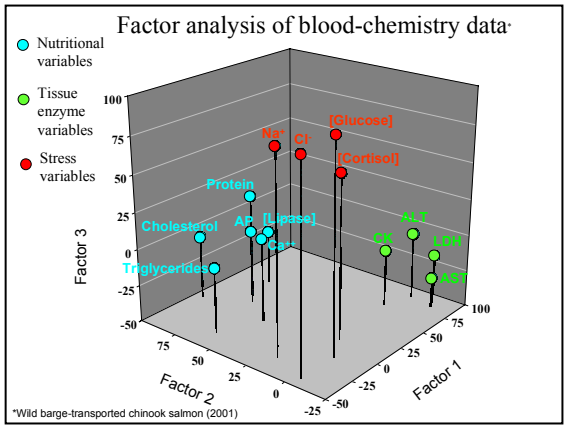
Is length correlated with number of bypasses?

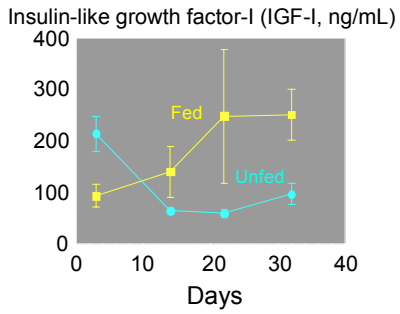
Year	Site	*n*	*P*	Coefficient	
1998	JDA	54	0.70		No
1999	JDA	111	0.33		No
2000	JDA	124	0.94		No
2000	BON	210	0.04	-0.13 bypass/10mm	Yes
2001	BON	279	0.06	-0.14 bypass/10mm	Yes
2002	BON	301	0.08	-0.13 bypass/10mm	Yes
2002	BON(w)	89	0.29		No
Overall					Yes (H fish at BON)









Physiological Indices

- Length, weight, and condition factor
- Gross necropsy: organ condition and weight
- Lipid, ash, protein, and water content
- Plasma nutritional indices (glucose, triglycerides, cholesterol, total protein)
- Gill Na^+, K^+-ATPase (parr-to-smolt transformation)
- Plasma enzymes (ALT, AST, LDH, CK, AP, lipase)
- Tissue enzymes (LDH, CK)
- Plasma electrolytes (Na^+, Cl^-, K^+, Ca^{++}, Mg^{++})