ISAB Artificial Production Review Report 3

Recommendations for the Design of Hatchery Monitoring Programs and the Organization of Data Systems

Independent Scientific Advisory Board

Northwest Power Planning Council
National Marine Fisheries Service
851 S.W. 6th Avenue, Suite 1100
Portland, OR 97204

Peter A. Bisson
Charles C. Coutant
Daniel Goodman
Robert Gramling
James Lichatowich
William Liss
Dennis Lettenmaier
Eric Loudenslager
Lyman McDonald
David Philipp
Brian Riddell

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Executive Summary

The ISAB recommends the development of a monitoring program to assess the effectiveness of the Columbia River basin hatchery system. Initially, monitoring data are required to establish criteria for the performance standards and indicators proposed to be used to evaluate when, where, and how artificial propagation may be used within the basin. Once criteria for performance standards and indicators are established, ongoing monitoring will be necessary to assure compliance with standards and provide a scientific basis for judging and proposing reforms in fish husbandry practices.

To analyze and understand the performance of fish produced by the hatchery system following their release into the natural environment we need to gather three types of information:

1. Specific details of fish culture practices inside the hatchery.
2. What happens to the hatchery produced fish after release.
3. What effect the hatchery-produced fish have on wild and other hatchery fish outside the hatchery.

Assessing how fish culture practices inside the hatchery (information type 1) affect what happens to hatchery produced fish after release (information type 2) is required to evaluate alternative fish rearing/release strategies and guide hatchery reform. Assessing the effects of hatchery produced fish on wild and other hatchery fish outside the hatchery is required to evaluate the success of supplementation and evaluate possible detrimental effects of mitigation and augmentation.

Sampling and tagging programs at all facilities need to be sufficient to estimate the SAR for each stock produced at each release location.

No organization has yet taken responsibility for comprehensive experimental design or data collection in the basin. This omission needs to be addressed at an institutional level. Monitoring will be required at hatcheries throughout the basin, as well as at sites in each subbasin, the migration corridor, the estuary, and the ocean. Standardizing data collection and reporting is necessary for the proposed monitoring effort to be most informative. Monitoring hatchery-produced fish outside of the hatchery is necessary not only to evaluate alternative culture practices, but also to evaluate the recovery of ESA listed stocks. Additional staffing assigned to this task will undoubtedly be needed.

Experimental research should begin to take advantage of the recent developments in "DNA fingerprinting" technology to evaluate supplementation and the effects of wild fish interbreeding with strays from mitigation and augmentation programs.

Once monitoring begins, there is no need to centralize the entire data storage and retrieval system. Internet technology allows for a very effective system to be developed by web links between modular sites that take responsibility for various functions, such as data

archiving or data access, and that specialize in particular types of data or particular types of analyses. Modularization and specialization among the various sites participating in the networked system should encourage efficiencies and allow for sound fiscal management. The data archiving function should be modularized so that there is one data archiving center for each class of data. At the moment, there are not enough such archiving centers, and important classes of data are not being compiled and archived in an accessible form. This shortcoming needs to be addressed. The delivery of data in a form suitable for archiving, on a specified timetable, should be a contracting requirement for all projects that generate such data. This requirement would represent a cultural shift that may not be eagerly embraced by some groups of data generators, but that shift is important and needs to be implemented. The data access function should be modularized to serve specified data access needs. The network of modularized data access sites should evolve with changing needs for analysis. The articulation of need should arise from the community of data users. Funding for data archiving and data access should be managed on a project basis, where each project serves a narrowly identified function (i.e., to archive a particular class of data, or to provide data access for a particular kind of analysis).

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October 3, 2000

The Northwest Power Planning Council, following a 1997 request from Congress, reviewed federally funded fish hatchery programs within the Columbia River basin (Artificial Production Review, Council document 99-15). The review produced a formal recommendation for coordinated artificial production policy within the basin, steps to implement the policies, and draft performance standards and indicators to measure progress toward achieving programmatic goals for artificial production.

In a letter dated November 15, 1999 Council requested the ISAB review those performance standards and indicators, focusing on three questions:

1. Are the draft performance standards and associated indicators the appropriate tools to periodically evaluate the effects of individual artificial production programs for the purpose of determining whether the principles, policies, and purposes in the Artificial Production Review (APR) are being fulfilled?

2. Are the draft performance standards and associated indicators the appropriate tools to adequately evaluate the effects of the artificial production activities in the basin?

3. If a performance standard, indicator or other means of measurement is not the most appropriate tool for this purpose, what other standard or indicator would you recommend?

The ISAB responded to that letter of request by proposing to prepare three reports dealing with the following topics:

1. Appropriateness of the Performance Standards and Indicators.

2. Consistency of Artificial Production Policies and Implementation Strategies with the Multi-Species Framework Scientific Principles and the Scientific Review Team Guidelines.

3. Development of an Appropriate Data System.

This is the third of these reports, suggesting elements to be included in the design of hatchery monitoring programs and the organization of data systems.

A variety of methods are used to culture salmon and steelhead within the Columbia River basin, and there are different purposes for culturing these fish. Information on the success of these hatchery programs is required to decide when, where, and how artificial propagation may be used within the basin to provide fishing opportunities, support endangered populations through captive rearing, and possibly contribute to rebuilding wild populations using supplementation. Judging the efficacy of alternative husbandry practices (hatchery reform) and the value of proposals for additional programs/facilities should be based on analysis of data obtained through comprehensive monitoring programs coordinated throughout the basin.

Elements of Monitoring Systems for Evaluating Artificial Production Programs

Types of Information

There are three types of information needed to evaluate the hatchery system.

1. Specific details of fish culture practices inside the hatchery.
2. Survival and harvest contribution of the hatchery produced fish following release.
3. Short and long term effects of hatchery produced fish on wild populations and other hatchery fish.

Routinely, hatchery personnel collect data on much of the activity that goes on inside the hatchery, both for their own internal management needs and to meet compliance with agency requirements. Because there is little expectation that the data might be used outside the individual hatchery, there is little standardization and long-term record keeping. Historically, however, there has been a modest level of monitoring aimed at addressing Type 2 information (the disposition of hatchery fish outside the hatchery), including the use of fin clip marking, occasional branding, coded wire tagging (CWT's) to identify harvested fish by batch, and at least some passive integrated transponder (PIT) tagging to identify individual fish as they pass detectors. A further strength of this information component is that most of the recovery data, both for PIT tags and for CWT's is archived in genuine (though imperfect) databases.

The most glaring weakness with respect to Type 2 information (survival and harvest contributions) has been difficulty linking the recovery data to specific fish culture practices (Type 1 information). There is no common data base for recording what goes on inside each of the many hatcheries involved. The masses of tag recovery data, which can provide estimates of Smolt to Adult Ratios (SAR's) and passage survival rates, cannot readily be correlated with the biological characteristics and husbandry practices experienced by the fish that exhibited those survival rates - a key information need. A first step in understanding how various hatchery practices impact these important performance characteristics is to improve monitoring in the hatchery system by institutionalizing and standardizing data collection and data handling for Type 1 information (e.g., stock origin and rearing conditions). Furthermore, it is important to coordinate this effort with the data collection and data handling efforts implemented for Type 2 information (e.g., analysis of CWT and PIT tag recoveries).

Type 3 information, monitoring the effects of hatchery fish on wild populations is tremendously important, but rarely done. Because monitoring of (and perhaps experimentation on) wild fish outside the hatchery does not generally fall under the purview of the hatchery operators or even the hatchery system as a whole, developing this aspect of monitoring requires institutional reform and cooperation at different levels within an organization. Furthermore, even though some monitoring of wild fish does take place, we are not sure there is consensus on a practical paradigm for obtaining data that answer the critical questions, much less consensus on what the critical questions are. For these reasons, collection of Type 3 information is a longer-term agenda item, but thoughtful recommendations for its development and implementation are needed.

Monitoring for Type 1 Information - Details of Fish Culture Practices Inside the Hatchery

The following types of data/metadata[1] should be collected each year for every "batch" of fish:

Stock Origin, Breeding Design, and Rearing and Release Conditions for cultured fishes

1. Species
2. Stock name, source and history
3. Parentage of the brood: hatchery origin versus naturally spawned parents; if both are involved, these should be treated as separate batches from those produced entirely from hatchery or naturally produced parents
4. Number of female parents
5. Size of female parents: with some sampling statistics defining how this was estimated, and providing confidence intervals
6. Age of female parents: with some sampling statistics defining how this was estimated, and providing confidence intervals
7. Dates of arrival of brood stock and water temperature at the hatchery or weir
8. Holding periods and temperatures of brood stock
9. Number of male parents
10. Size of male parents: with some sampling statistics defining how this was estimated, and providing confidence intervals
11. Age of male parents: with some sampling statistics defining how this was estimated, and providing confidence intervals
12. Mating design
13. Number of eggs per female: with some sampling statistics defining how this was

[1] Metadata are the documentation of objectives, measurement methods, sampling design, and association of primary data with a time and place (ISRP 2000-3: Review of Databases Funded through the Columbia River Basin Fish and Wildlife Program, NWPPC, Portland, Oregon)

estimated, and providing confidence intervals

14. Mean egg size: with some sampling statistics defining how this was estimated, and providing confidence intervals
15. Date of sperm collection/history of sperm treatment
16. Date(s) of egg stripping
17. Date(s) of fertilization
18. Fertilization success
19. Incubation conditions (temperature fluctuations - recorded with temperature loggers, not just averages, water source, substrate, jar, heath tray, etc)
20. Number of eggs fertilized: with some sampling statistics defining how this was estimated, and providing confidence intervals
21. Number of eyed eggs: with some sampling statistics defining how this was estimated, and providing confidence intervals
22. Egg to fry survival rate: with some sampling statistics defining how this was estimated, and providing confidence intervals
23. Hatching date(s)
24. Numbers of fry ponded: with some sampling statistics defining how this was estimated, and providing confidence intervals
25. Rearing history
    - translocation among facilities (dates and places)
    - ration
    - temperature
    - density
    - flow regime
    - cover and substrate
    - growth curve (size against time)
    - antibiotic/theraputant treatments
    - noteworthy events (disease outbreaks, pump or temperature control failures)
26. Fry to release survival rate (parr or smolt): with some sampling statistics defining how this was estimated, and providing confidence intervals
27. Release status (for each release batch)
    - Number and stage (fry, parr, smolt): with some sampling statistics defining how this was estimated, and providing confidence intervals
    - acclimation treatment
    - nature of release (volitional or not)
    - date(s) of release
    - length and weight at release: with some sampling statistics defining how this was estimated, and providing confidence intervals
    - location of release
    - ambient conditions at time of release (temperature, flow)
    - total numbers in each release batch
    - number CWT tagged in each release batch (and list tag codes)
    - number PIT tagged in each release batch (and list tag codes)
    - other marks (fin clip, temperature, or chemical signatures) for the release batch

Adults Returning to Hatcheries or Weirs, but not necessarily used for Breeding

By species and stock:
1. Dates and water temperature of arrival of brood stock at the hatchery or weir
2. Numbers of females
3. Size of females: with some sampling statistics defining how this was estimated, and providing confidence intervals
4. Age of females: with some sampling statistics defining how this was estimated, and providing confidence intervals
5. Number of males
6. Size of males: with some sampling statistics defining how this was estimated, and providing confidence intervals
7. Age of males: with some sampling statistics defining how this was estimated, and providing confidence intervals
8. Tags or marks on individual fish associated with the above data
9. Monitor the genetic composition of the returning population by estimating allele frequencies at allozyme (for retrospective analysis with previous baseline data) and microsatellite loci. This genetic monitoring should be conducted at least every three to four years.

Data Collection
To evaluate the efficacy of different culture methods across locations in subbasin or basin wide analyses, data collection at each facility must be standardized and uniform. Responsibility for developing the standardization, including quality assurance and quality control (QA/QC) measures, should be assumed by a region wide authority, for example the Council, National Marine Fisheries Service (NMFS) or the Columbia Basin Fish and Wildlife Authority (CBFWA), (ISRP 2000-3). Given the presumption that hatchery staffs are fully occupied with fish husbandry responsibilities, it is likely that additional staff will be required to organize and supervise collection of the data. The ISAB recommends considering a coordinated staffing effort with each facility having an individual assigned solely to the monitoring project and supervised through a regional monitoring effort.

Data Organization
The fundamental unit of data organization for Type 1 information should be the "batch," which in general is defined as each group of fish that has a common type of parentage (stock, stock history, and broodstock collection location), breeding design, common spawning and rearing experience and history, and common release time, location, and strategy. Once specific monitoring is designed, temporal and spatial boundaries need to be established for "batches" based on the requirements of the analytical framework. For example, individual families, or their subdivisions, reared and released using common conditions within a facility would be very fine scale batches. In contrast, pooling multiple stocks of a species, for example spring and fall run chinook, even when reared and released using common conditions at a single facility, would be a very course scale batch. Using individual families as batches would certainly constrain operational flexibility

within a hatchery, and depending on the monitoring design might not contribute increased precision to identifying trends. Using pooled stocks as batches reduces the likelihood of identifying those fish culture practices that produce increased returns.

Reporting Requirements and Format

Once data are collected they must be assembled and stored in manner to be available for analysis. A fixed format should be adopted for recording this information in machine-readable form, and delivery of the machine-readable data by a specified time should be an annual reporting requirement. Compliance with reporting requirements should be a necessary condition for continued funding.

Monitoring Type 2 Information - Survival and Contribution to Harvest of Hatchery Fish after Release

To make informed decisions on the efficacy of alternative culture practices, after artificially produced fish are released from hatchery facilities, managers and decision makers need to know how these fish survive through the migration corridor, contribute to ocean and in-river fisheries, and return to the basin to be spawned in a hatchery or spawn in the wild. To accomplish these tasks, all or an adequate sample from each batch of released smolts must be marked. In addition, different marking technologies lend themselves to providing different kinds of information. As an example, coded wire tags (CWT's) are of limited value in monitoring passage survival for individual hatcheries, except in the case of designed experiments (Burnham et al., 1987), but if there is good quantification of the sampling fraction, do provide estimates of harvest mortality. In contrast, passive integrated transponder tags (PIT tags) provide important information on survival through the migration corridor, and if sufficient tagging is performed has the potential to resolve questions concerning the effects of barge transport and in-river migration through dam by-pass systems. To resolve questions relevant to specific hatchery operations, to the basin-wide artificial production program, and to the effects of the hydrosystem and natural environmental variation, will require coordinating all facilities within the basin in a systematic marking program.

For each batch of fish produced, the numbers tagged, together with the types of tags used and the procedure for selection of the fish for tagging, constitute a "design" whether deliberate or not. It is important to have basin wide directives on these designs, e.g., to insure that fish tagged are representative of the batch. As a result, individual hatchery operation plans should state the number of fish to be tagged for each batch, how the fish were systematically selected for tagging (e.g., procedures for systematically dipping fish from each raceway), and should indicate how this marking fits into subbasin, province, and basin monitoring. The basin needs to develop a comprehensive monitoring plan demonstrating that the expected confidence limits on expected tag recovery information are sufficient for estimating important parameters including SAR, passage survival, composition of harvest, and straying rates. The monitoring plan should state the questions of interest (e.g., comparing various rearing regimes, stock sources, or hatcheries, or verifying that production for a particular stock is above replacement). The monitoring plan should explain why the expected confidence limits for the results are deemed adequate to resolve those questions of interest. Because policy makers will ultimately decide whether to expand, terminate, or make changes in the hatchery programs, they should be consulted as to the level of certainty they require. In this way, the precision of the analysis of the monitoring program can be designed to meet their expectations.

There is existing controversy over the suggestion to mark all hatchery smolts. One concern is that marking all smolts would invite selective fisheries for fish of hatchery origin, with the potential for unacceptable mortality to by-captured and released wild fish. Another concern is that fish produced in supplementation programs are needed to spawn in restored habitats, and these fish would be removed by a harvest strategy that targets hatchery fish. If CWT and PIT tagging sufficient for harvest and migration corridor monitoring are insufficient for determining straying rates or other evaluations where delayed detection marks would be acceptable, a solution to this acknowledged dilemma might be to use elemental marks, DNA "fingerprinting" or thermal banding of otoliths or other hard parts.

Each batch of salmon and steelhead at each facility needs to be tagged in numbers that are sufficient to estimate a SAR for each stock at each release location.

Monitoring Type 3 Information - The Effects of Released Hatchery Fish on the Ecosystem

Monitoring Hatchery Fish Spawning in the Wild

Artificially propagated fish used in supplementation programs are intended to spawn in the wild and become incorporated into the natural population. A measure of success of supplementation is that hatchery fish spawning in the wild produce progeny who then contribute to recovery by increasing lambda, the average population growth rate (McClure, et al., 2000, McElhaney et al., 2000), in wild populations the following generation. In the case of supplementation, therefore, we wish to know if hatchery fish successfully spawn and what effects interbreeding between hatchery and wild fish may have on the fitness of the wild population.

Artificially propagated fish used in mitigation and augmentation programs may stray into naturally spawning populations. In the case of mitigation and augmentation, therefore, we wish to know how much straying and interbreeding take place between hatchery origin fish and wild fish, and whether or not that interbreeding leads to unacceptable changes in the fitness of the wild population.

Demonstrating that artificially propagated salmon and steelhead spawned successfully in the natural environment can be demonstrated conveniently using genetic markers passed from parent to offspring. Genetic markers have been used in limited settings to compare the performance of hatchery and wild fish (Reisenbichler and McIntyre, 1977) and confirm that hatchery fish have spawned successfully in the wild (Chilcote et al., 1986).

Unfortunately, assessments of the effects of interbreeding between hatchery and wild fish on the wild population are lacking.

Recent developments in "DNA fingerprinting" permits us to address many of these questions. Determining the parentage and relatedness of individuals is possible using genotypic data from multiple single-locus nuclear markers. Confirmation of breeding, assessment of inbreeding and outbreeding depression, and quantification of relative fitness can now be investigated. Because these techniques determine individual genotypes via polymerase chain reaction (PCR) technology, only small fin clips or scale samples are required as a tissue source. Using these approaches to evaluate supplementation and the effects of wild fish interbreeding with strays from mitigation and augmentation programs has tremendous potential to provide uniquely valuable information to basin planners. We recommend that experimental research designed to take advantage of this powerful technology begin in earnest.

Monitoring the Ecological Effects of Hatchery Releases

As a consequence of direct releases, and potentially through the production of offspring, hatchery salmon and steelhead interact with other species in the natural environment (Pearsons and Hopley 1999). These interactions may be harmful (competition, predation, pathogen introduction) or beneficial (provide increased prey base, increase nutrients from adult carcasses, etc.). Assessing the magnitude of these effects is necessary to properly evaluate the consequences of releasing nearly 150 million smolts into the Columbia basin ecosystem. This assessment could contribute to determining appropriate release numbers for individual subbasins and provinces.

Establishing a Data System for Determining If Hatcheries are Meeting Performance Standards

Background

Beyond the context of hatchery evaluation, there is concern within the basin on how best to configure information systems to ensure access to data so that analyses needed to inform decision making are available. The Independent Scientific Review Panel (ISRP) recently reviewed the organization of databases funded through the Council's Fish and Wildlife Program (ISRP 2000-3). Most of the conclusions of this review are relevant to integrating data and analyses from a comprehensive monitoring of the entire artificial production program. The following is abstracted from that report. The data system needs to provide three functions:

1. Data collection;
2. Data archiving; and
3. Data access.

With current technologies it is feasible, and probably desirable, to separate these functions among multiple sites, in a "modular" fashion. As a result, it is important to investigate whether these data system functions are well served with the present configuration of data management activities in the basin, and to consider what changes might enhance them.

Data Collection

In an ideal situation, there would be some grand assessment of what data are needed to provide the information to support management decisions. Following that, some organization would have responsibility for designing a monitoring and experimentation program that could efficiently deliver those data. Finally, some organization would have the responsibility for implementing that design. Unfortunately, current reality is such that at the level of the big picture, none of these components of data collection are in place. No grand assessment of specific data needs has been done, not even a systematic inventory of data. No organization has taken responsibility for data collection program design, and no organization has taken responsibility for its implementation. Indeed, it is not even clear whether any existing organization has broad enough authority to take command of implementation, so implementation might well require a new cooperative venture among several organizations. The ISAB and ISRP have voiced concerns over this apparent omission. The recently completed ISRP review of data systems should help in the development of a strategy for an assessment (ISRP 2000-3).

Data Archiving

Data archiving is the compilation of data and associated metadata under a QA/QC (Quality Control/Quality Assurance) process, with some provisions for maintaining data integrity in a central facility. There must be consensus among all parties that generate data that this archive is "the" archive for a given "class" of data.

At the moment the ISAB is aware of two such archives for two different classes of data, the Coded Wire Tag (CWT) database maintained at StreamNet and the Passive Integrated Transponder Tag (PIT tag) database maintained at PTAGIS. The ISAB also believes that the U. S. Army Corps of Engineers has an archive of dam operations data and that the Ecosystem Diagnosis and Treatment expert system used by Council in the Framework process has assembled a compilation of habitat data, presumably from primary sites that serve as archives of those data. Other important classes of data seem to have no designated archival location, most notably, data sets on hatchery operations, harvest effort data, radio tagging data, and experimental results for studies on various hatchery/wild populations. Those data are thought to be in the hands of individual investigators, projects, or agencies, and are not readily accessible or inventoried. An inventory of these data classes and their status would be an appropriate first step in implementing this function.

Data Access

Data access involves providing reasonably convenient and effective means to search, sort, collate, and cross-reference data--possibly from multiple data archives--for purposes of analysis. The ISAB impression at the moment is that StreamNet and the Fish Passage Center provide limited menus of such functions, where as DART provides a different (and richer) menu. We do not yet know, however, about the data access functions of other data centers. The measure of adequacy of a data access system is a moving target, i.e., the perceived adequacy of a data access system is evaluated relative to the current needs of data users. When new kinds of analyses are undertaken, new data access needs are created that may not be well served by existing query systems. This implies that multiple data access centers might evolve around different data analysis paradigms and the needs of different data user groups.

Needs for Centralization

The new Internet technology allows the option of very effective networking of a "distributed" system. It creates opportunities for considerable efficiencies, provided there is an underlying logic that identifies which kinds of functions still need to be centralized, and which can be networked-- provided, of course, that all the needed functions are represented by modules somewhere in the network. For each "class" of data there needs to be a single archive, to guarantee data integrity and to preclude ambiguities. There can still be many archives, however, as long as each respective data class is housed in only one. There are in fact advantages to having multiple archive sites, each specializing in one data class. That specialization allows the staff of the archive site to have better understanding of the nature of their data, and of the activities that generate their data, both of which should encourage better QA/QC and better communication with the data providers and users. Note in particular that communication between the data archiving center and the data providers is essential to ensure completeness of the compilation. Finally, specialization among the archive sites will allow for more transparent book keeping that could provide an opportunity to contain the costs of the archiving function.

It would make good management sense to separate the funding for "data input" from the funding for maintaining the archive site. The data input activity should be budgeted into the respective data generating projects. Delivery of the data, in an appropriate form, and on a specified timetable, should be a contracting requirement for each project that generates data. The contracting requirement and separation of the funding should facilitate establishing new data archiving sites that are needed to accomplish the data archiving function for the important data classes that, at the moment, are orphans. To ensure that the data in each archiving site can be accessed by a common query system, there should be a minimal level of standardization required in the query system of each data archiving site. Such standards are now common knowledge within the information technology community, and should not constitute an undue burden to any archiving site.

With the current technology, there is no need for centralization of data access sites. We take it for granted that data access sites will generally need to link to more than one data archive site, so there is no need for a data access site to be housed within any particular data archive site. The ease of establishing links on the web also extends to links between data access sites. For this reason there is no intrinsic motivation for duplication of actual function among access sites, since each can readily link to another for a query function that has already been developed.

The only reason to invest in implementation of a particular query function within any data access site, is to address a need that is not yet met anywhere in the system. This incremental evaluation of the need to implement a new query would seem to lend itself to an RFP process whereby identified data access needs are described in detail from the perspective of the data user group and put out for bid. The bids may come from existing data access sites or from proposed new ones. This process should prove more efficient than attempting to create a single highly centralized one-size-fits-all data access site, where the connection between features and actual user needs could get lost and where the accounting for the cost of serving each user group would be harder to track. Just as specialization of data archiving centers could provide a benefit by encouraging a tighter bond between data generators and the data archive sites, specialization of data access sites could provide a benefit by encouraging a tighter bond between data users and the data access sites. The system as a whole should be managed through the project funding process, treating each data archiving site or data access site as a distinct project identified with serving a specified needed function.

Literature Cited

Burnham, K. P., D. R. Anderson, G. C. White, C. Brownie, and K. H. Pollock. 1987. Design and analysis methods for fish survival experiments based on release-recapture. American Fisheries Society, Monograph 5, Bethesda, Maryland.

Chilcote, M. W., S. A. Leider, and J. J. Loch. 1986. Differential reproductive success of hatchery and wild summer-run steelhead under natural conditions. Transactions of the American Fisheries Society 115:726-735.

Independent Scientific Review Panel. 2000. Review of Databases Funded through the Columbia Basin Fish and Wildlife Program. Northwest Power Planning Council. ISRP 2000-3. www.nwppc.org/isrp/isrp_2000-3.pdf

McClure, M., B. Sanderson, E. Holmes, C. Jordan, P. Kareiva, and P. Levin. 2000. A standardized quantitative analysis of the risks faced by salmonids in the Columbia River basin. Draft Report dated April 7, 2000. National Marine Fisheries Service, Northwest Fisheries Science Center, Cumulative Risk Initiative, Seattle, Washington. 125 pp + appendices.

McElhaney, P., M. Ruckelshaus, M. J. Ford, T. Wainwright, and E. Bjorkstedt. 2000. Viable salmonid populations and the recovery of evolutionary significant units. Draft report dated January 6, 2000. National Marine Fisheries Service, Northwest Fisheries Science Center, Seattle, Washington. 170 p.

Pearsons, T. N. and C. W. Hopley. 1999. A practical approach for assessing ecological risks associated with fish stocking programs. Fisheries 24:16-23.

Reisenbichler, R. R., and J. D. McIntyre. 1977. Genetic differences in growth and survival of juvenile hatchery and wild steelhead trout. Journal of the Fisheries Research Board of Canada 34:123-128.

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