INTRODUCTION

Hatcheries are estimated to produce 80% of the fish in several key salmon fisheries . There are currently about 100 hatcheries in the Puget Sound and coastal Washington and about 200 in the Columbia Basin. Most are production hatcheries intended to boost the supply of salmon for commercial and recreational harvest. Conservation hatcheries (supplementation programs) have both production and conservation objectives. They attempt to lessen the genetic and ecological impacts of hatchery releases on wild fish by producing fish in a hatchery that are fully able to reproduce in the wild . The techniques used in supplementation programs include minimizing genetic divergence from wild fish, maintaining low rearing densities, providing antipredator conditioning, maintaining appropriate seasonal timing of maturation, maintaining low rearing densities and controlling the size at emigration to be similar to that of natural ly-spawning fish. However, reviews of hatchery programs charge that until now they have lacked accountability and evaluation (Hilborn and Winton 1993, Lichatowich 1999). The Independent Scientific Advisory Board's recent review of salmon and steelhead supplementation programs in the Columbia River Basin questions whether supplementation programs are effective. They require taking wild fish as broodstock, they risk domestication effects and potential genetic anomalies, they risk increased competition with natural origin fish and may increase predation on natural origin fish (ISAB). The primary recommendations of this excellent report is to evaluate these issues by manipulating hatchery programs in an experimental framework by setting up comparisons with unsupplemented control populations and using target population abundances and fitness as a response variables. To discover whether supplementation programs are having their desired effects they have to be compared with reference streams and there needs to be increased coordination among projects. At present the reproductive performance of hatchery origin adults or even the consequences of the widespread straying of conventional production hatchery fish are unknown. We do know that there is a negative association between hatcheries programs and threatened salmon populations (Levin et al. 2001) but the direct and indirect mechanisms by which hatchery programs are affecting endangered salmon are largely unknown. We agree with the conclusions of the ISAB report and we argue for an even more comprehensive experimental program than it proposes.

COMMENT: THEY PROPOSE COMPARING STREAMS WITH AND WITHOUT HATCHERIES. I BELIEVE OUR COMPARISON SHOULD BE THOSE RETAINING A HATCHERY AND THOSE IN WHICH THE HATCHERY IS REMOVED (OR ALTERED].

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APPLICATION OF EXPERIMENTAL APPROACHES TO THE RECOVERY OF ENDANGERED SALMON: THE ROLE OF HATCHERIES

A. Active adaptive management

Clearly salmon scientists and managers in the Pacific Northwest should structure their actions so that the results will lead to new information that can be used to guide future actions. The efficacy of recovery actions will be affected by local and regional environmental and habitat features, temporal changes in the environment, genetic adaptations, and local and regional human factors like habitat degradation, harvest, hydropower and hatcheries (4Hs) and other factors. Hatcheries are only one of these factors. Because there are so many simultaneous processes affecting salmon, there needs to be a concerted effort to design studies that attempt to sort out the relative importance of possibly limiting factors. The only way to accomplish this objective is to define objectives carefully and to set up comparisons that allow principles of experimental design to be incorporated into research and management actions.

Some of this work will require a new level of spatial integration. Key criteria for spatial integration were discussed in the committee's December 2002 report and are listed at the end of this section. That report should also be consulted on the need to evaluate in a comprehensive way recovery actions that may be taken in different parts of the salmon freshwater habitat – from high creeks to estuaries – but that nevertheless affect the productivity of a single wild salmon population. Such integrated analysis will be the only way to obtain information on the scale of the question of the relative effects of the different human impacts on salmon.

For salmon the idea of treating management as large-scale experimentation is already being implemented in parts of the Columbia basin under the rubric of "adaptive management" (Lee 1989) although not at the scale proposed here. The term "adaptive management" is also espoused by the Hatchery Scientific Review Group for Puget Sound and coastal Washington, but their meaning emphasizes monitoring and evaluation rather than experimentation. The term "adaptive management" is being used so variously that it is losing its meaning (Ludwig et al. 2001). To assure that we differentiate what we propose from a more general policy of learning by experience, we use the term "active adaptive management "as proposed by Walters and Holling (1990). Walters (1986) called for a two-step process: first, a concerted effort to integrate interdisciplinary experience and scientific information into dynamic models that attempt to make predictions about the impacts of alternative policies; second, large-scale long-term management experiments designed to fill important information gaps needed to differentiate among the alternative management options. In several past cases the modeling step has clarified the likelihood of various processes but then practical impediments have prevented the implementation of the second step, the long-term experiments (Walters 1997). Even so, the excellent major recent review of hatchery programs in the Columbia Basin (ISAB) recommends new standards of accountability for hatcheries, coordination of hatchery programs within regions, general decreases in hatchery production, and basin-wide experimentation, all laudable steps. There is even the beginning of a coordinated program for the Columbia River Basin (IHOT 1995) led by an interagency team that recommends the elimination of hatcheries where the prognosis for freshwater habitat rehabilitation is high. Thus, the possibility of designing a large-scale experimental program for the Columbia Basin is improving. Even so, the complex institutional setting in which salmon management is embedded there and elsewhere will require a new level of interagency cooperation. The program we would like to see would have a long-term comprehensive basin-wide experimental design and a larger proportion of marked fish than presently occurs. Here are some of the explicit assumptions of the current programs that could be tested with large-scale experimentation involving hatcheries. References after each statement question its validity and/or suggest that research is needed.

1. Hatchery releases do not cause extreme ecological stress to natural fish in streams.
2. Supplementation hatchery programs increases the number of natural-origin adults on the spawning grounds (McClure et al. 2003).
3. The negative consequences of taking wild fish for broodstock are only minor.
4. The increased predation on natural-origin fish in a mixed-species fishery is not significant.
5. Hatchery releases do not seriouslyinfluence the marine growth and survival of natural fish (Emlen et al. 1990).
6. The proportion of spawners that are strays from production hatcheries is minor.

B. Some Examples of Previous Experiments and Proposals for Future Experiments

There are some outstanding examples of past experiments that illustrate how efficiently an experimental approach can address a question of how ecological processes are operating in nature. From 1925 to 1936 Foerster (1936, 1938) tested the relative efficiency of natural and artificial propagation of sockeye salmon in Cultus lake, British Columbia, to contribute to the population in the lake. During their 1-year residence in the lake, artificial propagation provided no advantage over natural spawning in maintaining the run. Based on this result, the province of British Columbia closed its hatcheries from 1940 to1980 (Lichatowich 1999). From 1980 to 1985, Nickelson et al. (1986) compared the effects of stocking with hatchery coho presmolts versus no stocking in 30 Oregon coastal streams. In the 15 stocked streams , the hatchery presmolts displaced the smaller wild juveniles and then the hatchery reared adults spawned too early, so the stocking failed to rebuild the wild population. Reisenbichler (draft ms) has proposed a series of smaller-scale genetic experiments that could identify domestication problems with hatchery fish. For example, he proposes common garden experiments in semi-natural environments.

C. Other questions about the potential for negative genetic effects of hatchery fish on naturally-produced fish will also require experimentation, but not necessarily on the scale of active adaptive management. How important are domestication effects, or inbreeding or outbreeding depression when there are one or two hatchery-origin parents?

An Illustration: Hatchery Experiments

Closing production hatcheries or altering their production mode is among the more likely recovery actions; indeed, in a recent conversation Bob Lohn stated he expected they would be widespread. Such actions should be planned and evaluated, to the extent possible, in the context of an overall spatially extended experimental design. (Here we discuss only hatchery closure, but intend our comments to refer to all recovery-targeted changes in hatchery operation, including closure of weirs that control entry of hatchery salmon into a watershed.)

Our aim is to provide one possible general conceptual framework for carrying out hatchery modifications in an integrated program. We will not discuss the myriad statistical decisions and details that will arise in implementing such a program and analyzing its results.

The goal - estimating effects

The aim is not to test the hypothesis that hatcheries have an effect on wild salmon populations – they do, nor that closing a hatchery will affect the recovery of the wild salmon population – it will. The aim is to estimate the effects of (1) a hatchery, or (2) hatcheries in general, or (3) hatcheries of a given type in a given region, on (a) one native salmon population or (b) all populations in a region, or (c) populations of a given salmon type.

The above numbered questions define a central problem underlying any likely experimental design. Each production hatchery is unique, its effects determined by its own characteristics and those of the affected salmon in their unique environment. But is there sufficient commonality of effects that hatcheries across the Northwest are effectively replicates? Alternatively and for example, are the effects of hatcheries in Puget Sound similar enough that they can be regarded as replicates, but are not replicates of those in coastal Oregon?   The experimental design should attempt to answer these questions.

Key design issues

*Local design: **BACIP***: ~~The~~ One basic *local* design is to close (or otherwise modify) a hatchery and to compare various aspects of subsequent performance of the affected wild salmon population with those in a population whose hatchery operation(s) has(have) not been altered. BACIP stands for Before-After-Control-Impact, Paired. In this case, a modification of the original BACIP design, the Control population retains its unaltered hatchery or hatcheries, the "paired" Impact is the "treatment" population whose hatchery or hatcheries have been removed or altered; and control and impact populations are paired in the sense discussed below.

Measurements are taken in both populations Before the treatment is imposed. Such "before" measurements should be made whenever possible, since such data greatly strengthen inferences that can be drawn. A single observation is the ***difference***, measured at some point in time, between the treatment and control populations. The *average* difference, over time, is estimated for the Before period. The difference is then measured at a sequence of times After the treatment is imposed, and again the *average* difference in the After period is estimated (over at least 10 years). We then ask: how did the treatment affect the *average difference* between the two populations? For example, we might find that before the treatment the control population, on average, had a native salmon density twice that of the treatment population, but that in the After period that difference increased, on average, to 8-fold. (Our report of xxx describes a range of genetic, phenotypic, demographic and population features that might be measured.)

The experimental unit: Although a hatchery will be manipulated, the unit from which data will be collected is the salmon population. Thus, consideration will need to be given to the comparability of the salmon populations and the number and similarity of hatcheries that affect each population, as discussed next.

Pairing populations: An important and useful feature of the BACIP design is that treatment and control populations do not need to be ecologically "the same." *They simply need to track changes in their shared environment (e.g. in weather and climate) in the same way*. We choose pairs of populations that seem similar in major respects, but they do not need to be similar in all respects; they just need to respond similarly to much of the temporal environmental variation, especially to variation with effects lasting more than one year.

Experimental blocks: This aspect of the design should respond to the three numbered questions above. One possibility is to regard different regions, and salmon species within regions, as blocks.

As noted above, we might expect a priori that the effect of production hatcheries is substantially different in Puget Sound and coastal Oregon. We would not, therefore, pair two hatcheries chosen from these two regions. We will want to know, however, if hatcheries in the two regions indeed have different effects. We may find that the effects have the same sign (e.g. wild salmon abundance increases after hatchery removal in both areas) and differ only in the magnitude of their effect. Thus, by treating the regions as "blocks," we can detect regional differences, but may also be able to combine results from different regions to estimate more effectively generic effects of hatcheries. As always, there will be a trade off between replication within blocks and number of blocks examined.

Timing of treatments: In each block, we would have a collection of pairs of salmon populations, the members of each chosen to be as similar as possible. The treatment (i.e. hatchery removed) and control (hatchery unaltered) ~~hatcheries~~ population would be designated at random from each pair. In an ideal world, this choice would be made at a single time across all populations and all blocks (unless we were interested in how hatchery effects change between different periods of time). Differences between each control-treatment pair would then be measured for up to 10 years before the treatment is to be imposed, and the treatment would then be imposed simultaneously across all experimental units.

The real world will not match this ideal. Closures will be done at different times in different places. But the long term effect of the treatment (i.e. the estimated change in average difference between treatment and control) may well not depend on when the treatment is done.

Statistical versus ecological significance: It needs to be emphasized that we are looking for large effects. If hatcheries have effects so small that only a high level of replication would allow statistically significant detection, then the effects are not worth estimating. Although implementation of the experimental design will not be perfect, we would expect substantial hatchery effects to be detected in spite of deviations from design perfection.

Interim Recommendation

Because of the great desirability of obtaining Before data, we recommend that TRTs in each region seek out likely treatment and control pairs of salmon populations and begin a program of monitoring key variables as soon as possible. Even if some pairings ultimately receive no treatment, the extent to which different salmon populations track environmental variation in parallel will be useful in interpreting future data.

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EXCERPT FROM REPORT OF DECEMBER 2002

B. Principles Underlying Successful Recovery Actions

The committee recognizes that many recovery actions will be taken by local jurisdictions. Two factors will make recovery difficult to achieve if there is only local decision-making.

(1) Although many important processes occur at the spatial scale of local jurisdictions, many occur at much larger scales, and all processes integrate and interact to determine salmon productivity over larger spatial scales. The effect of local actions on salmon recovery therefore cannot be estimated only locally.

(2) All of these processes occur in temporally and spatially variable environments. The effect of single actions, therefore, cannot be determined outside of a framework that accounts for spatial and temporal variability.

The challenge is how to optimize the process of recovery, given these conditions. The committee believes that the following are prerequisites for success.

1. Recovery actions must be viewed in a specific overall framework of Active Adaptive Management (AAM). Decisions will always be made in an uncertain world; AAM results in comparisons that allow inferences about the causes of differences. Then future management is adjusted to accommodate the new knowledge.

2. AAM requires an explicit experimental framework in which each local decision is a component of a spatially larger design. This requires that each local jurisdiction make decisions in coordination with other jurisdictions in the region.

3. AAM requires that measurements of the effects of actions in different areas are in common units estimated by the same protocols so they can be evaluated in a common framework.

4. Because different processes affecting salmon integrate over large regions, i.e. across the salmon life cycle (point (1) above), there needs to be a common scientifically sound framework for exploring the likely effects of different recovery actions on overall salmon ESU productivity.

5. Points 3 and 4 establish that local decision-making needs to take place in an explicit national/regional scientific framework. It should be the job of regional administrators and scientists to work together to create the overall framework.