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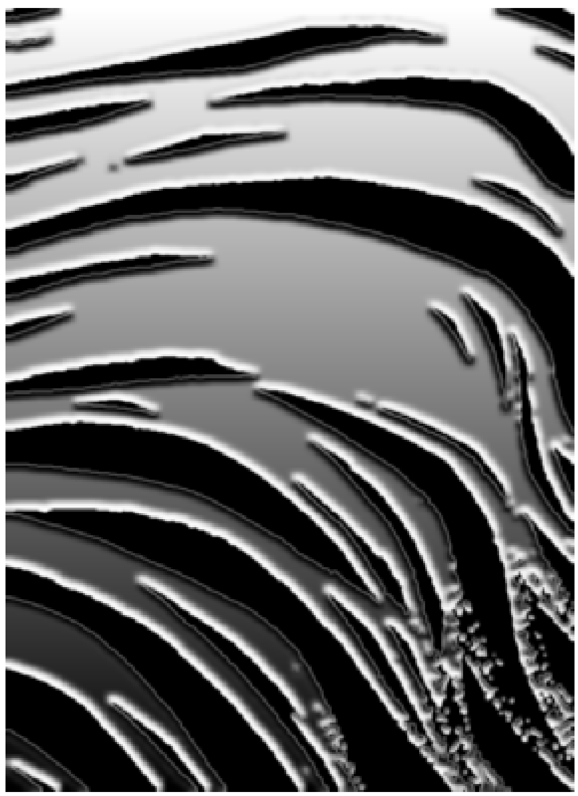
Review of Lower Snake River Flow Augmentation Studies



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Assignment

At its January 23, 2001 meeting, the Northwest Power Planning Council (Council) requested the ISAB to review a recent report by Carl Dreher of the Idaho Department of Water Resources and four co-authors on the topic of flow augmentation in the lower Snake River (Dreher et al. 2000). That report analyzed and interpreted results of studies by the National Marine Fisheries Service (NMFS) of the survival and migration timing of tagged hatchery juvenile fall chinook salmon released in test batches and detected at Lower Granite Dam (Muir et al. 1999 and subsequent unpublished data). The Council was interested in both the ISAB's reaction to the specific report and its view of the implications of the report (and the Muir et al. studies) for the Council's mainstem rulemaking regarding flow augmentation.

In particular, the ISAB was asked to answer the following questions:

1. Does the analysis conducted by Dreher et al. employ generally accepted scientific and statistical methods and are the conclusions consistent with the results?

2. Does the analysis provide new insights into the biological role of water flow and augmentation in the recovery of listed anadromous fish in the Columbia and Snake rivers?

3. What implications do the results from this analysis have on strategies, particularly the use of flow augmentation in the lower Snake River in regard to recovery of anadromous fish?

4. Based on this analysis, research conducted by NMFS over the last several years, and other existing information, what is the ISAB's assessment of the biological role of water velocity, temperature and other attributes of water flow in regard to the recovery of anadromous fish in the Snake and Columbia rivers?

5. Based on this analysis, research conducted by NMFS over the last several years, and other existing information, what changes would the board recommend in regard to the experimental design of ongoing studies of the migration of anadromous fish, particularly Snake River fall chinook (to tease out the effects of flow, temperature, turbidity, and release timing)?

Summary of Response

The following paragraphs briefly summarize the ISAB's response to the questions posed by the Council. More extensive discussion follows in a later section.

Question 1: Yes, the analyses by Dreher et al. (2000) use generally accepted, standard scientific and statistical methods. Neither the Dreher et al. analyses nor other analyses of the NMFS data, however, have presented results from especially sophisticated techniques, such as multivariate statistical methods or multiple regression modeling (reports by Connor et al. of data on wild fish have presented multiple regression analyses, however). It is likely that more useful information remains in these data sets, to be revealed by future statistical analyses that dig a little deeper.

While the narrow statistical results obtained by Dreher et al. are legitimate, their overall conclusion that the studies cannot be used to justify flow augmentation goes beyond the data and the statistical analysis in its negative implications. The Board observes that, by the same criteria, the data are also inadequate to ***deny*** beneficial effects of flow augmentation. The report rightly concludes that the data analyzed are inadequate to separate the intimately correlated variables of flow, temperature, and turbidity and date of release. But that may not be the most important management issue. If flow correlates positively with survival, it may not matter whether this effect is mediated causally through the effect of flow on temperature, or turbidity, or water velocity, or unmeasured factors, as long as the result is higher survival.

Question 2: The analysis by Dreher et al., particularly the graphs, does provide new insights into the experimental results and thus furthers our understanding of the biological role of water flow and augmentation in the recovery of listed anadromous fish in the Columbia and Snake rivers. Details of relative timing of migrations and survival among release groups in relation to flows and temperatures were clarified and the analyses suggest new hypotheses for observed effects.

Question 3: The Dreher et al. report, in conjunction with the work of Connor and Anderson and the continuing work of Muir et al., indicate to the ISAB that the specific timing and temperature of augmented flows are important for determining whether they are useful for salmon survival. There may be room for constructive fine-tuning of the pattern of flow augmentation to benefit migrants. Better understanding of the various mechanisms whereby augmentation could increase survival would facilitate such adjustments.

The simplistic operating premise of the management efforts in connection with flow and survival in the lower Snake River has been to get the smolts to migrate as rapidly as possible. But this loses sight of the fact that fall chinook are rearing during this time and may not be ready to migrate. Also, once the smolts are past the Lower Snake they still are subject to mortality and still have ecological requirements, and their performance during the remainder of their migration may be conditioned on many aspects of their experience in the Lower Snake, not just how fast they got through it. Ideally, we should attempt to manage the smolts' passage through the Lower Snake so as to integrate this episode in an optimal way into the entirety of the life cycle.

Question 4: The ISAB recognizes many biologically important roles for the amount of water in the Snake and Columbia rivers. The roles include water elevation (that influences the amount of riparian area flooded and thus shelter and food availability for underyearlings), water velocity (for passive migration of migrants when they enter the channel), temperature (depending on the source volumes and temperatures), and water clarity (higher flows have greater erosive power and thus increase turbidity, thus offering visual shelter to small fish). The relative importance of each of these roles, and perhaps others, for survival of juvenile fall chinook salmon is not yet clear. The research by NMFS and others (e.g., Connor, Anderson) are gradually clarifying these roles, and should continue. The Board did not attempt to synthesize here all the work that has been done.

Question 5: The Board has recommendations for changes in experimental design and for new experiments to tease out the importance of various environmental factors. These are detailed in the discussion below.

General Impressions: Because the ISAB felt obliged to review several other reports in order to view the Dreher et al. (2000) report from a broader perspective, we developed impressions beyond the specific questions we were asked. Therefore, we summarized several key points, as we see them, about flow augmentation from the studies conducted so far (some points may not be clear until after the background, analysis, and concluding remarks have been read):

• Flow augmentation should continue, largely because Connor's studies show benefits for wild fish and the NMFS studies show high correlation of flow and survival in a designed study;

• Figures in Connor (2000) of flow, water temperature, and adjusted flow and water temperature (without flow augmentation) give a better understanding of the magnitude of the influence of flow augmentation than do the figures in Dreher et al. (2000), partly because of the scale on the vertical axes. Regardless of how the data are modeled, the beneficial effects of flow augmentation on flow and temperature in the late spring and summer appear to be in the ranges that would be biologically important;

• The precautionary principle favors continued use of flow augmentation in conjunction with continuing field experiments;

• Use of tagged hatchery fish allows for well-designed studies of the effects of environmental factors on overall survival, but hatchery fish may not be perfect surrogates for wild fish, suggesting that more batch tagging and release should be done with wild migrants, when available, in conjunction with studies with hatchery fish;

• The temporal spread of releases of hatchery fish in the studies by Muir et al. was not intended to be representative of most of the wild population (which migrates early) but intended as a range of conditions over which wild, juvenile fall chinook might migrate (thus experimentally selecting environmental conditions that could demonstrate different levels of survival and travel times);

• Simple regression analyses are bound to fail to segregate effects of co-varying factors, so in those circumstances multivariate methods and other sophisticated approaches need to be applied;

• Correlation between survival of juvenile fall chinook and flow does not imply cause and effect, but cause and effect cannot be refuted when strong correlations exist.

• Definition of cause and effect is not necessary to make useful predictions, and with the present data for fall chinook in the Lower Snake, higher flow appears to benefit survival, whatever the actual cause;

• Focus on velocity and travel time alone as the benefits of flow augmentation is too narrow, and does not reflect other biologically valuable effects of more water;

• Augmentation on the Snake River was intended primarily to aid adults, but can have benefits for juveniles, too, if timed appropriately;

• There are effects of temperature that are especially unclear, such as the effects of low Clearwater River temperatures on potential delays in migration, including over-summering and migration the next spring;

• There is need for control of temperature and dissolved oxygen of water released from Hell's Canyon Dam, particularly in summer when it is intended to benefit the downstream river with augmented flow;

• Fast travel time in spring and summer is not necessarily the best for survival of fall chinook, based on adult returns and the benefits of larger size at migration for increased survival.

• More detailed information on the trajectories and timing of individual fish passing through the river and Lower Granite Reservoir would be helpful (such as from telemetry);

• It is important for studies to be conducted in this low-flow year (2001) to fill in the matrix of environmental conditions represented in the period of study from the early 1990s (high and low flows, high and low temperatures, etc.);

• There is need for manipulative scientific studies of effects of increased turbidity on survival of fall chinook in the Snake River.

• The NMFS studies should be reanalyzed to predict the effect of flow augmentation on survival of the batches of hatchery fall chinook using the same philological approach of Connor (2000).

• Survival of juvenile fall chinook salmon in the Lower Snake to Lower Granite Dam (the focus of these studies) needs to be evaluated in the context of survival during migration through the rest of the hydropower system.

• The Fish and Wildlife Program could aid future water management by developing guidelines for establishing the conditions when flow augmentation is beneficial for migrating fish (and when it would not be beneficial).

Review Process

The Board received and read the 59-page report by Dreher et al. (2000) in early February. The Board also reviewed correspondence from the Fish Passage Center regarding the Dreher et al. report (reports received are at the end). At the Board's February 21, 2001 meeting, the Board heard summary presentations, received supporting materials, and entertained discussion of the issues from:

1. Carl Dreher and Christian Petrich (Idaho Water Resources Institute, University of Idaho) on the Dreher et al. (2000) report;

2. Dr. James J. Anderson (University of Washington) on "Flow augmentation review: theory and experiments to identify effects of flow augmentation on fall chinook smolt survival";

3. William Muir and Dr. Steven Smith (NMFS, Northwest Fisheries Science Center) on "NMFS Snake River fall chinook survival studies" (the studies reanalyzed by Dreher et al. 2000);

4. Michelle DeHart (Fish Passage Center) on the Center's views of flow augmentation.

Other guests and staffs of the Council and NMFS also participated in these discussions.

At its March 28, 2001 meeting, the Board also heard presentations from Ken Tiffan (USGS Biological Resources Division) and Billy Connor (US Fish and Wildlife Service) on their studies of wild fall chinook salmon in the Snake River and Columbia River at Hanford. Mr. Connor also sampled hatchery chinook salmon released in the studies by Muir et al. (1999 and following). E-mail correspondence with Mr. Connor intended to define the scope of his presentation resulted in exchange of much relevant information.

The Board's draft report was provided to Bill Muir for checks for omissions or errors concerning the original study. The final draft was adopted by consensus of the Board on April 20, 2001.

Background

Flow in the lower Snake River in summer has been managed by drafts of water from Idaho Power Company's Brownlee Reservoir on the Snake River (reflecting releases from upstream U.S. Bureau of Reclamation reservoir projects) and the U.S. Army Corps of Engineer's Dworshak Reservoir on the Clearwater River, since the beginning of the "water budget" in the early 1980s under the Council's program. A specific program of summer flow "augmentation" to enhance salmon survival and mitigate migration delays was begun in 1991 (Connor et al. 1998). Water specifically for cooling the lower Snake River has been released from Dworshak Reservoir since 1992, principally to benefit upstream-migrating adult fall chinook salmon (Karr et al. 1998). A second objective is to improve survival of fall chinook juveniles during rearing and migration. This water is foregone from storage and is added to natural flows to aid the conservation and recovery of Snake River salmonid populations under the Endangered Species Act. This flow augmentation is also part of the strategy of the Council's Fish and Wildlife Program. The proximate goal of flow augmentation has been to increase water velocity and/or reduce water temperatures in the lower Snake and Columbia rivers.

Although high adult returns have been generally associated with historical high flow years during juvenile out-migrations (high natural runoff), the efficacy of managed flow augmentation during summer for aiding survival of fall chinook juveniles was controversial and had not been conclusively established at the time that the flow augmentation policy was adopted (ISG 1996). Nonetheless, the strategy was biologically reasonable, positive correlations were expected between flow and survival, and a precautionary logic argued that some level of investment in flow augmentation be continued as long as there is no conclusive evidence that it was not effective. For purposes of conservation decision-making, the burden of proof should be to demonstrate that flow augmentation is not effective, rather than the other way around. In this spirit, flow augmentation has been considered a likely benefit and has been retained.

Opportunities to conduct field experiments to test the hypothesis of benefits from flow augmentation have been sought. Since 1992, W. P. Connor and associates have PIT-tagged wild, juvenile chinook salmon captured in the Snake River below the Hells Canyon Complex and in the lower Clearwater River and followed their arrival and survival at Lower Snake River dam projects (Connor et al. 1998; Connor et al. 2000; and subsequent unpublished data). Summer flow augmentation was determined by regression analyses to decrease fish travel time and increase survival to Lower Granite Dam, thus supporting the benefits of flow augmentation (Connor et al. 1998). Multiple regression models were developed to forecast survival and passage under different flow conditions, including estimates of what passage times and survival might have been had the flow augmentation program not been in effect (Connor et al. 2000). Because of the limitations of tagging wild fish (in terms of low numbers, poor control of timing of capture and release, and confounding of smolt age and season at time of tagging), these studies recommended replicate within-year releases of PIT-tagged subyearlings with larger numbers of fish of standardized ages.

From 1995 to 2000, the NMFS, in cooperation with Connor, other agencies and the Nez Perce Tribe, investigated the migration characteristics and survival of hatchery-raised, subyearling fall chinook salmon in the Snake River basin (Muir et al. 1999 and subsequent unpublished data). Hatchery raised salmon were used instead of wild salmon, which occurred in numbers too low for such experimentation (Connor et al. 1998; Connor et al. 2000). The timing of releases and size of hatchery fish at release were manipulated in an attempt to match the size of the wild fish present in the Snake River at that season.

Batches of juvenile salmon (numbering in excess of 1,000 in each batch) were tagged with PIT (Passive Integrating Transponder) tags and released in the Clearwater River, and three sites on the Snake River downstream of Hells Canyon Dam (Pittsburg Landing, Billy Creek, and Asotin). Sequential releases (usually 6) were spaced between late May and mid-July at each location. Tagged fish could be detected when passing Lower Granite Dam, the first dam encountered, and at subsequent dams with PIT-tag detectors (especially Little Goose, Lower Monumental, and McNary). Most analyses have focused on survival and migration time to Lower Granite Dam for comparisons among batches, because of low numbers detected downstream.

Certain environmental factors were measured during the time of migrations, including flow, temperature and turbidity (water clarity). Measurements were generally taken at Lower Granite Dam. Travel times for specified percentiles of passage were estimated, as was survival for the batch. Indices of environmental variables were created to summarize the integrated experiences of flow, temperature, and turbidity for the respective batches of migrating fish during the times from release to several percentiles of dam passage (e.g., 5^{th} percentile; equal to the time when 5% of the fish had passed the dam). Initial results were published (Muir et al. 1999) and subsequent data have been made available. In general, higher survival has been strongly correlated with higher flows, and the correlations have been used as part of the justification for continued flow augmentation.

Dreher et al. (2000) independently reviewed the NMFS data in Muir et al. (1999), including results for the years 1995 through 1998. The purpose of the review and reanalysis was to examine the results “in the context of determining the efficacy of flow augmentation for enhancing the survival of subyearling fall chinook.” In particular, relationships between flow rates, water temperatures, travel times, and estimated survival between points of release and detections at Lower Granite Dam were examined. Fifth percentile indices were used (the report discussed why an alternative index, 25-75%, used initially by Muir et al. 1999 was not appropriate). These comparisons were used to draw independent conclusions about flow rates, travel times, subyearling survival, and the effectiveness of flow augmentation. No analysis was given of the value of flow augmentation to survival and migration of adult fall chinook.

The principal conclusion asserted by Dreher et al. (2000) is that “the existing data [1995-1998], despite showing an apparent correlation between flow and survival, do not imply a cause and effect relationship” and “should not be used as a basis to justify flow augmentation.” The ostensible basis for this assertion was that the NMFS study’s experimental design did not address other factors that appeared to have strongly influenced migration characteristics and survival. Multiple factors affected survival, and they were not separated either by the design or by the analysis. Dreher et al. emphasized their finding that date of release showed a very high correlation with survival. Dreher et al. hypothesized a temporal factor of "readiness to migrate" that confounded the design and the analysis. Migration of early releases appeared to be delayed, yet these releases had the highest observed survivals. Dreher et al. questioned use of passage time of the 5^{th} percentile to represent the overall migration conditions for a release group. Arrival times at Lower Granite Dam appeared to be clustered, despite different release times, suggesting the importance of other factors not analyzed by Muir et al. (1999). Dreher et al. concluded their report with a recommendation, in effect a proposed policy reversal, alleging that "until the specific factors influencing survival are better understood, the flow and survival data reviewed in this report should not be used as a basis to justify flow augmentation."

ISAB Analysis

Quality of the Dreher et al. analysis (Question 1)

The data analysis by Dreher et al. employed standard scientific and statistical methods. In fact, all of the presentations of the NMFS data on flow-survival relationship in the Lower Snake to date have used standard, relatively simple statistical methods, and none have explored the potential for more complicated (but professionally accepted) advanced multivariate statistical methods. The methods used by Dreher et al. are simpler than the regression analyses used by Muir et al. (1999) or the multiple regression analyses of Connor et al. (2000). Nevertheless, the simple methods (including some effective graphical presentations) were adequate to reveal some relationships in the data that have not received attention.

The Board found the new presentations informative and suggestive of some new hypotheses. In particular, we were impressed by the figures of sequential detections overlayed with flows, temperatures, and Dworshak flows (figures 3.6.1-1 through 3.6.1-8); cumulative detections (figures 3.6.2-1 through 3.6.2-3); and release dates, arrival dates, and survivals overlayed with flow, temperature, and Dworshak flow (figures 3.6.2-2, 3.6.2-4, 3.6.2-8, 3.6.2-10, 3.6.2-12, 3.6.2-14, and 3.6.2-16). It is important to note that continuing studies by Connor indicate that the wild fish do not exhibit exactly the same migration behavior as the hatchery fish that are the basis for the analyses of NMFS and of Dreher et al. The NMFS studies are well designed and conducted to mimic characteristics of wild fish as closely as possible, but this fact imposes some limits on the use of the NMFS or the Dreher et al. analyses for drawing conclusions about the wild fish that are the real focus of conservation concern.

Consistency of Conclusions with Results (Question 1)

While the narrow statistical results obtained by Dreher et al. are legitimate, their overall conclusion that the studies cannot be used to justify flow augmentation goes beyond the data and the statistical analysis in its negative implications. The Board observes that, by the same criteria, the data are also inadequate to ***deny*** beneficial effects of flow augmentation. The report rightly concludes that the data analyzed are inadequate to separate the intimately correlated variables of flow, temperature, and turbidity and date of release. But that may not be the most important management issue. If flow correlates positively with survival, it may not matter whether this effect is mediated causally through the effect of flow on temperature, or turbidity, or water velocity, or unmeasured factors, as long as the result is higher survival

Factors associated with time of release had an effect larger than anticipated in the original experimental design (although later release groups were expected by Muir et al. to experience higher mortality). The experimental design was appropriate for identifying such differences. The different migration timings of different release groups certainly suggest mechanisms other than simple effects of the variables measured (especially when these variables were measured primarily at Lower Granite Dam). A revised experimental design would be helpful to resolve these new questions, but that does not mean that flow augmentation necessarily should be abandoned in the interim.

New Insights (Question 2)

The analysis provides new insights into the experimental results and thus furthers our understanding of the biological role of water flow and augmentation in the recovery of listed anadromous fish in the Columbia and Snake rivers. The graphical analyses of tag detections at Lower Granite Dam (Figures 3.6.1-1 through 3.6.1-8) clearly demonstrate that the migration characteristics of the release groups of hatchery fish differ according to date of release. Three migration patterns are distinguishable in these graphs that were not identified in previous statistical analyses: (1) initial rapid movement of a few fish to Lower Granite Dam, (2) mass movement of a large number of fish to the dam, often most of the fish in a release group, and (3) a prolonged "dribbling" of a few fish for many weeks after release. Early and middle release groups showed all three migration characteristics. The later releases of hatchery fish, however, showed only prolonged dribbling after an initial movement of a few fish (also shown in the graphs of cumulative arrival times, figures 3.6.2-1 through 3.6.2-3). The major peak was missing. This pattern was consistent among years and release sites. The analyses suggest that some mechanisms governing the initiation and speed of migration are operating quite differently in the early and later release groups of hatchery fish.

The graphs of percentage survival for each release group and arrival of each tagged fish at Lower Granite Dam against the backdrop of plots of flows and temperatures by date (figures 3.6.2-2, 3.6.2-4, 3.6.2-8, 3.6.2-10, 3.6.2-12, 3.6.2-14, and 3.6.2-16) show the importance of release timing for survival. The figures in Dreher et al. illustrate a clumping of arrival times for multiple groups, e.g., the median arrival times of the first four release groups in the Clearwater in 1996 all occurred within a day or two (a phenomenon not identified in previous statistical analyses), which also suggests common migratory mechanisms. These graphs amplify the observation that each release group is subjected to a suite of widely varying flows and temperatures that is difficult to characterize by any simple index. Truly good migration conditions (high flow for rapid migration along with low temperatures for optimal physiology) exist only in the early period that encompasses the beginning of the time fish are rearing and migrating for early releases and no longer exists for later releases (temperatures rise to above-optimal levels, and flows diminish markedly). Middle releases get exposed to some of the good conditions. Survival rankings of release groups seem to reflect this relative exposure time to good conditions. Contrary to the Dreher et al. interpretation, this suggests that an index of conditions early in a release-group's migration may be especially instructive for determining survival. Early release groups are also provided the opportunity to feed in flooded riparian vegetation (typical of the underyearling strategy; ISG 1996), something later groups released at lower flows are not able to do.

The timing of the augmentation from Dworshak is consistent with the original major objective of these flows to cool the river for adult migration in August and September (Karr et al. 1998). Thus, the graphs of flows and temperatures demonstrate that augmentation from Dworshak Reservoir does not always occur at times that will benefit the largest fraction of the juvenile migrants, but this augmentation may still be significant for the juvenile fish that are rearing or migrating at that time, as suggested by the analyses of Connor, and for the upstream migration of adults. Dworshak flows often occur as prolonged spikes in mid summer, after major flows have fallen markedly, and after the highly surviving early release groups of juveniles have mostly passed Lower Granite Dam. The augmentation occurs near the migratory midpoint of the poorly surviving release groups. It is still quite possible that wild and late released hatchery juvenile fish would have even worse survival if the flows were not augmented.

The Dreher et al. report does not, however, show Snake River augmentation flows, that is, flows in the Snake River that are above those that would occur under normal operations. It remains unclear in their report how much lower the flows would have been and how much different temperatures would have been without "augmentation." In contrast, Connor (unpublished) has attempted to reconstruct the un-augmented flow and temperature conditions of the Snake River, in order to clarify the changes. Anderson et al. (2000) point out that flows from the upper Snake River can be warmer that those of the lower Snake River, and thus artificially elevated flows from the Hells Canyon complex can exacerbate damaging high temperature effects of salmon in the lower reaches and act counter to the cold water flow augmentation from Dworshak.

We note that the briefings and unpublished reports provided by Anderson, Muir, Smith, Connor, and Tiffin also contributed new insights. The information content of these data has by no means been exhausted by the analyses to date. It has emerged from our reading, and from the recent briefings, that migration behavior of these smolts is rather complicated, with large differences in migration time within fish of the same release group, and large differences possible between release groups. This means that one-number summaries of migration time (such as passage time for the first 5%) and average survival rates for the entire release group may be missing some biologically important details. Especially since it appears that the wild fish have rather different migration behavior from the hatchery fish that have been used as "surrogates" for them in some studies. Some of the important details cannot be resolved with PIT tags alone, so the use of radio tags may need to be expanded in future studies. But, in this connection, study planners also need to consider the evidence, as seen from previous briefings by other researchers (and from some presentations at the survival estimation workshop held at NMFS in November 2000), that PIT tag survival estimates do not always agree with radio tag survival estimates. Also, some of the more sophisticated release and detection designs that were presented at the survival estimation workshop should be considered.

Implications of Results for Flow Augmentation Strategies (Question 3)

The Dreher et al. report, in conjunction with the work of Connor and Anderson, indicate to the ISAB that the specific timing and temperature of augmented flows are important for determining whether or not they are useful for salmon survival. Releases are based on past studies of flow and water temperatures, but there may still be room for constructive fine tuning of the pattern of flow augmentation, and a better understanding of the various mechanisms whereby augmentation could increase survival would facilitate such adjustments.

In some ways, the operating premise of the management efforts in connection with flow and survival in the Lower Snake has been simplistic. It has been presumed that the objective should be to get the smolts to migrate as rapidly as possible. But this loses sight of the fact that fall chinook are rearing during this time and may not be ready to migrate. Also, once the smolts are past the Lower Snake they still are subject to mortality and still have ecological requirements, and their performance during the remainder of their migration may be conditioned on many aspects of their experience in the Lower Snake, not just how fast they got through it. Ideally, we should attempt to manage the smolts' rearing and passage through the Lower Snake so as to integrate this episode in an optimal way into the entirety of the life cycle.

Biological Roles of Various Factors (Question 4)

The ISAB recognizes many biologically important roles for the amount of water in the Snake and Columbia rivers. These multiple roles were discussed in the ISG report Return to the River (ISG 1996, 2000). The roles include water elevation (that influences the amount of riparian area flooded and thus shelter and food availability for underyearlings), water velocity (for passive migration of migrants when they enter the channel), temperature (depending on the source volumes and temperatures), and water clarity (higher flows have greater erosive power and thus increase turbidity, thus offering visual shelter to small fish). The relative importance of each of these roles, and perhaps others, for rearing and survival of juvenile fall chinook salmon and other anadromous fish in the Snake and Columbia rivers is not yet clear. The roles and their relative importance appear to differ with calendar time and with time in the developmental cycle of the migrants. The research by NMFS and others (e.g., Connor, Anderson) are gradually clarifying these roles, and should continue.

The Board did not attempt to synthesize here all the relevant work that has been done. The report by Dreher et al. is a useful contribution to the ongoing synthesis of information from various perspectives.

Recommended Changes in Experimental Design (Question 5)

There is need for better understanding of the influence of volume of river flow on local water velocity, directional cues, and migration behavior and rates for juvenile salmon through Lower Granite pool. With very low flows it is reasonable to expect that fall chinook will have difficulty finding the dam, as has been experienced in the pools behind other dams, e.g., Brownlee and Pelton, and demonstrated by Venditti et al. (2000). The Principal Investigators or other researchers are encouraged to design monitoring studies to evaluate the potential benefit of flow augmentation on migration of juvenile salmon through Lower Granite pool. For example, measurements should be taken of the water velocities and turbulence intensities in the migratory corridor from the upstream end of the reservoir to the dam at different flows representing base flow and various degrees of flow augmentation. These hydraulic studies should be accompanied by measurements of fish migration, such as using fixed hydroacoustics at the sites where velocity and turbulence are measured. It could be particularly important for such studies to be initiated in 2001, when flows are expected to be especially low.

There is need for additional controlled and uncontrolled studies of the effects of the environmental factors: flow, temperature, and turbidity on survival of fall chinook. A target design for more complete data to understand the interaction effects of these three factors on survival would be to include all possible combinations of "high and low flow", "high and low turbidity", and "high and low temperature" in the data set. Appropriate definitions for high and low levels of these factors would have to be determined by the Principal Investigators. Again, the anticipated low flows of 2001 offer an important opportunity to develop data on especially low flow conditions, which may also entail high temperatures and low turbidity.

Several of these eight possible combinations likely exist in the NMFS studies already conducted. In our incomplete knowledge of the situation it seems that perhaps only two combinations would need to be purposely manipulated and they would not necessarily increase mortality of fish. The possible combinations are:

1. High flow, high turbidity, low temperature. Adequate data probably exists.
2. High flow, high turbidity, high temperature. Reasonable data may exist.
3. High flow, low turbidity, low temperature. Reasonable data may exist.
4. High flow, low turbidity, high temperature. Reasonable data may exist.
5. Low flow, high turbidity, low temperature. It might be possible to create this condition with added sediment.
6. Low flow, high turbidity, high temperature. It might be possible to create this condition with added sediment.
7. Low flow, low turbidity, low temperature. Adequate data probably exists.
8. Low flow, low turbidity, high temperature. Adequate data probably exists.

We encourage the principal investigators to survey their past study conditions for the existence of data for these eight combinations, to fit predictive models to existing data, and if judged to be warranted, to propose manipulative studies to fill out the data set. Predictions of survival with and without flow augmentation should be given. Predictions might be based on “model averaging” (Burnham and Anderson 1998), because usually several models that include interaction and non-linear terms have about the same accuracy and precision for predictions. Economic and social issues involved with studies of increased turbidity are beyond the expertise of this review board.

As noted above, some of the important details of fish migration in different flow regimes (augmented or natural) cannot be resolved with PIT tags alone. Therefore, the use of radio or ultrasonic tags may need to be expanded in future studies. However, study planners also need to consider the evidence that PIT tag survival estimates do not always agree with radio tag survival estimates and only the larger fall chinook are capable of carrying current radio tags. This may suggest that details of migratory behavior may differ, as well. Nonetheless, more detailed information on migratory trajectories and timing are needed to resolve current uncertainties. Also, some of the more sophisticated release and detection designs that were described by Skalski at the survival estimation workshop should be considered.

Concluding Remarks

This review of the Dreher et al. report by the ISAB has had two underlying objectives. The first objective has been a review of the Dreher et al. report itself for scientific and statistical quality, the contributions it may have made to the scientific debate over survival of juvenile fall migrants under various environmental conditions and the fish’s developmental state, and the implications of its results for the specific flow augmentation strategies in the lower Snake River. The second objective was less clearly articulated in the questions from the Council but implied in both the overall conclusions of the Dreher et al. report and the thrust of the Council’s questions. This question is whether flow augmentation is a strategy that the Council should continue to embrace for the Columbia River basin.

Regarding the first objective, the ISAB found the Dreher et al. report informative and useful for the ongoing debate. New information was gleaned from the existing studies. Only through such critical analyses from a perspective different from that of the original researchers will we eventually come to an experimental design that provides sufficient information for an effective and fully justifiable management strategy for fall chinook salmon in the Snake River. Contrary to what some may perceive, the ISAB believes that the Dreher et al. report did a service for the basin.

Regarding the second objective, we reiterate what was said in answer to question 3. Flow augmentation is not universally good or bad. The specific timing and temperature of augmented flows (and turbidity, as well as other factors yet to be identified) are important for determining whether such flows are useful for salmon survival. The specific goals for augmentation must be evaluated in the context of the water sources available at particular times (their qualities, not just quantities). Current augmentation releases are based on the results of past studies indicating generally the beneficial effects of higher flows and lower water temperatures. However, the overall advisability of flow augmentation as a strategic policy hinges on managing it in a more detailed fashion. A better understanding of the various mechanisms whereby augmentation could increase survival would facilitate such a management strategy and allow for adjustments to its application in particular situations like the lower Snake River. A useful goal for the Fish and Wildlife Program would be to develop guidelines for conditions when flow augmentation would be beneficial and when it would not (e.g., temperature of the added water should not be warmer than the water being augmented, when the augmented water exceeds 20C, for then the augmentation is likely not beneficial to salmon survival and may be detrimental based on thermal requirements [Coutant 1999; McCollough 1999]).

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